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Land-Change Science and Political Ecology: Similarities, Differences, and Implications for Sustainability Science

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Key Words

coupled human-environment system, human ecologies, human-environment relationships

Abstract

Land-change science (LCS) and political ecology (PE) have emerged as two complementary but parallel approaches of addressing human-environment dynamics for sustainability. They share common intellectual legacies, are highly interdisciplinary, and provide understanding about changes in the coupled human-environment system. Distinctions in their problem framings and explanatory perspectives, however, have accentuated their differences and masked the symmetry in much of their findings relevant for sustainability themes. Focusing on their shared interests in the human-environment interactions of land use illuminates the differences and similarities relevant to these themes. Divergence is found primarily in regard to their different foci of interests about causes and consequences of land change. Convergence is revealed in the identification of the complexity of the interactions and the importance of context in land-change outcomes and in the general consensus found in such synthesis issues as forest transitions, vulnerability, and coproduction of science and application.

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Contents

Cultural ecology: in anthropology and geography, either the functional relationship between cultural and environment or systematic approaches to environmental behavior and decision making

LCS: land-change science

Vulnerability: the degree to which a human-environment system is likely to experience harm because of exposure to a hazard

PE: political ecology

Coupled human-environment system (also the social-ecological system): the interdependencies of the two subsystems that make single-subsystem analysis incomplete

INTRODUCTION

Several human-environment research traditions emerged over the last century that have provided wide-ranging, if often divergent, contributions to the research themes of sustainability science. At least two of these traditions—or portions of them formerly labeled cultural ecology and risk-hazards research—were instrumental in the development of sustainability science, which, in turn, championed the development of land-change science (LCS), including its vulnerability component. These same traditions are also tied to political ecology (PE), a research theme that addresses conceptual and substantive problems that are highly relevant to sustainability, land change, and vulnerability. LCS and PE are complementary, but autonomous, research endeavors that stand at an epistemological and explanatory distance from one another, muting potential interchange relevant for sustainability. This article reviews those parts of these research endeavors directed to land-based sustainability topics, demonstrating divergences in their problem framing and resolution and discussing convergences around key sustainability themes, including forest transitions, vulnerability, and environmental application. Understanding these dimensions of LCS and PE is enhanced by a brief tracing of their research legacies residing in geography and anthropology, which provided the initial intellectual directions regarding land use and land-use/cover change as a coupled human-environment system.

EMERGENCE AND DIVERGENCE OF RESEARCH TRADITIONS

Alexander von Humboldt's (1) search for the unity in nature serves as a good marker for the modern reformation of human-environment intellectual traditions and one from which the human ecologies of the twentieth century can be seen as distant progeny. Simplifying, this lineage descended to the German geographic tradition of *Landschaft* or landscape as the totality of things within a territory, eventually taking on the meaning of human-environment relationships (**Figure 1**) (2). By the early twentieth century, the geographic factor, or the search for the inorganic controls over the organic, dominated much of geography in the United States. Its relegation of people and culture to the explanandum in explanatory designs held little appeal in anthropology (3, 4, p. 9) and was abandoned by geography forthwith, owing to its connection to environment determinism.

By the mid-twentieth century, various human-environment orientations were emerging in geography, anthropology, and beyond. Reinterpreting *Landschaft*, the cultural-historical landscape orientation in geography followed a natural history to understand the material landscape, eschewed theory-led research, and, over time, moved toward the humanities in terms of base approach and appeal (5). Drawing on the concept of cultural area (6), cultural ecology emerged in anthropology focused on explaining relationships between culture and environment in a loosely functional way (7), often addressing the concept of adaptation (6). This work sought the constellation of variables—the cultural core—that best captured the relationships between socioenvironmental configurations (e.g., hunting and gathering on

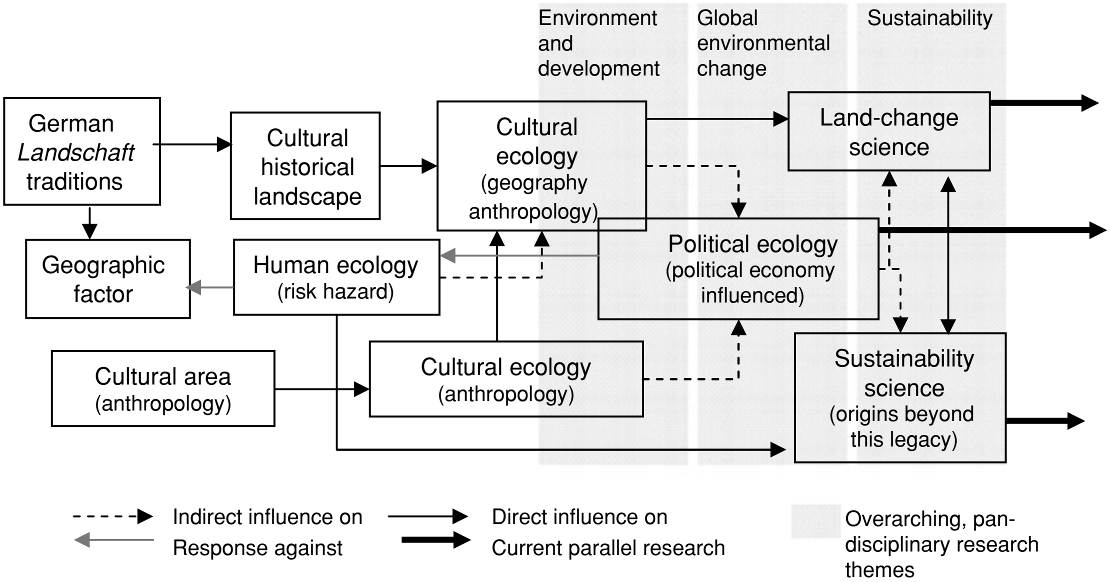

Figure 1

Simplified lineage of the human-environmental traditions addressed. Notes: Other interpretations of the research clusters identified in this figure exist (1, 57). Land-change science, for example, is a part of sustainability science. We have separated it here because of its explicit research agenda (56), the large number of self-labeled practitioners (40, 48), and the comparisons made with political ecology.

semiarid grasslands) and specific forms of social organization (e.g., patrilineal bands) or cultural characteristics (e.g., mytho-religious practices) (3, pp. 33–34; 4, pp. 9–10).

In contrast, human ecology, as that term was originally employed in geography, proposed to examine societal adjustments to the environment (8, p. 3; see 9, 10 for other meanings), ultimately focusing on responses to and preparations for natural hazards, or what would become known as risk-hazards research. This work took on a decidedly social science orientation but focused more on societal problem solving and application than on theory construction (11). A broader interpretation of human ecology emerged in anthropology, in part a reaction against the cultural ecology approach in the discipline (12). Originally focusing on system-based analysis, it was subsequently enlarged to entertain a variety of holistic assessments of human-environment issues as captured in the journal *Human Ecology*.

Geography adopted a somewhat different meaning of cultural ecology from that originally developed in anthropology (13). The term was employed by geographers seeking to distinguish their approach from that of the cultural landscape tradition and to signal its alignment with the systematic sciences (14, 15). Various aspects of land or landscape remained the substance of study, and theoretical constructs were drawn from decision making and behavioral science as well as system and ecosystem science (16). Similar influences shaped anthropological interests as well (17), leading to the fusion of geographical and anthropological approaches that constituted a non- (or less-) functionalist, cultural ecological approach (16, 18, 19), although questions of human adaptation to the environment were addressed.

In the development of theory and concepts, these research interests contributed significantly to, among other examples, the induced intensification thesis (20–22) and the social amplification of risk (23), as well as to such themes as human adaptation (7, 19, 24) and the large-scale human impacts on the environment in the Western Hemisphere prior to 1492

Human ecology: either societal adjustment to the environment, largely applied to natural hazards, or the interaction of human culture with the environment

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(25–27). In terms of development practice, they yielded insight for policy reform on floodplain management in the United States (28), alleviation of water shortages in Africa (29), adaptation to drought (30), and local knowledge-based farming practices (20, 31).

With various antecedents (e.g., 10, 32, 33), PE emerged in the latter part of the twentieth century as parts of cultural ecology and risk-hazard analysis began to converge toward sustainability science and its LCS linkage (**Figure 1**). Although the PE term was not new, its use was reinvigorated by Blaikie & Brookfield (33, p. 17) with an expansive meaning intended to combine "the concerns of ecology and a broadly defined political economy," which included the decision-making components of cultural ecology and risk-hazard approaches but with renewed emphasis on contextual variables and political-economic influences. This interpretation of PE was not inconsistent with that to develop in LCS (below), potentially yielding cooperative studies. It was, however, initially fused with approaches more explicitly applying critical theory "that anticipated" many concerns in PE, even though the label itself was not employed (34, 35). This early phase of PE was attentive to questions of environment and development or vulnerability within development, employing a structural perspective in which local outcomes (e.g., producer decision making and risk evaluation) were linked to indirect or distal forces (e.g., economic restructuring of national economies) (36).

As the field gained momentum, however, its practitioners began to embrace other explanatory and theoretical approaches, becoming more inclusive in character to include feminist (37), poststructuralist (38, 39), and postcolonial (40) concepts and techniques. Some work sought to explain contemporary environmental trends and trajectories, such as those in the conservation zones of East Africa, by reference to historical and systemic starting power conditions, including colonial and developmental relations and habits (41). Other approaches stressed the way imposed forms of environmental knowledge, as in green revolutionary technology transfer, displaced appropriate or locally specific farming practices at the expense of sustainable management (42). Still other research demonstrated the power-laden roots of ecological explanations, which were shown to account for the persistence of flawed and faulty environmental assessments, as in the colonial roots of misunderstandings of West African deforestation (43) and North African desertification (44). This expansion came at a cost, as the term PE itself became contested among different communities using the term (45–47). The various interpretations remained united, however, in their suspicion of approaches not explicitly questioning the politics inherent in explanation itself (33), and for some individuals, science-based explanations in general. They also retained an orientation geared toward explaining what political and economic factors produced and perpetuated socioecological vulnerability and undermined sustainable outcomes.

Cultural and human (risk-hazard) ecology also evolved in new directions (**Figure 1**), many of them aligned with the interdisciplinary interests engaging global environmental change. Various practitioners of cultural ecology, joined by ecologists, resource economists, and others, helped develop LCS to address land dynamics as a foundation of global environmental change research (48–50). This approach treats land as a coupled human-environment (or social ecological) system and addresses its change and implications through the integration of the natural, social, and geographic information sciences, including remote sensing. Likewise, parts of the risk-hazard community pushed for the development of sustainability science in which vulnerability research—influenced as it was by critiques from what was to become PE-inspired vulnerability (34)—was reshaped to incorporate resilience themes from ecology (51) and to address explicitly the vulnerability and resilience of the environmental subsystem (52–55). LCS subsequently adopted land systems vulnerability as a major research component (56).

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LAND-CHANGE SCIENCE AND POLITICAL ECOLOGY: COMMON AND UNCOMMON GROUND

LCS and PE may be seen as two different but complementary approaches to human-environment (or nature-society) relationships, both of which are intellectually connected to cultural and human ecology (57). LCS operates within the international science research frameworks to which its base research questions and explanatory perspectives are tied (56). PE addresses a range of human-environment problems beyond those of land change (e.g., air quality, marine habitat), although it utilizes a common approach to tie local problems to global systems (58). A substantial portion of PE, however, shares many, though not all, of the research interests of LCS, but PE is usually guided by different base research questions and employs different explanatory frameworks (e.g., 54, 59), detailed below.

Focus of Study

LCS, which may be viewed as a contemporary, science-based restatement of *Landschaft* studies (2), devotes attention to human-environment dynamics on the terrestrial surface of Earth (land dynamics), seeking to uncover attributes about land uses and covers and the processes of their change to inform the sciences of global environmental change and sustainability (56). PE typically examines many of these same dynamics with an inherited emphasis on informing development, especially in regard to improved human well-being among disadvantaged people (60, 61). Both research subfields profess to treat land dynamics in terms of interactive processes of the human and environmental subsystems. Similarly, they both share interests in such topical problems as land degradation (62, 63), desertification (64–66), deforestation (67, 68), conservation (69, 70), institutions and governance (71, 72), ecological impacts of economic development (73, 74), and equity and environmental trade-offs (55, 75, 76). In addition, much of the work in both subfields shares interests in spatial themes, such as the efficacy of park or reserve boundaries (e.g., 41, 70, 77, 78), the role of spatial connectedness to understand human-environment relationships (e.g., access, isolation, and distance) (79, 80), and the use of spatial knowledge and information (e.g., 81, 82). Both approaches utilize geographic information technologies extensively, although LCS devotes considerable attention to advancing geographical information science methods, especially remote sensing.

Problem Framing and Explanation

This remarkable commonality notwithstanding, LCS and PE differ significantly in their problem framing and, in many cases, their analytical approaches. **Table 1** identifies the base research issues shared between LCS and PE as well as the different ways in which those issues are expressed. Those for LCS are synthesized from its formal, international research agenda (56). As a bottom-up research endeavor, PE has no formal agenda, but a number of major works stake out the range of questions pursued among its practitioners (10, 42, 45, 83, 84). Each approach, of course, maintains research topics not stressed in the other.

An examination of these questions reveals that both approaches are concerned with the synergy of the coupled human-environment system and the systemic outcomes of this interaction. LCS, however, maintains a significant interest in the structure and function of the environmental subsystem in its own right, including connections to Earth's system. Environment is treated as both an ambient condition of and a forcing function on land dynamics. In contrast, PE may attend to material environmental processes but directs attention to their role in land-use and social change—the human subsystem—rather than to their own inner dynamics.

LCS seeks to understand the array of forcing functions affecting land management, including proximate and distal factors or those immediately and indirectly linked to land-use and -cover outcomes (**Table 1**, A1). The factors

Table 1 The framing research questions of land-change science and political ecology[a]

Questions	Land-change science	Political ecology
A. Questions from the human subsystem to the biophysical subsystem	1. How does the constellation of drivers captured in globalization, institutional, and demographic processes affect local-to-regional land-use decisions and practices? 2. How do changes in land management practices affect the structure and function of terrestrial and freshwater ecosystems?	1. How and to what degree do control over the environment and knowledge of the environment, along with the distribution of environmental access and authority, influence environmental conditions and change? 2. What are the implications for the sustainability of environmental management regimes and ecosystems?
B. Questions from the biophysical subsystem to the human subsystem	1. How do changes in Earth's system affect ecosystem structure and function and what are the feedbacks of ecosystem changes on Earth's system? 2. How do ecosystem changes affect ecosystem service provisions and what are the human consequences (e.g., governance, household well-being) of changes in these services?	1. How do environmental degradation and change differentially affect varying human communities and groups (e.g., by income, race, gender)? 2. What are the implications of environmental conditions and change for shifting environmental risk regimes, social justice, and sustainability of human use and socioeconomic well-being? 3. Who defines environmental outcomes and conditions and to what political and ecological effect?
C. Synthesis questions	What are the critical pathways of change in land systems and which institutions enhance decision making and governance toward sustainable pathways, including coupled system resilience and vulnerability?	What political and economic arrangements accelerate or decelerate reductions and enhancements in human vulnerability and ecosystem sustainability?

[a]Questions not shared between the two research subfields are omitted.

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and processes explored reflect those observed, as informed by a large range of social and environmental science theories and concepts, including those addressing household economics, governance, institutions, ecosystems, and landscape. In contrast, drawing on critical gender, postcolonial, and other such constructs, PE focuses on the factors and processes in question through the lens of control, knowledge, and access themes (**Table 1**, A1).

Both approaches follow land management practices to their environmental consequences, although each expresses this concern differently (**Table 1**, A2). Part of LCS, for example, examines land management practices on the structure and function of ecosystems and landscapes, in which a large number of environmental goods and services may be hidden from the land manager (72, 85) and which affect and are affected by changes in Earth's system (**Table 1**, B1). For example, the role of the functional diversity of an alpine ecosystem under land-use stress may be examined in regard to its capacity to deliver ecosystem services (86). PE emphasizes the environment with regard to its immediate resource implications for land management, subsistence, or environmental hazards. This emphasis may not include the full array of ecosystem provisional services, but it will likely include the flow of values of that ecosystem beyond its immediate ecological context. For example, the resources produced in that alpine ecosystem under stress (above) would be traced along a global commodity chain that affects the value of those resources and hence the land stresses incurred by the ecosystem (87).

Both approaches are concerned with human-induced environmental degradation and scarcity as well as the environmental feedbacks on land use and human well-being

(**Table 1**, B2). LCS, however, seeks to identify and understand the processes and mechanisms in environmental subsystem that generate the feedback, for example, soil nutrient flows and their impacts on forest regeneration and, ultimately, land management (88). PE, in contrast, is more concerned with implications of the feedbacks for questions of social justice and power, for example, declining authority of local communities over forest resources, the impact of changing control on forest regeneration, and, ultimately, ambient ecosystem conditions (80).

The synthesis questions in both fields also overlap, especially in regard to the search for institutional-political economic influences on vulnerability and sustainability, although these concerns are expressed differently (**Table 1**, C). LCS seeks to identify, model, and quantify the tipping points in coupled systems—those that generate nonlinear outcomes, flipping the system into new states or conditions—many of which address primarily the environmental subsystem (73). It treats ecosystem vulnerability and resilience equally with societal vulnerability, as in instances where changes in ecosystem dynamics, generated by either or both climate change and overgrazing, trigger shifts in grasslands to desert (65).

Conversely, PE seeks to identify and qualify the persistent trends and logics in coupled systems, for example, those that generate social conflict over resources, lead to shifting monopolies of environmental control, and impinge on the maintenance and reproduction of environmental systems (10, 35, 42). It also treats ecosystem vulnerability symmetrically with social vulnerability, as in places where changes in agro-ecosystems, generated by either or both the accumulation of capital and declining yields, trigger degradation of soil quality (64). In addition, PE seeks to identify and categorize common patterns from diverse conditions and develop a qualitative vocabulary to identify and evaluate the relative causal force of persistent sociopolitical systems on environmental and social outcomes.

It is clear from these framings of the questions that LCS incorporates biophysical processes through attention to ecosystem and Earth system interactions, including their roles as drivers on land change. PE, in contrast, addresses biophysical processes through their flows into and out of the human production systems, linking them to distal factors in the human subsystem. These distinctions and the framing of the major research questions (**Table 1**) reflect the dissimilar research ideologies (i.e., systematic sets of ideas) of the two approaches that translate into different modes of explanation.

This is not the place to delve into the details of the logico-philosophical distinctions between the favored explanatory forms of LCS and PE. It is sufficient to note that LCS adheres to a postpositivist vision of science—to simplify, the "scientific method" adjusted to account for critiques of logical positivism (89), foremost through the adoption of critical realist ontology in which real-world phenomena and processes exist, if only imperfectly understood. It continues to employ, however, empirical tests of the relationships examined and seeks the general principles that may be revealed in them.

PE, in contrast, is skeptical of postpositivism and the claims by some of its practitioners that it is the least subjective of the major explanatory forms. PE utilizes either or both structuralist and constructivist explanatory approaches. The first employs critical realism, ontologically understood to imply a hierarchy of structures, mechanisms, and events in which apparently diverse outcomes are the result of the contingencies and convergence of causal processes (90). A materialist (post-Marxian) approach is used to interpret empirical data in an effort to transcend individuals and events and distinguish general structures from contingent conditions (91) through a dialogic-transformative method (viewed as overly value-laden by postpositivists). The second approach, various forms of constructivism, fuses ontology and epistemology through the belief that what can be known is prefigured in part by social, political, and historical conditions. It examines habits and categories of environmental thought and language, focusing on the habitual and institutionalized

Postpositivism: the ontology, epistemology, and methods of science adjusted to account for critiques from alternative explanatory frameworks

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constructs that individuals and groups bring to bear to interpret human-environment relationships (92). These two approaches are commonly used in tandem, although not without debate within the field itself.

These distinctions mean that, for the most part, LCS generates and collects data systematically (e.g., 93) and, ideally, seeks to employ tests to determine the relationships among the data. These tests may be exploratory, teasing out statistical relationships and their significance among sets of variables thought to be linked to some land dynamic (e.g., 94, 95), or guided by diverse theories of the midrange, which, as a set, compete with one another (e.g., 96, 97). Models are constructed, tested, and used to project land change and its consequences for the near term (98–100), and in some cases are evaluated in regard to detailed case studies with historical dimensions (e.g., 101, 102). PE, for the most part, focuses on an in-depth single or multiple-site comparison for interpretive analysis. This typically involves exploration of how and whether higher-order and common driving structural processes interact with local conditions and with key variables typically including tendencies in political economy (e.g., toward the accumulation of capital) as well as in knowledge and information power (e.g., toward the production of discourses/ideologies that serve dominant interests) (37, 76, 84, 103). Explanatory models are qualitative and prescriptive, though not narrowly so, offering imperatives and cautions drawn from consistent and logical patterns. Examples of the research outcomes from these approaches are provided in the next sections.

Research Results

The different framings and explanations notwithstanding, LCS and PE often reach similar conclusions about specific facets of human-environment relationships and provide one another potential insights in those cases where they differ. Some of these similarities and differences are explored here, focusing on outcomes of the major research questions noted in **Table 1**.

Human drivers and causes of land change. Both LCS and PE concur that a cascading web of interactive factors drives land-use/-cover change and that the complexity of the interactions, especially given the variance in the environmental conditions at play, often leads to different land-use outcomes, even under similar initial conditions (49, 104). Both also agree that the proximate factors of change (e.g., soil quality or farm-gate prices) linked to land managers' decisions are influenced by distal factors (e.g., international trade agreements) that sustain or change the sociopolitical-economic setting in which those decisions are made (10, 105). For example, tropical deforestation involves changes in access to forest lands, which follow typical pathways from extractive activities (e.g., timber concessions) that may involve displacement of indigenous communities and invariably require infrastructure development, usually roads, which in turn may stimulate permanent occupation by migrants or some combination of infrastructural changes and migrant occupation or commercial ranching (61, 106). Once occupation is established, household life cycles and land pressures affect subsistence-oriented economies, while markets and policy play major roles in commercial economies (94, 96, 107). Such agreement between LCS and PE is achieved in spite of differences in the attention given to proximate and distal factors and to the methods used to establish their relationships to land change.

Although often informed by case study observations shared with PE (below), causal factors in LCS are ideally established quantitatively, guided by a range of theories specific to different dimensions of social and environmental sciences (108). Economic theories and models have been tested across multiple cases of the same kind of land change, for example, tropical deforestation or agricultural intensification (109, 110). The conditions in which specific proximate factors maintain strong and significant correlations with different types of land-use/-cover change have been demonstrated for infrastructure and roads (97), governance and institutions (72, 111), household life cycles

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(96), labor availability (112), tenure and social obligations (113, 114), and crop prices (115). These factors are connected to distal ones largely through the narrative, either by providing the characteristics of the political economy in which the proximate factors operate (103) or by specifying the proposed steps or networks of processes operating from the local to global scale (95, 105). For the most part, the totality of land-change factors are examined without overt appeal to a prior notion of fault, although the goals of the study commonly attempt to determine the proportional impact of each factor or set of factors of the change examined.

PE typically begins by selecting and investigating case-based outcomes or socioenvironmental events as informed by theory that stresses the role of distal or exogenous processes that usually operate to disadvantage local land managers and are often captured in social conflict and land or resource degradation. Such processes include specific development interventions (e.g., wetland conversion and rice cultivation programs in West Africa) (e.g., 116), acute resource use conflicts between local and corporate stakeholders (e.g., forest use struggles in the Canadian Pacific Northwest) (e.g., 40), or contested land-use strategies or degradation events between the state and land users (e.g., use of fire as a management technique) (e.g., 117). Cases are typically scrutinized through sustained local observation, which includes participant observation, interviews, and oral histories of involved communities and participants, often coupled with archival analysis of related historical documents to form interpretive explanations of local outcomes with reference to distal variables. Among others, the driving factors examined include conservation regimes imposed by exogenous authority (41), rapid institutional changes in management of common pool resources through privatization and commoditization (82), and shifting of market governance and risk arrangements, especially in volatile commodity economies (118). Similar to LCS, variants of PE employ quantitative methods using survey, environmental, and remote sensing data, although statistical tests per se are not required to be consistent with structural and constructivist approaches.

These differences notwithstanding, in some cases, LCS and PE studies have led to strikingly similar assessments of the causes of land change or their impacts (see above). For example, both have demonstrated the exaggerations and simplifications involved in desertification (or arid land degradation) and tropical deforestation, especially as translated from the researcher to the policy- or decision-making communities (43, 40, 65, 119, 120). Exemplary is work on land degradation in the Sahel in which both communities challenged claims about poor land management practices, especially by long-standing, local land managers, as the root cause of desertification there (43, 65). In other cases, LCS and PE differ considerably, foremost in regard to the PAT variables (population, affluence, and technology). LCS has examined the statistical relationship of population with various aspects of land change across the range of spatiotemporal scales. It finds that at the macroscales (global and historic), P and perhaps A and T track with land change and can be set in a causative framework inasmuch as they may be seen as surrogates for demand of environmental resources and the consequences of producing them (121, 122). At this scale, PAT may be seen as superseding structural or other societal forces at play. Beyond the macroscale, however, the PAT variables display significant variance and often do not provide robust correlations with land change (49, 123). PE concurs with this last observation but goes further in its critique of the use of the PAT variables, noting that they are systematically linked to structures determining the flow and concentration of capital, power, and decision making, factors that are the underlying determinants of any empirical connections that may be found between land change and PAT. Emphasis on PAT, therefore, masks attention to the more important causal structures. Such caution, however, may lead to oversight of potentially significant relationships, especially in the case of population, which has potentially important multidirectional

PAT: population, affluence, technology

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influence on socioenvironmental outcomes (124).

Land cover and environmental feedbacks. Both approaches share an explicit interest in environmental feedbacks, although again contrasts are evident. LCS devotes attention to the internal processes of change in the environmental subsystem that serve as forcing functions on land use and thus the human subsystem (73). Climate change and its consequences on ecosystem function and, ultimately, ecosystem service for land use are perhaps the most noted examples (86, 125), but many others are examined, such as industrial-based pollution of the troposphere, which, under certain atmospheric-land surface conditions, generates chemical processes that lower crop yields and affect human health (126). PE does not deny such forcings, but its attention focuses on the variable consequences of such factors as climate change and variability for different sectors of society, mediated by changing economic conditions (e.g., producers versus consumers, affluent and poor) (see 127, 128).

LCS and PE also share interests in feedbacks as the emergent properties of systems and their role in nonlinear dynamics. LCS draws on complexity and resilience theory (51, 129), especially as they inform system dynamics and the condition of ecosystem goods and services. Recent work on functional diversity and ecosystem delivery of services illustrates this orientation (86). PE has drawn more from that part of ecological systems theory stressing dynamic disequilibria (104, 130), especially in regard to the implications of policy driven by recall to overly simple notions of equilibrium and stability on local communities and marginal social groups (80, 117). This orientation, for example, indicates that desertification in parts of the Sahel is much more a response to climate flux than to land-use burning, and policies directed to reducing that burning not only err but have major implications for the land users (119). This strong overlap in LCS and PE regarding socioecological dynamics is again marked by a disjuncture in emphasis and explanatory approach.

LCS seeks to identify the thresholds and tipping points in nonlinear systems (51, 65) and to explore how nonlinear feedbacks can produce diverse, evolved, and self-organized outcomes (129). Stress is placed on identifying how complex conditions, through slight alterations in initial conditions and divergent trends in socioenvironmental feedbacks, can produce variable outcomes (65). Complexity studies search for predominant factors and tendencies in the self-organization of systems that lead to predictable environmental results (131). The usefulness of such an approach for sustainability lies in the ability to explain and project apparently disparate (both desirable and undesirable) socioenvironmental outcomes.

Conversely, PE has incorporated insights into complexity to stress the inevitable diversity of outcomes and conditions as well as the problematic nature of environmental management regimes premised on inherited assumptions about environmental response, resiliency, and stability. Specifically, PE expresses concern about simplifications of concepts borrowed from ecological science for policy and development applications, including carrying capacity and area-biodiversity and biodiversity-stability relationships (132, 133). Through case study analysis, PE argues that these concepts are not only poor predictors of socioecological outcomes but are used to reinforce and maintain unsustainable outcomes and increasing vulnerability for disempowered populations.

Synthesis. Synthesis research is directed to specific problems or processes that are a product of, and whose solutions reside in, coupled system assessments (134). An example emanating from the sustainability and environmental sciences is the search for win-win solutions—human-environment conditions that provision human well-being and do not threaten Earth's system (54). For land systems, the ultimate win-win solutions involve land architectures in which the configuration (magnitude and pattern) of land uses and covers sustain the coupled system accordingly, from the local to global scale of assessment (51). LCS and PE share

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common problem interests that potentially inform the search for sustainable land architectures, three of which are briefly illustrated here: (*a*) vulnerability as fundamental to sustainability outcomes, (*b*) the forest transition and its implications for global forest cover and other environmental transitions, and (*c*) the coproduction of scientific knowledge about coupled human-environment systems.

Perhaps the synthesis issue that has involved the strongest melding of sustainability science, LCS, and PE is vulnerability. Recall (**Figure 1**) that risk-hazard research originally served to shape sustainability science (53), that initial formulations of PE addressed problems of risk hazards (33, 34, 59), that these critiques were later folded into vulnerability as addressed by sustainability science (54), and that the LCS research agenda added vulnerability as a major synthesis issue (56). This interaction and ongoing dialogue has fostered a common view that assessments of natural hazards and environmental risk require an understanding of the conditions that make the system (or components within a system) likely to experience harm with exposure to a hazard (52, 54). Identifying and explaining these conditions takes attention away from simple mechanisms of exposure and response to address the causes and system linkages that generate and sustain the harm, a characteristic that now pervades risk-hazards research almost regardless of the subfield in question (58, 135–140).

At least two distinctions remain between LCS and PE approaches to vulnerability, however. Consistent with its focus on societal conditions, PE-based vulnerability research emphasizes the components of the human subsystem that make certain social groups differentially and persistently exposed, sensitive, and adaptive to particular hazards (58, 59, 128, 137). Much of the answer resides in different levels of entitlements, social capital, and political and economic power of the groups. Examples of the less empowered and more vulnerable include communal farmers in northern Mexico (128, 141), female-headed households on former homelands in South Africa (139, 142), and the urban poor in hurricane-prone cities in the American South (136, 143). In contrast, and reflecting the integral role of ecology, LCS examines the vulnerability of the coupled human-environment (or social-ecological) system wherein subsystem interactions draw attention as they affect the vulnerability of one another (54, 144). Examples include the vulnerability of crop production to wind-borne evaporative salts from the desiccated Aral Sea owing to excessive water use by upstream irrigation (145) and, in Sonora, Mexico, of coastal shrimp farms from the pollution caused by excessive use of fertilizers on the upstream irrigated wheat farms, and of crop production from overextended hydraulic works and water withdrawals in the face of decadal oscillations in precipitation (144). In either case, the impacts of the hazards in question on the operation of the environmental subsystem are treated in tandem with those on the human subsystem.

As a whole, this research informs sustainability science by demonstrating that vulnerability involves multiple, interactive hazards acting on complex social-environmental conditions; that different components of the human and environment subsystems have different levels of exposure, sensitivity, and coping capacity; that the complexity of hazard-coupled system interactions renders significant variation in outcomes by place or case; and that, owing to this complexity and variance, the knowledge base applied to vulnerability assessments should be varied and flexible, including the stakeholders in question (139, 140, 146).

The forest transition constitutes another synthesis theme addressed by LCS and PE. On the basis of historical analysis of the developed world, the transition refers to the significant, but not full, recovery of forests after long periods of forest loss, at least as measured by area of forest cover (147, 148). Embedded with modernization themes and structured similarly to the demographic transition model, the forest transition is typically explained by differential land values and concomitant shifting social priorities that reduce pressures on forest lands as the economy moves from

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extractive to industrial and postindustrial phases of socioeconomic development (147–151). To some extent, the demonstration of the transition and its explanation are tied to the scale of the analysis. Generally supported by statistical analyses undertaken at cross-national scales (150, 152, 153), the transition and its explanation are much more difficult to demonstrate at local to regional scales. In the latter cases, considerable variation exists in the trajectories of forest change and their causes, especially in much of the developing world, which has not yet witnessed a prolonged phase of forest recovery. Many former tropical forests appear to be maintained in long-term successional growth (154); numerous factors interact to impede their transitions to older growth (67, 155–157), and the structure and ecosystem functions of the forests that may recover raise significant social-environmental questions (158).

Regardless of its origins in LCS or PE, this branch of research informs sustainability science by systematically identifying the barriers to and drivers and mediating influences of large-scale ecosystem change. Specifically, the collective lessons of the research stress that the forest transition thesis reflects processes embedded in the history of midlatitude forest use, a history that may not play out similarly in other areas or biomes of the world (154, 157). It is noteworthy, for example, that what might be taken as forest recovery in parts of the developing world constitutes monocultures of tree plantations (120), a land change that is also evident in parts of the midlatitude (158) and that carries serious resource and socioeconomic implications.

Science for public use is a major goal of sustainability (159, 160). This goal raises questions about how to achieve coproduction (science-society) of the problems addressed and answers applied that are scientifically and socially sound (161, 162) and how to make the knowledge produced useful to the broad spectrum of interested stakeholders and decision makers (53, 163, 164). LCS identifies sustainability applications as major synthesis activities, and parts of the LCS community have begun to make the step from the study of land change to informing policy and practice relevant to sustainability (146). Many of its practitioners not only participated in the Intergovernmental Panel on Climate Change, but also produced a special volume on *Land Use, Land-Use Change, and Forestry* (165; also 166). This volume stakes out the role of this land-cover change in global climate change and establishes methods of measuring, monitoring, and carbon accounting, a set of activities that continue through the Global Land Project as it links to the Earth System Science Partnership. In another noted effort, the recently completed Millennium Ecosystem Assessment, involving many crossover participants with LCS, stakes out the role of ecosystems for human well-being, providing a framework on which policy can be built (73). In yet another effort, land-change research permeates the Drylands Development Paradigm (146), which offers a template for both research and application for sustainable land practices in arid lands by linking the coupled systems approach with the coproduction of knowledge and practice.

Coproduction is also a pivotal point of PE research (167), with a focus on sustainability through reworking the science-society interface. Unlike LCS, which enters the policy dialogue through centralized or formalized institutional arrangements (above), PE stresses localized interventions and action-oriented research practice at the household, community, or agency scale. Explicitly involving researchers in debates and discussions with client communities or agencies on question formation and application, PE practice tends to stress the tensions as well as the productive interchanges inherent in the sometimes divergent needs of researchers, policy makers, producer communities, consumers, and interest groups (80). Sustainable outcomes in this case are evaluated on diverse and often ad hoc terms, although they are often communicated and adjudicated through larger networks of academics (e.g., the Society for Applied Anthropology) or state and community groups (e.g., tribal government). As a model for reworking science-society relations,

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PE's approach is different from but complementary to that of LCS.

CONVERGENCE WITH DIVERGENCE: SUMMARY AND OBSERVATIONS RELEVANT FOR SUSTAINABILITY THEMES

Rich intellectual traditions have developed across the disciplines to examine human-environment relationships. Among those examined here the science-based cultural and human ecologies (i.e., risk hazards) loosely joined forces during the latter half of the twentieth century to participate in the development of global environmental change and sustainability research agendas. Over the past two decades, self-labeled work in cultural ecology gave way to other labels, one of the most robust for sustainability science being LCS, which joins the natural, social, and GIS sciences in the search for understanding land change as a coupled human-environment system, complete with implications for both subsystems. During the same period PE arose both as a critique of and alternative to human ecology, eventually expanding topically to issues addressed by cultural ecology and LCS. Inspired by critical, gender, and postmodern theories, PE also addresses the coupled system but with a decided focus on the implications for the human subsystem, especially those characteristics of the system that are inherently uneven in impact; those elements of the system rooted in social, cultural, and economic power; and those sectors of society that are otherwise unempowered, marginalized, and less entitled.

Although LCS works explicitly within international global environmental change and sustainability agendas, PE takes a more local and diffuse pathway toward questions about environment and development. Each is concerned, however, with human-environment relationships as they play out through the manipulation of the terrestrial surface of Earth. This shared interest directs both approaches to similar research problems, but the differences in their base concerns and approaches often lead to divergent emphases. This divergence is captured most clearly in the explanations of land change and the role of environmental feedbacks on the human subsystem. LCS has begun to quantify the relative roles of the major drivers of different types of land change, placing them with various socioeconomic, institutional, and environmental theories of the midrange. PE, drawing on a political-economic metatemplate, documents how chains of factors operate hierarchically and across space and time. It stresses how material conditions, as well as interpretations of environmental systems, influence socioecological outcomes. Environmental narratives and categories are understood both to set the terms through which environmental conditions and change are understood and to influence behaviors (e.g., land use) and policy (e.g., land-use restrictions).

Together, LCS and PE demonstrate the global-to-local linkages of factors generating land change, the general patterns of environmental consequences that ensue, and how both change as the spatiotemporal scale of analysis changes. They also demonstrate that the complexity of human-environment interactions generates significant variance in specific outcomes within either the human or environmental subsystems. LCS, in concert with other ecological research programs, has begun to document the feedbacks of land-cover change through their consequences on the different types of ecosystem services, whereas PE identifies the differential impacts of the affected services on various social units. In this way, sustainability science is informed of the limitations of generalization and provided with a foundation upon which to assemble place-based approaches to land dynamics for application. Such assembly necessarily requires formal elaboration of concepts and theories drawn from lessons learned in the documentation of variable place-based observations. Perhaps the next phases of LCS and PE will undertake this crucial formalization and synthesis.

If research on causes and feedbacks demonstrates complementarity between LCS and PE research, that on synthesis illustrates significant

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convergence regarding certain concepts (e.g., vulnerability), theories (e.g., forest transition), and methods (e.g., coproduction). The emerging conceptual metatemplates for vulnerability reconcile human, PE, and ecological resilience concerns, expanding analysis from the factors that make systems or their components (both societal and environmental) differentially exposed, sensitive, and responsive to hazards to outcomes. The fusion of ideas and views in vulnerability research is sufficient to render distinctions between LCS and PE almost invisible. Taken as a whole, vulnerability studies directed to sustainability themes are too new to advance substantive claims with any authority; they do identify the means and methods that must be considered in undertaking assessments, and their implications for decision making.

Similar convergences are also found in regional- and global-scale assessments of land-cover change, as evidenced in research and theory development on the forest transition, among other topics. Both communities of researchers recognize the global increase in forest cover and its link to shifts in the economy of places with recovery. They also point to the character of much of the recovery as cultivated monocultures—a cover type that is likely to expand significantly as China's Grain for Green Project develops further—and sustained successional growth, especially in the tropics. The ecological implications of this cover expansion notwithstanding, the combined research suggests that the evidence does not yet support the kind of economic shifts linked to deciduous, broadleaf forests of the midlatitudes for tropical forests.

So too, LCS and PE have identified common ground for effective outreach: Sustainable outcomes involve coadaptation of the human and environment subsystems, and coadaptation is advanced by participation of, investment in, and entitlements for multiple stakeholders, including the immediate land managers in question. Science must engage in the difficult coproduction process of problem resolution, one that is increasingly affected by the expanding commodification of nature (84, 168), which moves beyond goods and services, historically considered resources (e.g., potable water), to the maintenance of the biosphere itself.

Convergence on forest transition, vulnerability, and outreach demonstrate that similar conclusions about land dynamics or their implications may follow from professed different approaches. The term professed is not used casually. The mixing of methods and the influence that different practitioners have had on one another have given rise to a research form that might best be described as "hybrid" ecology (13, 57). The framing of the research, the analytical methods employed, and the voice used to convey the results are shaped by the specific problem tackled. This claim is not trivial. A significant number of individual researchers cited in this paper would be differentially labeled LCS or PE, depending on the reader, and in some cases, two different works by the same researcher would be labeled, respectively, LCS or PE. This kind of mixing or crossing of research realms does not reconcile the distinctions in the main explanatory perspectives of LCS (postpositivism) and the two of PE (structuralism and constructivism), but it fosters an understanding and appreciation of divergent approaches (65).

Finally, basic research is not conflated with outreach application, but various types of praxis are explored. In this outreach, LCS and PE may work together in productive hybrid ways. Some of the key lessons for practitioners drawn from the Dryland Development Paradigm (146, p. 848) exemplify: (*a*) desertification is an emergent outcome of complex causal factors of a coupled human-environment system with place-time specific pathways; (*b*) rangeland systems adjusted for one climate condition change system's thresholds that can lead to crises when climate changes; (*c*) dryland development schemes are often driven by divergent and external political and economic objectives with important implications for people and environment; (*d*) poverty trap thresholds tend to be linked to low productivity and development in drylands; and (*e*) win-win (environment-development) outcomes appear to be enhanced through participatory and coproduction methods. These developments between LCS and PE are consistent with those emerging in sustainability science more broadly.

SUMMARY POINTS

1. Distinctive topical and methodological visions of human-environment relationships, especially in geography and anthropology, helped to shape the immediate precursors of land-change science (LCS) and political ecology (PE).
2. LCS and PE share many topical research themes cogent for sustainability science, but their different problem framings and explanatory foci impede linked understanding that should prove beneficial for sustainability themes.
3. LCS may be directed to phenomena, processes, and outcomes in either the human or environment subsystems, including their interactions, whereas PE, although inclusive of research into ecosystem processes, overtly frames problems in regard to the human consequences of system interactions.
4. The two research subfields concur on the complexity of, and many of the linkages among, the causal factors in land change but differ in the attention given to the population, affluence, and technology (the PAT variables), biophysical forcing functions, and hierarchical political economy linkages.
5. LCS searches for tipping points in the resilience of coupled human-environment systems, typically at the site of ecosystem change, and PE focuses on the environmental outcomes of human activity across scales, especially including both the material influences of policy and economics and the impact of ideas and concepts embedded in policy (e.g., equilibrium, pristinity, or degradation).
6. Both approaches have established that land-change processes are complex, with outcomes strongly influenced by context (place and history).
7. Recent conceptualizations of forest transitions, vulnerability, and applications, founded on the coproduction of human-environment problems and solutions, illustrate improved understanding generated by the research synergy of the two approaches.
8. The more convergent forms of LCS and PE may be so fused in problem framing and methods that concept of a hybrid land change or ecology is not far fetched.

FUTURE ISSUES

1. Research needs to identify those conditions in which general principles of land change operate and those contexts that strongly mediate the outcomes of their operation.
2. Future work should identify the critical phenomena and processes of and methods of analysis for assessing sustainable land architectures.
3. Studies should adjudicate findings across diverse explanatory practices.
4. Integration of research within the practices of the coproduction of science and application should be pursued.

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Volume 33, 2008

Contents

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III. Management, Guidance, and Governance of Resources and Environment

IV. Integrative Themes

Indexes

Errata

An online log of corrections to *Annual Review of Environment and Resources* articles may be found at http://environ.annualreviews.org