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REVIEW

Traditional fire-use, landscape transition, and the legacies of social theory past

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Abstract Fire-use and the scale and character of its effects on landscapes remain hotly debated in the paleo- and historical-fire literature. Since the second half of the nineteenth century, anthropology and geography have played important roles in providing theoretical propositions and testable hypotheses for advancing understandings of the ecological role of human–fire-use in landscape histories. This article reviews some of the most salient and persistent theoretical propositions and hypotheses concerning the role of humans in historical fire ecology. The review discusses this history in light of current research agendas, such as those offered by pyrogeography. The review suggests that a more theoretically cognizant historical fire ecology should strive to operationalize transdisciplinary theory capable of addressing the role of human variability in the evolutionary history of landscapes. To facilitate this process, researchers should focus attention on integrating more current human ecology theory into transdisciplinary research agendas.

Keywords Traditional fire-use · Anthropogenic landscape transition · Human ecology · Paleofire · Historical ecology · Pyrogeography

INTRODUCTION

This paper reviews the literature on the nature and role of traditional fire-use in landscape change, a significant concern for transdisciplinary research in what I refer to here as historical fire ecology. People have been using landscape fire to alter and manage human environments for millennia. However, the historical role and significance of fire-use in the transformation and maintenance of landscapes remains unresolved. Debate exists across a wide variety of socioecological contexts ranging from hominin–savannah interactions to the cultural landscapes of late Holocene agriculturalists (Simmons and Innes 1987; Krech 1999; Vale 2002; Daniau et al. 2010). A number of highly cited review papers have called for improved understanding of the role of humans in influencing the variability of fire regimes and landscape patterns through time and space (Pausas et al. 2009; Bowman et al. 2011). While humans influence fire regimes and landscape patterns in a number of ways, arguably one of the most historically significant ways is through the intentional use of fire in a land management context (Coughlan and Petty 2012). Consequently, research in historical fire ecology has a clear need for integrative, transdisciplinary theory capable of addressing the variable role of traditional fire-use in the evolutionary history of landscapes.

This paper contributes to this theory-building effort by reviewing salient and persistent theoretical propositions and hypotheses (i.e., legacies) originating in the social sciences. I primarily highlight theoretical contributions from geography and anthropology which offer the potential to bridge the disciplinary gap between social and biophysical sciences by providing empirically testable hypotheses. The objectives of this review are to illustrate the ways in which theoretical legacies carry both constructive and confounding contributions for current research foci. I begin this review with a historical narrative, tracing selected scholarship on historical fire ecology starting with its roots in the nineteenth century. I then discuss how confounding theoretical legacies are insinuated in present scholarship. Specifically, I focus the discussion of two high-impact research agendas currently emerging from biophysical-centered approaches to fire and landscape change. I suggest that current efforts in historical fire

ecology can benefit by recognizing and reframing legacy propositions from a contemporary human ecology theoretical perspective.

METHODS

Historical legacy propositions were reconstructed following the generally accepted history of thought in human ecology (e.g., Harris 1968; Trigger 1989; Sutton and Anderson 2013). I sought references on the role and nature of fire-use in landscape change within the work of foundational scholars. I then distilled propositions most relevant to current research agendas (as identified below). Although many of these works have been relatively influential individually, the common threads between them have received little attention from fire historians and others reviewing the development of theory in historical fire ecology. I include contributions from fire ecology (proper) and its antecedents only where concepts were relevant to bridging social and biophysical disciplines. Similarly, I excluded references to applied fire science, specifically prescribed burning, since I was interested primarily in social science efforts to develop theory on traditional fire-use.

Current research agendas were identified through a systematic review of the literature. I searched Google Scholar and Web of Science for the literature from 1999 to 2014 using the search terms "historical, fire ecology, and humans"; "paleoecology, fire, and humans"; and "landscape, fire ecology, and humans". I filtered the search results by number of times cited and judgmentally selected reviews, syntheses, and empirical studies with the most cogent theoretical statements on the relationships between humans, fire, and landscape. In the discussion section, I organize a sample of this literature by research agenda.

LEGACY PROPOSITIONS AND THEIR HISTORY

Evolutionism and environmental determinism

Nineteenth century theories about the relationships between humans and their environment held that humans on lower ends of variously conceived stages of "civilization" lacked the organizational and technological capabilities to actively transform the conditions of their existence. Outside of "civilization," peoples and their cultures were more or less determined by the environments in which they lived. In their efforts to understand the relationship of the past to the present, scholars fused the newly devised theory of evolution with concepts of stadial, unilineal cultural progress, falling back on environmental determinism to explain differentiation between peoples (Trigger 1989).

Marsh (1965) was one of the first modern scholars to articulate propositions that specifically concerned human–fire–landscape interaction. Marsh argued that human agency impacted the environment through "the direct violence of hostile human force" (1965, p. 5). In accordance with his contemporaries, Marsh conceived of the permanence of human effects on the environment as a function of a people's relativity mobility and the level of "civilization". He acknowledged the use of fire by less sedentary peoples to modify landscape, but considered the effects relatively ephemeral.

Evolutionists such as Morgan (1964) formalized a similar view of human evolution into a series of phases where the lower periods corresponded with the "infancy of the human race" as it made slow progress against the forces of nature. Morgan (1964) suggested technological and economic change as one of the significant markers of transitional progress, but the theory fell short in explaining contemporaneous diversity in human–environment relationships. While others proposed broadly construed environmental limitations on civilization, Fredrick Ratzel's theory of anthropogeography offered a systematic approach to the study of diversity in human societies in relation to the environmental geography (Freilich 1967).

Mason's (1894) "technogeography" framework synthesized the theories of Ratzel and Morgan, suggesting that human history was characterized by periods of "land holding." Linking the theory of human evolutionary development more specifically to environment-changing technology, Mason posited the advent of agricultural fire-use as a period in an additive sequence with other "industrial" forces wielded by humankind. Like Morgan's scheme, the period of agricultural fire-use followed immediately after a period of "harmless dependence" upon the environment. Mason also drew heavily on Marsh in his interpretation of human–environment interactions: "Man attacked the earth with firebrands, burning forests and creating wastes," (Mason 1894, p. 159).

Mason and contemporaries elaborated on the commonly held belief that humans were originally "noble savages" who lived in harmony with (or at the mercy of) the environment. Theory aimed to explain the "rise of humanity," suggesting that the noble savage evolved into civilized masters of the environment by passing first through a phase of irrational destruction of the environment wrought by the adoption of new land-use strategies such as agriculture and land-altering technologies such as agrarian fire. Technogeography clearly placed fire-use by shifting agriculturalists as the principal technological component by which humanity first began to actively (if negatively) manipulate the environment. However, from the perspective of "modern" land management, traditional (pre-industrial) fire-use was "primitive," irrational, and ecologically

destructive. In summary, Mason's most important contribution concerned the proposition that *the use of fire by humans at different phases of techno-economic development differentially effected the environment through time and space.*

The culture area and environmental possibilism

Evaluating Mason's claims required empirical investigation. The problem lay in the fact that while a variety of theories pointed to the relative importance of material conditions and strategies of production for explaining the human condition, empirical research efforts lacked appropriate and compatible units of analysis. Based largely on how museums were then cataloging material collections, Mason's (1894) technogeography offered the culture-area concept as a way to explain the differentiation of sociocultural groups across geographic space. In terms of fire, the outcome of human–fire-use either improved landscapes by promoting agriculture or created "wastes" depending both on the stage of human development and the "oikoumen," the society's geographic "culture-area". Culture-area studies formalized the idea that the "ethnic unit," conceptualized as a discrete social group with common customs, beliefs, and values, was to be studied in relation to its geographical region (Wissler 1927). In this sense, the culture-area concept provided a working hypothesis concerning fire-use: *Holding techno-economic phases constant, the diversity of human–fire–landscape relationships across cultures (i.e. ethnic units) can be explained as function of the culture's geography*.

In its early form, the culture-area was little more than an attempt to operationalize the analysis of human progress under the differential effects of a deterministic environment. Mason's understudy and successor in the ethnological division at the United States National Museum, Walter Hough, aptly summarized the early culture-area conception of human–fire relationships in the title of a 1926 report: "Fire as an agent in human culture." Although the report is mostly concerned with domestic and industrial applications of fire (e.g., hearths, ovens, and kilns), Hough's discussion of fire as a "biological factor" postulates that "the clearing of the prairies also influenced the distribution and habits of Indian tribes" (1926, p. 8). In other words, fire, as an environmental factor, shaped culture, with little acknowledgement that humans might be the source of that fire. Hough further postulated that "civilizational progress" along with the growth of population extended the reach of human–fire-use through "the chase of animals, perhaps aiding in the domestication of several species, the cutting of timber, and the clearing of land for agriculture" (Hough 1932, p. 406).

Boas (1904) proposed an alternative approach to understand the development of sociocultural variability. From Boas's point of view, the teleological theory of uniform human progress was a spurious assumption based on the "exaggerated valuation of the standpoint of our own period, which we are only too liable to consider the ultimate goal of human evolution" (Boas 1904, p. 524). Boas proposed that "In place of a simple line of evolution there appear a multiplicity of converging and diverging lines … the striking feature seems to be diversity," (Boas 1904, p. 522). Sociocultural evolution was not unilinear, but rhizomatic. In order to accommodate the complexity of convergence and divergence in the process of cultural transmission, Boas and students discarded the concept of the evolutionary phase. Instead they sought explanation for cultural variability in the particular history of culture groups. Nonetheless, the environment was accorded a role as selective force limiting diffusion and prompting modification of culture traits. The categorical classification of broad subsistence types such as hunter–gatherer, pastoralist, agriculturalist, and industrialist was retained as heuristic rather than formal categories.

With the influence of Boas, scholars continuing Mason's work in culture-area studies rendered the theory more pliable with respect to the cultural variation by accommodating theories of cultural diffusion and environmental possibilism (Wissler 1926; Kroeber 1936; Steward 1938). However, most scholars of this period ignored fire-use at their field sites or failed to find significance in it (Lewis 1972, 1978).

In spite of these intellectual currents, or perhaps because of their deficiencies, environmental determinism remained strongly entrenched in the discipline of geography throughout the beginning of the twentieth century (Freilich 1967). Deterministic explanations were especially prominent with respect to prehistoric settlement and land-use. Geographers continued to portray Neolithic (in Europe) and Pre-Columbian (in America) farmers as incapable of significantly altering forested landscapes because of their lack of iron tools such as ax. Environmental determinists asserted that prior to the Iron Age, forests were a barrier to human settlement (Clark 1947).

British archeologist Grahame Clark was one of the first scholars to move beyond armchair speculations concerning the historical and ecological significance of agropastoral fire-use. Clark (1947, 1989a) used sedimentary pollen and charcoal to refute deterministic hypotheses that early agricultural peoples did not possess the knowledge or ability to clear forests for settlement. His insights were derived from a novel approach to research that made use of the ecosystem concept (Tansley 1935), paleoecological methods, and employed an interdisciplinary team to investigate Neolithic settlement at the landscape scale (Clark 1989b). Clark drew on historical European slash-and-burn agriculture as historical analogs for interpreting changes he observed in

sedimentary archives. In his seminal work, *Archaeology and Society*, Clark (1957) articulated a perspective that not only countered extreme environmental determinism, but also rejected the prevailing notion that humans were external agents merely impacting the environment. Rather, for Clark, human–environment relations were reciprocal. The paleoecological investigation of landscape history was an integral part of the archeological practice:

> "It is because the interaction between cultures and the other elements in the ecosystem is reciprocal that a study of habitat and biome is of such vital importance to the prehistorian: from it he cannot merely learn the conditions under which prehistoric communities developed their culture, but quite often by noting the impact of culture on vegetation, for example, he can gain direct information about land-utilization that would otherwise elude him" (Clark 1957, p. 176).

Clarke's thinking had been heavily influenced by work in dynamic ecology (Tansley 1935). Early dynamic ecology often implicitly included humans as ecological actors. Human-caused fire was initially classified as a biotic cause, of "successional-retardation". The term "fire climax" or "subclimax" was introduced to account for geographic areas held in a constant state of succession by frequent fire (Phillips 1935; Tansley 1935). Fire disturbance was immediately problematic for ecological theory not only because it forced exceptions to the rules of succession, but also because many researchers believed it to be mostly human caused (Phillips 1935). Yet natural ignition sources, such as lightning, were well documented. Additionally, newly emerging paleoecological methods provided ample evidence that fire had been an important ecological disturbance in North America prior to human settlement. Hence, ecologists were increasingly of the opinion that humans were not the only or most significant source of ignitions in the world. Since ecologists were preoccupied with understanding non-human nature, ecological research goals moved away from ascertaining the influence of human–fire-use on ecological succession. Instead, ecologists attempted to remove humans from the equation in order to observe natural processes. The question of human influences on vegetation cover was primarily left to the human-centered disciplines.

Climax and succession concepts from dynamic ecology also influenced culture-area approaches in American geography and anthropology (Kroeber 1936). Indeed, they underpinned the development of the environmental possibilistic approach. As scholars adopted more and more ecological theory, they also began to challenge the validity of the various polemics clouding understandings of fire-use and human–fire–landscape interaction (Sauer 1950; Stewart 1951, 2002). Sauer's (1956) emphasis on human agency as an important ecological factor was paramount to this shift in theory. Sauer's legacy challenged the deterministic tendencies inherent in the culture-area hypothesis with a more dynamic version: *landscapes themselves reflect a history of human activities*.

Cross-fertilization between anthropology and geography during this period is especially evident in the "Berkeley school" scholarship, led by Carl Sauer and Alfred Kroeber, a student of Franz Boas (Lewis and Anderson 2002). In anthropology, the most obvious example of Berkley school cross-fertilization is the work completed by Kroeber's student, anthropologist Stewart (1951, 2002). Stewart assembled an extensive bibliographic analysis of ethnohistorical and other documentary evidence of Native American "burning of grasslands and forests". Notably, he also directly attributed his research interests in the ecological effects of fire-use to the influence of both Sauer and Kroeber (Stewart 2002).

Stewart mined both primary and secondary ethnohistorical sources. As Henry T. Lewis has pointed out, Stewart presented comprehensive and convincing documentary evidence that "habitat burning was a universal feature in almost all hunting–gathering societies" (Lewis 2002, p. 31). Stewart concluded that "Indians burned the forests of the eastern United States to such an extent that the general vegetation first observed by Europeans was not at all what could be expected from an evaluation of soil and climate" (2002, p. 70). He grounded this and other claims of significant and drastic landscape consequences of fire-use in the culture-area concept:

> "Anthropologists have shown that practices typical of part of a culture area are usually present throughout the entire culture area. When samples are widely scattered, as they are in the case of woodland burning, over a region of uniform environment and cultural similarity, the samples are assumed to represent the whole area." (2002, p. 71).

The result was a polemic that has been interpreted as implying the axiom, *cultural fire-use determines regional biogeography*. However, as others have pointed out, the majority of the evidence Stewart presented was not empirical, but anecdotal or biased historical accounts (Russell 1983). Even where he did cite ethnographic field observations they were incidental to the research objectives of the observer.

The cultural–ecological synthesis

Some of the earliest empirical studies to address the specific economic rationale of fire-use in livelihood activity

focused on horticultural societies in tropical and sub-tropical systems, i.e., "slash-and-burn," "shifting," or "swidden" cultivation (e.g., Conklin 1954; Barlett 1955; Conklin 1961). These studies emerged from Harold Conklin's ethnoecology approach to human ecology. Mentored by Wissler, Kroeber, and Sauer, Conklin's work highlighted fire-use as a key component for transforming and "domesticating" landscapes. It showed the cyclical importance of fire to land-use practices that formed the backbone of economic production in a wide variety of societies across the Earth (Conklin 1961). Conklin's (1954) empirical case study in the Philippines described how swidden fires were controlled by both timing and placement of ignitions as well as by labor invested in constructing fire breaks and piling fuels. These practices contained fires within the swidden field while ensuring fire severity levels high enough to transform intended fuels into nutrient-rich ash. Conklin and others established a new research program for fire-use by showing that fire-use practices could be a rational and "constructive" form of land-use. The legacy they leave is aptly summarized by Conklin:

> "The specific form that a system of swidden agriculture may exhibit within a given geographical or cultural province depends on the extent of available land, labor, and capital; the local settlement pattern; the degree of social and political integration with other segments of the larger society; and on a large number of more specifically agronomic variables, such as the kinds of principal crops raised …, types of crops associations and successions, crop-fallow time ratios, dispersal of swiddens, the presence of livestock, the use of specified tools and techniques including special methods of soil treatment, the vegetation cover of land cleared, climate, soil conditions, and topography" (1961, p. 27).

The hypothesis builds on the culture-area concept, by synthesizing the thesis–antithesis of environmental and cultural determinisms. However, rather than searching for central tendencies, it examined the variability of fire-use and its environmental effect as a component of a cultural–ecological system. As a consequence, the hypothesis that emerges does away with the need to fit observations into tightly constrained techno-economic phases or biogeographic regions. It states simply that *diversity in coupled fire–land-use practices across culture groups and environmental settings can be explained as a function of local group- and site-specific factors*.

Other emerging approaches, such as Julian Steward's cultural ecology, attempted to explain population, society, and culture by virtue of the interaction between a particular environment and the "cultural devices" of its exploitation. Steward sought to supplement the Boasian historical approach with the concept of "adaptation" and "culture core" largely derived from French human geography via the work of Carl Sauer (Harris 1968). Steward's theory differed from more deterministic human–environment models since the factor constraining a particular culture was not the environment, per se, but "the manner in which it was exploited" (Steward 1938, p. 230). The focus on adaptation to local environmental conditions marked a shift in research interests from cultural geography as pattern (culture-area studies) to cultural geography as process (cultural ecology) (Sutton and Anderson 2013). Geographically, research shifted its gaze from culture-area regions to local environments. These transitions led to a shift away from culture or 'ethnic unit' as the unit of analysis to relatively discrete sociopolitical groups. Continual refinement of units of analyses in cultural ecology eventually led to a focus on specific institutions (e.g., households) and, in human behavioral ecology, individuals (Sutton and Anderson 2013).

Cultural ecology's interest in processes opened the door for new understandings of the relationship between traditional fire-use and landscape change. This emerging research agenda piqued the interests of a few anthropologists and geographers to focus on forager (hunter–gatherers) use of broadcast fire (Jones 1969; Lewis and Bean 1973). The most influential concept from this period is Jones' "fire-stick farming" hypothesis (1969). Jones hypothesized that *fire-use is predominantly a resource management strategy, employed to maintain and expand focal subsistence resources.* In addition, it called into question the conventional notion that foragers were simply the passive subjects of nature.

Following Jones, Lewis (1972) sought to integrate newly developed understandings in fire ecology with cultural–ecological theories of the evolution of agriculture. In doing so, he flipped the agricultural fire hypothesis on its head. Lewis suggested that fire-use did not just result from agricultural subsistence strategies, rather, "fire, employed by man, played a significant role in the emergence of agriculture," (1972, p. 195). Although the concepts were anticipated by Clark's (1957) proposition that human–environment relationships were reciprocal, Lewis nevertheless advanced a novel hypothesis: *Human–fire–landscape interactions are co-evolutionary.* This focus on evolutionary process began to question the validity of the conventional divide between forager and agriculturalist, specifically with regards to the use of fire.

Environmental history and revisionism

From the late 1970s onward, social science research on traditional fire-use entered a period that might be termed

the "environmental history phase". Heavily influenced by theory in political economy and emerging political ecology, scholars began to focus on the history of how political and social forces influenced historical fire ecology, in part, by disparaging and prohibiting traditional fire-use (Lewis 1978). Critical revisionists grappled with explaining why fire-use, among other human activities of historical ecological significance, had been ignored and misunderstood in conventional environmental narratives (Pyne 1982; Dove 1983). Scholars used historical documentation to tackle Euro-centric myths such as the destructiveness of fire (Lewis 1978; Pyne 1982) and the idea of the "ecologically noble savage" which posited that foragers had little effects on the landscape (Headland 1997). Scholars of this period also began to make more extensive arguments that humans were a dominant force shaping landscapes even in systems conventionally considered "pristine" (Cronon 1983; Denevan 1992).

In the humanities and social science circles, these critiques were incredibly helpful for rethinking traditional fire-use and its social contexts, particularly for post-colonial situations. Yet, with some exceptions, scholarship of this period made little headway bridging disciplines and providing novel, empirically testable propositions with regards to the nature and effect of traditional fire-use on landscapes. Many biophysical scientists remained skeptical of claims of human influence to fire regimes based on historical evidence alone. In the absence of clearly operationalized theory, biophysical scientists interpreted such arguments as simply building uncritically on Stewart's (2002) "culture determines biogeography" hypothesis. As a consequence much of this work was dismissed based on lack of attention to issues of scale and overreliance on biased and ecologically vague historical accounts (Russell 1983; Vale 2002).

On the other hand, since the 1990s, scholars in ecology and physical geography have increasingly recognized the historical signature of traditional fire-use in a wide variety of landscapes (Grissino-Mayer et al. 1994; Clark and Royall 1995; Delcourt and Delcourt 1998). This research has provided ample empirical support for Sauer's hypothesis that human–environment interactions are spatially inscribed in the landscape through the agency of human–fire-use (Sauer 1956). These studies were heavily influenced by theoretical developments in landscape ecology (Forman and Godron 1986), the incorporation of history into ecological studies (Christensen 1989), and related developments in fire ecology (Agee 1998).

The ecological interest in landscape and historical disturbance processes developed out of interests in understanding spatial dynamics, that is, not only how ecological processes influence patterns (e.g., ecological succession and landscape mosaics) but also how spatial patterns influence processes (Turner 1989). Although landscape ecology clearly influenced scholarship on traditional fire-use during the environmental history phase, concepts were appropriated for use in qualitative arguments rather than as a tool for empirical research design.

In contrast, developments in landscape ecology were not lost on the more general study of human ecology. For example, theoretical concepts and methodological tools from landscape ecology played a key role in re-conceptualizing the use of ecology in empirical human ecology (Winterhalder 1994; Gragson 1998). Indeed, the few scholars interested in human–fire ecology were early adopters of concepts from landscape ecology (Lewis and Ferguson 1988). Over the last 15 years, human ecology-centered studies of traditional fire-use have not only adopted theoretical concepts from landscape ecology, but have also incorporated geospatial analyses and other methods developed by landscape ecologists. For example, several studies combine ethnographic and ethnohistorical insights on traditional fire-use with spatially explicit environmental data (Laris 2002; Black et al. 2006; Natcher et al. 2007; Bird et al. 2008; Laris 2011; Bird et al. 2012; Johansson et al. 2012). Other studies include spatial modeling simulations (Bean and Sanderson 2008; Perry et al. 2012). Lastly, a few recent interdisciplinary historical fire ecology projects have combined historical, archeological, ethnological, and paleoecological methods and perspectives (Johnson et al. 2010; McCune et al. 2013).

DISCUSSION

Emerging approaches to human–fire–landscape dynamics are predominantly interdisciplinary efforts, but are nevertheless driven by relatively distinct human behavior-centered (human ecology) or biophysical-centered perspectives. While human ecology approaches are represented by renewed interest from scholars already grounded in ecologically oriented social theory (e.g., evolutionary and ecological anthropology, political ecology, historical ecology), biophysical-centered approaches must also grapple with the effects of human behaviors on fire and landscape dynamics. As a consequence, biophysical-centered approaches have developed their own frameworks for incorporating human–fire-use. Yet, legacy propositions from social science (Table 1) remain heavily influential even in biophysical-centered approaches, both aiding and confounding the interpretation of research results. Here, I discuss legacies apparent in the theoretical approaches of two high-impact research agendas (pyric-phase and ecological vulnerability frameworks) in what has recently been termed human pyrogeography or human dimensions of fire ecology (Bowman et al. 2011; O'Connor et al. 2011). I

Table 1 Legacy propositions and hypotheses reviewed in this article

Proposition/hypothesis	Description	Attribution
Significance of fire-use	First environmentally transformative technology	Mason 1890s, Clark 1940s, Stewart 1950s
Fire-use variability	Techno-economic stages determine effects of fire-use	Mason 1890s
Chronology of variability in magnitude	Agricultural fire first benchmark	Mason 1890s, Clark 1940s
Nature of fire-use	Traditional fire-use irrational	Mason 1890s, Pinchot 1910s
Fire-use variability	Geographic area explains diversity in fire-use	Hough/Wissler 1920s
Fire-use variability	Population increases reach and effects of fire	Hough 1930s
Significance of fire-use	Human agency is inscribed in landscape, often via fire	Sauer 1920–1950s
Significance of fire-use	Most societies use landscape fire	Stewart 1950s
Significance of fire-use	Fire-use determines environment of culture-area	Stewart 1950s
Fire-use variability	Fire-use–landscape interaction depends on site-specific socioeconomic and ecological factors	Conklin 1950s
Fire-use as process	Fire-use as resource management strategy	Jones (1969)
Fire-use as process	Fire-use as part of evolutionary process	Lewis (1972)

juxtapose these research agendas with recent literature in human ecology and suggest some pathways for reframing theoretical approaches to understanding the role and nature of traditional fire-use in landscape transition (Table 2).

The pyric-phase research agenda (including precursors and variants) investigates fire history in order to understand the relationships between broadly construed techno-economic strategies and fire ecology. In contrast, the ecological vulnerability research agenda investigates the biophysical controls of fire regimes and seeks to understand how and why humans have or have not altered landscapes through the use of fire (Roos et al. 2014). The pyric-phase research agenda is most cogently represented by a number of reviews and syntheses of human–fire–landscape interactions (Pausas et al. 2009; Bowman et al. 2011; Seijo and Gray 2012; Bowman et al. 2013; Valese et al. 2014). These reviews posit a generalized schema of phases that rather closely resembles key concepts laid out in Mason's (1894) Technogeography. The reviews neither directly reference Technogeography (with the exception of Valese et al. 2014, who cite Hough 1932) nor do they adopt its teleological currents. However, the reviews do reproduce substantive aspects, such as the proposition that phases of human–fire–landscape interaction can be classified according to broadly defined techno-economic categories.

Pausas et al. (2009) present a three-phase human–fire–history scheme based on an adaptation of Guyette et al.'s (2002) theory of successive stages in Missouri's (USA)

Table 2 Papers by number of times cited (as of November 2014) and theoretical framework

Author	Year	Number of citations		Number of citations per year[a]	General framework
		Google Scholar	Web of Science		
Guyette et al.	2002	201	120	16.75	Pyric-phase
Marlon et al.	2008	274	196	45.67	Ecological vulnerability
Pausas and Keeley	2009	224	139	44.80	Pyric-phase
Whitlock et al.	2010	77	Not indexed	19.25	Ecological vulnerability
Bowman et al.	2011	111	65	37	Pyric-phase and ecological vulnerability
Archibald et al.	2012	44	26	22	Ecological vulnerability
McWethy et al.	2013	12	7	12	Ecological vulnerability
Laris	2002	143	76	11.92	Political ecology/land change science
Bird et al.	2008	116	71	19.3	Evolutionary-ecological anthropology
Natcher et al.	2007	22	11	3.14	Sustainability studies
Smith	2011	41	25	13.67	Evolutionary-ecological anthropology

[a] Based on number of citations (Google Scholar)/years since publication (2014–publication date)

anthropogenic fire regimes. Guyette et al. (2002) based their scheme on empirical analysis of relationships between population density and fire occurrence as recorded in annual tree rings. However, they relied on fuel limitations and cultural factors to explain the significant deviations from an otherwise positive linear correlation between populations (as a proxy for ignitions) and fire-scar events. Pausas and Keeley (2009) suggested instead that various ignition or fuel-depended phases correspond to three generalized socioeconomic classes: hunting and gathering (ignition dependent), agropastoralism (fuel limited), and industrialization (fuel driven). The second most cited review, Bowman et al. (2011), synthesizes similar stadial schema with theory in complex adaptive systems. This approach suggests that similar techno-socioeconomic arrangements result in similar fire-society feedback loops. As a result, human–fire relationships are analogous among the discrete techno-socioeconomic categories, e.g., hunter–gatherer, agropastoral, and industrial societies (Roos et al. 2014).

While variability between techno-economic strategies is clearly highlighted by the pyric-phase approaches, the variability of fire-use and management within each category of techno-economic strategy has been ignored or underemphasized (e.g., Natcher et al. 2007). Indeed, empirical investigations have yet to test the assumption that variability in fire-use strategies (and their associated fire regimes) is greater between the putative techno-economic categories than it is among those categories. This may be especially relevant for small-scale societies which, among foragers alone, are enormously variable in terms of their human–environment relationships (Kelly 1995). As a consequence, it remains unclear if conceptually lumping techno-economic strategies according to normative, cladistic assumptions of techno-economic similarity provide any analytical utility for historical fire ecology. Since the Boasian era, anthropological science has focused on non-deterministic explanations for human variability. As outlined above, a focus on human–fire–landscape interaction as coevolutionary process has called into question the theoretical utility of fitting traditional fire-use strategies into a static techno-economic typology. This may be particularly true for understanding place-based differences in fire usage between the putative foraging, agropastoral, and industrial phases.

Empirical evidence does, however, suggests that changes in fire regimes (pyric-transitions) are very often associated with changes in techno-economic strategies for a variety of times and places (Coughlan and Petty 2012; Bowman et al. 2013). As a consequence, a more theoretically cogent reframing of Mason's legacy proposition might suggest that *the use of fire by humans with different techno-economic strategies (as opposed to phases) differentially effects the environment through time and space*. Thus, it behooves us to scrutinize the historical trajectories of individual landscapes in relation to the socioeconomic histories of the human groups that inhabited them. Given sufficient and comparable information, comparisons between fire-use strategies and their coupled landscapes may yield interesting and generalizable results.

The ecological vulnerability research agenda emerged from paleoecological research in studies of tree rings and sedimentary charcoal records (Marlon et al. 2008; Whitlock et al. 2010; O'Connor et al. 2011; McWethy et al. 2013). The vast majority of paleofire studies focus on biophysical controls of fire regimes, especially climate. Because past human–fire-use confounds attempts to understand climatic controls over fire, a fundamental step in the investigation of climate-fire interactions has been to ask when, where, and at what scales humans have used fire to transform landscapes. Again, the approach references the study by Guyette et al. (2002), suggesting that prior to the modern era, population densities, as proxies for ignitions, determine the magnitude of human-caused fire effects on the landscape. This proposition is combined with theory in alterative stables states which posits that landscape transitions result from shifts in periodicity or magnitude of disturbance events that cause feedbacks, ultimately surpassing the system's ability to absorb changes (McWethy et al. 2013). The approach proposes that for most of the Holocene, while population densities were everywhere low, human-caused effects were at the local scale, except where particular biomes were more vulnerable to fire-use-induced feedbacks (McWethy et al. 2013). Therefore, holding population densities constant (i.e., below particular thresholds), the researcher can compare biomes and their fire histories to derive the natural conditions that control human capacities to impact their environments. As a consequence, the underlying assumption of this approach states that variability in human–fire–landscape interaction is determined by biome-level environmental conditions: "the potential for human activity to change fire regimes depends on the strength of the natural controls on fire, namely, climate and fuel," (Whitlock et al. 2010, p. 15).

While this research agenda does not reference Technogeography, it clearly draws on deterministic ideas fleshed out by the early culture-area studies. Ignoring the fact that using population density as a proxy for ignitions is theoretically weak (Coughlan and Petty 2012), the proposition that the magnitude and extent of traditional fire-use is determined by particular population densities rests on erroneous assumptions of variability (or lack thereof) within small-scale societies. Indeed, mobility, settlement, and subsistence strategies have varied considerably among foragers (Kelly 1995) and are likely more variable among agropastoralists.

Natural controls undoubtedly constrain the effects of human–fire-use on particular landscapes, however, socioeconomic preferences, values, and goals also play a significant role. Socioeconomic considerations are tied to the spatiotemporal availability of focal resources, which in turn help determine patterns of settlement, mobility, division of labor, among other factors. A simple example of the importance of considering the relationship between socioeconomic parameters, fire-use, and ensuing landscape effects concerns the effective difference between strategies that use maintenance fires (low to moderate severity) and those that use transformative fires (high severity fires) (Lewis 1994). The choice between these strategies depends on socioeconomic preferences, ecological knowledge, and the condition of the landscape at any given point. For example, coastal dwelling foragers with subsistence focused on marine resources should hypothetically have little effects on forests beyond settlement localities. However, if starchy rhizomes found primarily in early successional vegetation substantially reduce the risk of starvation during particular seasons, people may, in fact, convert portions of forest through the use of fire. Once sufficient patches of early successional vegetation exist, either from natural disturbance or from past human land uses, fire-use may simply be used to maintain those patches rather than expand them.

Fire-use decisions may also involve consideration of socioeconomic tradeoffs. For example, if forests require significant labor to clear or maintain, or if cultural preferences value fire-sensitive resources, people may choose to exclude fire from certain areas. In the agropastoral landscapes of the western Pyrenees, patterns of settlement and land-use are highly structured by topography since higher altitude areas are not suitable for cultivating crops (>800 msl). Between 800 and 1200 msl, pastures dominate south-facing slopes, while mesophilic Beech (*Fagus sylvatica*) forests tend to dominate north-facing slopes. Increased solar radiation and foehn wind exposure on south-facing pastures provides fuel characteristics amenable to the efficient use of pastoral maintenance fires. Climate-fuel dynamics on north-facing pastures make burning more difficult and ultimately require more time and labor investment (Fig. 1). In addition, traditional farming households required small-wood and other fire-sensitive forest products. As a consequence, topographic controls on fire ecology constrained pasture expansion on north-facing slopes through its consequences for return on effort ratios given available labor and economic needs of Pyrenean farming households. However, these same topographic controls facilitated fire exclusion and therefore conservation of north-facing woodlands (Coughlan 2014). Thus, the

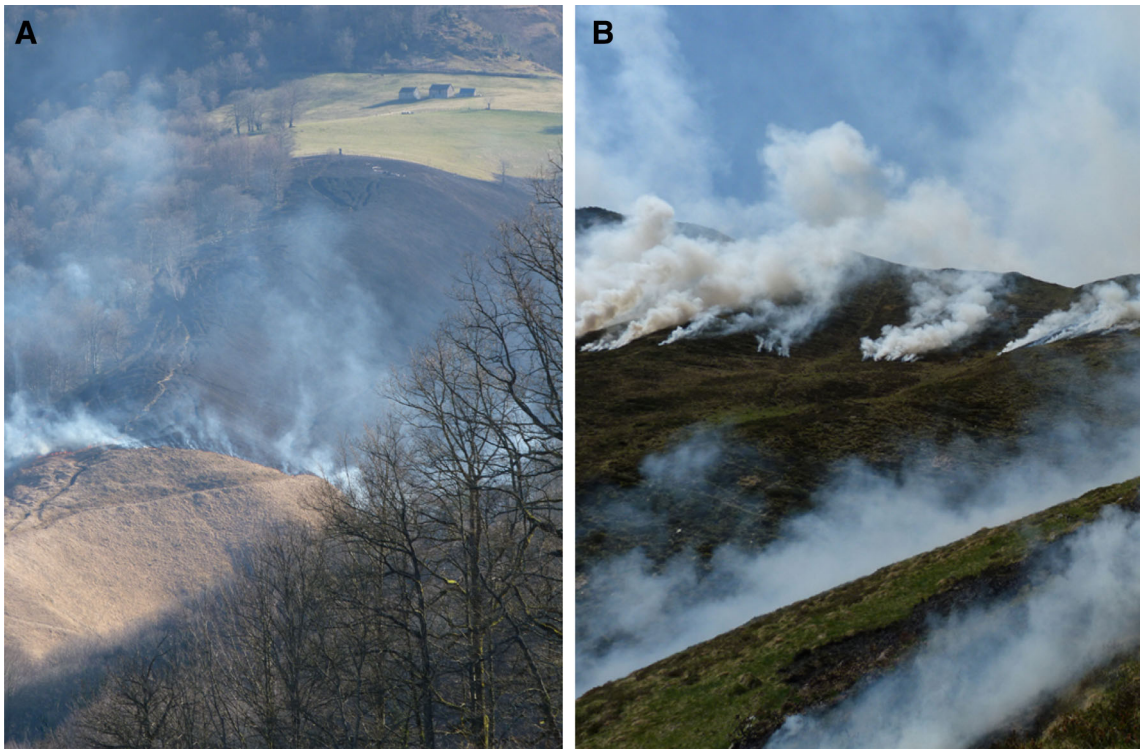

Fig. 1 *Photo A* a traditional pasture maintenance fire in the western Pyrenees burns homogenously down a south-facing slope but did not penetrate north-facing woodlands. *Photo B* in a nearby location, pasture maintenance fires on a north-facing slope required multiple ignitions and burned patchily (Photos by Michael R. Coughlan, Larrau, France, 2011)

potential for humans to change fire regimes depends upon natural conditions and the specific socioeconomic arrangements and preferences of the society in question.

This discussion does not suggest that we dismiss the approaches espoused by these two research programs in pyrogeography. They remain valuable for testing hypotheses about global to subcontinental scale human–fire interaction (e.g., Marlon et al. 2008). This is because local variability is necessarily averaged and obscured at the macro-scale resolutions required for modeling Earth systems phenomena. For example, human populations have shown steady increases over the Holocene, even if populations dipped significantly in particular times and places. However, correlations between fire activity and population densities do not imply causation because people are not fire-lighting automatons. Similarly, the global chronology of techno-economic systems has followed transitions from foraging to agropastoral to industrial societies. However, the history of techno-economic change is complex and often non-linear for any given society. As a consequence, the variability of traditional fire-use through time and space is also likely to be complex, as each society must not only adapt its fire-use to its economic demands but also to landscapes shaped by previous socioecological interaction. In terms of accounting for the causal relationships between traditional fire-use and landscape change (or persistence) in a given place, pyrogeography frameworks fail to offer substantive explanations. Consequently, scholars employing these frameworks should be diligent in emphasizing both theoretical bases and the scalar limitations of their studies.

A synthesis of pyrogeography approaches with human ecology approaches that builds on later theoretical legacies (e.g., Conklin 1961; Jones 1969; Lewis 1972) may offer a more theoretically robust approach with cross-scale and cross-disciplinary applicability. Human ecology approaches incorporating ethnographic, archeological, and historical evidence have amply demonstrated that small-scale societies employ specific fire-use strategies for the purpose of achieving land management goals (Bird et al. 2008; Laris 2011; Bird et al. 2012; Lightfoot et al. 2013; McCune et al. 2013). Consequently, where people do use landscape fire, their effects on fire regimes are neither incidental to human decision making, nor accidental outcomes of subsistence efforts. This hypothesis, first offered by Jones (1969), does not suggest that humans are in "harmony" with nature or that they were always agents of beneficial change. As Marsh (1965) pointed out long ago, humans have functionally transformed landscapes, often degrading them. However, it is clear that humans have not always and everywhere transformed entire landscapes through the intentional use or unintentional promulgation of fire. Similarly, where humans have transformed landscapes, trajectories of degradation have not always been the inevitable consequence. Consequently, simulation models and theoretical explanations concerning human ignitions need to be based on empirically informed understandings of human behavior given the time and place under scrutiny (Archibald et al. 2008).

Another human ecology approach, niche construction theory (Smith 2011), offers a possible pathway for explaining variability of human–fire–landscape interaction through time. This theory builds on and expands efforts by Lewis (1972) concerning the coevolution of fire-use and agriculture. These efforts suggest that fire-use is a significant part of coevolutionary processes between humans and landscapes. An integral component of this effort will involve the empirical investigation of social and economic systems, current and past, that depend upon traditional fire-use (Sullivan III and Forste 2014; Schmerbeck et al. 2015). Theory will also need to be informed by studies of traditional ecological knowledge and practice (Huffman 2013). Lastly, as has been poignantly noted by others (Roos et al. 2014), efforts will need to integrate multiple kinds of data and methods to arrive at explanations for the associations between social change, fire history, and landscape evolution.

CONCLUSIONS

This review highlighted several important legacy propositions and hypotheses that continue to influence on-going scholarship in human–fire–landscape interaction. While far from comprehensive, this review of the literature on fire-use and landscape transition provides considerable material relevant to current research efforts. Discussion of this literature identified both positive and negative aspects of these legacies that can help refine research questions and priorities.

Effective contributions should build on previous efforts by taking advantage of the historical development of the field, rather than bypassing them in favor of convenient generalizations. In this vein, current biophysical-centered approaches should test the scalar limitations of their frameworks. They should also recognize that the human component cannot be reduced to one parameter such as population or techno-socioeconomic category. For their part, current human ecology contributions to the study of human–fire–landscape interaction must improve their visibility and compatibility with interdisciplinary paleo- and historical fire research efforts (Lightfoot et al. 2013).

There is an urgent need for more explicit and theoretically cognizant statements of the assumptions that underpin historical fire ecology research efforts. Without such efforts researchers may fail to recognize underlying

legacies that confound their ability to account for the local-level causes of macro-level processes, such as climate change, land conversion, and the increasing occurrence of large-scale catastrophic wildfires. Scholars of historical fire ecology should strive to incorporate ethnological, archeological, and other types of evidence that can contribute to important and on-going debates in historical fire ecology. Likewise scholars should investigate how theory in human ecology can help strength transdisciplinary research design and the interpretation of results.

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