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Human ecodynamics: A perspective for the study of long-term change in socioecological systems

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ABSTRACT

Human ecodynamics (H.E.) refers to processes of stability, resilience, and change in socio-ecological relationships or systems. H.E. research involves interdisciplinary study of the human condition as it affects and is affected by the rest of the non-human world. In this paper, we review the intellectual history of the human ecodynamics concept over the past several decades, as it has emerged out of classical ecology, anthropology, behavioral ecology, resilience theory, historical ecology, and related fields, especially with respect to the study of long-term socioecological change. Those who study human ecodynamics reject the notion that humans should be considered external to the environments in which they live and have lived for millennia. Many are interested in the resilience and sustainability of past human-natural configurations, often striving to extract lessons from the past that can benefit society today. H.E. research, involving the study of paleoenvironments and archaeology, has taken shape around a series of methodological advances that facilitate the study of past chronology, paleoecology, paleodemography, mobility, trade, and social networks. It is only through integrated study of 'coupled human-natural systems'—'socio-ecosystems'—that we can hope to understand dynamic human-environmental interactions and begin to manage them for sustainable goals. Local and traditional or Indigenous knowledge provides another important influence to human ecodynamics research, and we explore how such knowledge can provide both expert witness into the operation of socioecological systems and insight into the human/cultural dimensions of those systems. Ultimately, we conclude that human ecodynamics is more encompassing than a number of related approaches and can provide a nexus for productive research. Through its interdisciplinary breadth, the framework unites scholarship that tends to be more isolated to address complex problems that are best tackled with diverse perspectives.

1. Introduction

Human ecodynamics refers to the integrated, non-linear workings of ‘coupled human and natural systems’ in landscapes through time (Kirch, 2007; McGlade, 1995:126). Archaeologists straddle the social and natural sciences and are well situated to study past human ecodynamics (Van der Leeuw and Redman, 2002), and the term has become increasingly popular in the past decade when referring to research into the dynamic integration and co-evolution of human and natural systems, or socioecosystems (Kirch, 2005, 2007). The human ecodynamics approach was a central organizing principle of the interdisciplinary Čı́xʷicən (pronounced *ch-WHEET-son*) project, results of which are featured in other papers in this special issue of JASR. Čı́xʷicən is a traditional village of the Lower Elwha Klallam Tribe, located on the north coast of the Olympic Peninsula in Washington State, dating between 2700 years ago and the present (Campbell et al., this issue). Here we review the concept of human ecodynamics and related approaches to long-term, human-environmental change to situate the Čı́xʷicən Project and others like it in an intellectual history and to explore ecodynamics concepts and methods, especially as relates to the deep histories of coastal systems.

While the term *human ecodynamics* has gained currency in academic writing since 2007, its use is commonly undefined. Indeed in many applications a reader could be forgiven for wondering if the term is just the latest repackaging of research on human-environmental interactions, a focus of inquiry stretching back at least to Darwin and one at the core of many variants of ‘human ecology’ over the years. Poul Holm (2016), in a thoughtful and generally supportive review of a recent

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collection titled *Human Ecodynamics in the North Atlantic*: *A Collaborative Model of Humans and Nature through Space and Time* (Harrison and Maher, 2014), searches in vain for an overarching conceptual framework (and model) orienting the contributions. He concludes:

> *Human Ecodynamics seems to be an umbrella term to describe "humans and their environments as made up of landscapes and seascapes," and it involves collaboration between archaeologists … and researchers from other human, social, and natural sciences… but it does not add up to an interpretative model* (Holm, 2016:307, emphasis added).

Whether or not this is a fair critique of the Harrison and Maher volume, the claim resonates more broadly, leading us to dig deeper into the roots and guiding principles of human ecodynamics (H.E.) research.

In this paper, we explore a series of interrelated questions that should be useful to those of us trying to advance work on human-environment relationships based on archaeological perspectives. Where does the H.E. concept come from? What are its influences? What, if anything, separates H.E. from related frameworks such as historical ecology or resilience theory? Does H.E. contain a defined theoretical or methodological commitment and dedicated set of practitioners? Is it useful in other ways, for example in facilitating interdisciplinary collaborations? What can Indigenous knowledge contribute to human ecodynamics research? How can H.E. research contribute to society addressing contemporary problems and needs in human-environment relationships?

2. Conceptual foundations in the study of human ecodynamics

An attempt to document the evolution of a concept like human ecodynamics must first acknowledge the semantic baggage loaded onto the double term. To pursue research into human ecodynamics is at once to acknowledge and to question the distinction between the human and ecological. The term presumes the legitimacy, or at least ontological hegemony, of distinct domains of study and implies a conjunction or building of bridges. Such bridge-building has been at the heart of environmental social science for decades. Of course, the binary distinction between *humans/humanity/culture* and *nature/environment* was deeply engraved in Enlightenment philosophy (and Judo-Christian cosmology) and has since come to influence much of modern global science and policy (see Cronon, 1995; Vining et al., 2008;1–2). While some disciplines sit far from the boundary and may be comfortable in the nature-human dichotomy (physics and political science, perhaps), others like ecology and ecological anthropology haunt the border and struggle to rectify an ontology of crisp distinction with the intuitive feeling that true understanding requires the complete dissolution of the boundary. This is not the place for a rigorous philosophical examination of the problem. We raise the issue simply to acknowledge the irony in having to use terms, such as 'human ecodynamics', 'socio-ecosystems' and 'coupled human and natural systems,' that reify the very construct that some scholars seek to problematize.

With that caveat, we turn next to explore the history of ecological thinking in both "natural" and "social" domains through an examination of the disciplines of (mostly non-human-centered) ecology and (human-centered) ecological anthropology. In the latter case, we focus on theories that have influenced archaeological approaches to human-ecological processes and long-term change.

2.1. Trends in twentieth century ecology and ecological anthropology

Human ecodynamics emerged in the late 20th century from a set of intersecting themes and methods in biology, ecology and ecological social sciences (primarily anthropology). Its major conceptual commitments, therefore, should be understood in the context of changing ecological and anthropological thought through that period. Ecology is defined as "the study of the structure and function of ecosystems" (Odum, 1953). Many of the principles of contemporary ecological theory were established by the mid-20th century and provided the foundations for a holistic science of nature (Odum and Barrett, 2005:2–4). Theories of succession, energy and material cycles, population dynamics, and system feedbacks led ecologists of the time to view ecosystems as holistic equilibrium-seeking systems in their natural (i.e., non-human influenced) states (see Worster, 1990, 1994). Ecosystems were defined as emergent entities composed of hierarchically nested physical and biological interactors. Defined by the systemic relationships of component parts transferring matter, energy, and information, ecosystems could be studied at any level of organization and with reference to physical, biological and/or social inputs and interactions. Importantly, this view also provided a foundation for 20th century conservation policies that sought to restore "natural" or "pristine" ecosystems by removing human inputs and extractions and allowing the systems to "recover" to their "healthy" states.

By mid-20th century, anthropologists and archaeologists—especially those studying small-scale, often hunting and gathering, societies—came to see close relationships between human social organization and the ecosystems they inhabited. Julian Steward's (1955) 'cultural ecology' is the most explicit, and his view that cultural evolution should be understood through the lens of adaptation to environmental conditions formed the ecological cornerstone of Processual Archaeology initiated by Anglo-American archaeologists starting in the 1960s (Binford, 1962). While the reasons differed somewhat in specifics, at this time ecological and anthropological theory shared a focus on the explanation of the aggregate and abstract "emergent" structures of ecosystems and cultures/societies, respectively, according to explanatory principles at those levels of aggregation (e.g., group-functionalism/'adaptationism', cybernetic systems theory, and similar constructs). Disaffection with the aggregate level of analysis drove both fields down parallel and often overlapping paths in the subsequent decades (Fitzhugh, 2000).

In the ecological domain, empirical and theoretical developments in the latter 20th century challenged the belief that ecosystems could be explained as self-regulating and equilibrium-seeking entities, triggering a paradigm shift that continues to reverberate (Worster, 1990). Empirical studies failed to support the orderly model of ecological change (succession to climax communities) and ecologists started questioning the existence of homeostatic regulatory mechanisms, especially in non-human influenced states (Connell and Slatyer, 1977; Drury and Nisbet, 1973). Instead, a growing chorus of field ecologists, theorists, and computational modelers turned to examine the place of *disturbance*, *individual-level competition*, and *non-linear complexity* in ecological dynamics (Davis, 1984; Holling, 1973, 1986; May, 1974). Where previously ecologists sought to generalize the functioning of relatively stable systems, when they started looking for stability, they found instead that disturbance and disruption were common and systems do not necessarily return to the same "equilibrium" states after perturbations. It turns out that ecosystems are complex entities, sensitive to initial conditions and with interesting and contingent histories. Those histories affect how systems are configured and function at any given time. Thus, the causal factors driving particular ecological changes appeared overwhelmingly complex, random, and, it was soon discovered, non-linear. Confronted with this complexity, ecologists turned to mathematical developments in modeling chaotic, complex, non-linear systems (Bak and Chen, 1991; Kauffman, 1991, 1993; Simberloff et al., 1997; Worster, 1994).

Equilibrium ecology was also undercut by developments in evolutionary biology. Inspired by implications of the synthesis of Darwinian and genetic theory, evolutionary biologists in the 1960s began questioning then-prevailing views about the evolutionary coherence of ecosystems as integrated, functional entities and of the group level adaptations presumed to organize their constituent taxa (Lewontin, 1970; Williams, 1966). Prior to that time, scholars assumed that species and populations (and societies or "cultures") evolved at the group and even species levels to take advantage of available opportunities (resources, spatial configurations, climates, etc.) and to solve external challenges to group survival and well-being. Developing understanding of genetic mechanisms of evolution instead suggested that population and ecosystem characteristics should ultimately emerge from the attributes and actions of individuals within them (Dawkins, 1976; Trivers, 1971). That insight propelled the field of evolutionary ecology (Pianka, 1974).

In a parallel way, anthropologists (starting in the 1960s) and archaeologists (from the early 1980s) started to question the group-functionalist foundations of cultural ecological models (see Biersack, 1999; Johnson, 2010; Vayda and McCay, 1975). Group-functionalist principles applied to "emergent" cultural entities came under both materialist and idealist critique, and for some (the strong idealists) the very connection between humans and their material environments were deemed irrelevant (Hodder, 1986; Sahlins, 1976). For others, the non-human environment remained important to the understanding of social structure and change, but the question of mechanisms and motivations of agents within social groups took on paramount importance. Intra-group conflict, competition, inequality and exploitation (between classes, genders, and individuals) revealed flaws in adaptationist models and drew attention to the strategic and political aspects of social organization and change (Brumfiel, 1992; Earle, 1978). For ecological anthropologists and archaeologists, in particular, the group-functionalist critique led to a profound shift in focus of analyses from cultures and societies to the behavior of individuals and agents (Dobres and Robb, 2000; Fitzhugh, 2000). Human behavioral ecology, discussed in the next section, was one outcome for those inclined to reductive and deductive approaches (see Winterhalder and Smith, 1992 for a justification of scientific reductionism). Archaeological engagement with political ecology was another (Van Buren, 2001). Given the increased complexity of interactions implicit in individual-based models of social change, some archaeologists turned to the notion of historical contingency—the idea that change is the result of unique, complex, and indeterminate historical trajectories of interactions (both human and non-human) (Bintliff, 1999; Engelstad, 1991; Trigger, 1998). Like the shift in analytical focus from groups to individuals, attention to historical contingency has echoes in ecology, in this case with the development of chaos and complexity theory, as noted above.

Importantly, if ecological and social aggregates are indeed products of complex, non-linear, interdependent and contingent histories, then ecologists and anthropologists need to pay much more attention to place-based histories of change when trying to understand these organizations and relationships in particular settings and times. Another ramification—one still underappreciated—is that human influences on environmental systems have long legacies with cumulative effects, that there is no such thing as a singular "natural," "healthy" or necessarily human-free state of nature, and conservation efforts are better spent seeking sustainable, rather than "pristine," ecosystem targets (see, for instance, Maschner et al., 2013). For both reasons, human and environmental history, archaeology and paleoecology become more critical than ever for understanding environmental changes in the past. In the next sections we explore elements of the 'new ecologies' (the strands of thought carrying forward from the late 20th century rejection of equilibrium based ecology and group-functionalist ecological anthropologies) as they have come to influence current H.E. research.

2.2. Human behavioral ecology and niche construction

Emerging from common roots in natural history, ecological theory has always been closely linked to concepts of biological evolution. Evolutionary mechanisms are usually assumed responsible for the morphological and behavioral characteristics that provide relative fitness to the organisms and populations found in ecosystems at any given time. As such, ecosystems can be viewed as emergent (and evolving) properties of the evolutionary histories of their components — a temporal construct. Reciprocally, those evolutionary histories arise from the interactions of organisms in ecosystems — a spatial construct. Ecosystems condition the field of evolutionary possibilities for change at any given moment. Collectively this bivalent, time-space dynamic makes explaining ecological change uniquely challenging. How can we explain the evolution of system components (e.g., populations and ecological communities) *and aggregate* systems themselves? Evolutionary ecology was developed explicitly to study the intersection of ecology and evolutionary biology in order to take on the first of these questions: how to study the evolution of populations and adaptive design of organisms in terms of their changing ecological settings (Winterhalder and Smith, 1992). This biologically coherent paradigm explicitly set out to develop understandings of the 'microfoundations' of evolutionary history, and as such, could be an important ingredient in efforts to explain ecodynamic processes (see Winterhalder, 1994, for an argument for the centrality of evolutionary ecology in any 'historical ecology').

Behavioral ecology is the branch of evolutionary ecology studying ecologically adaptive (i.e., fitness enhancing) behavioral strategies (Krebs and Davies, 2009). Behavioral ecologists employ optimality models tuned to ecological parameters to derive deductive predictions about how behaviors should vary as environmental conditions change. Those predictions are compared with empirical observations, and the degree of coherence between predictions and observations help guide refinements in models and build or challenge confidence in starting assumptions. *Human behavioral ecology* (HBE) was born when a handful of anthropologists, and later archaeologists, started applying the behavioral ecology framework to understand patterned human behavior (Winterhalder and Smith, 1981, 1992, 2000). Initial approaches focused on simple economic optimization of foraging alternatives among small-scale, subsistence-based communities. Optimal foraging theory models, carried over from the study of non-human animals, dominated this early research (e.g., Winterhalder, 1981; Yesner, 1981). Over the last 40 years, HBE has helped develop a broad theoretical tool kit for understanding the ways people evaluate choices in food procurement, mobility, divisions of labor, task-group membership, social affiliation, prestige and social subordination (Boone, 1992; Kaplan and Hill, 1992; Kelly, 1995; Smith, 1981; see Nettle et al., 2013).

From its early foundations in optimal foraging, HBE theory has been integrated into more complex evolutionary models of socio-ecological systems and used to understand or predict constellations of human behavior in the past that may have driven system-level changes (e.g., Broughton, 1994; Butler, 2001; Fitzhugh, 2003; Kelly, 1995; Kennett, 2005). In these and similar applications, HBE has provided broad insights. Even so, the HBE approach sheds only limited light on the evolution of the social institutions and larger socio-ecosystems in which those behavioral strategies are enacted. Some HBE scholars have sought to overcome this deficiency through simulation modeling (e.g., Agent-Based Models) to evaluate the extent to which complex organization can emerge simply from the compounded strategic decision making of large numbers of optimizing agents (Kohler and Gumerman, 2000; Winterhalder and Kennett, 2006:19). Even so, HBE may not be framed properly to answer many questions about the evolution of systems per se, only how human optimizers should organize their effort within the systems in which they find themselves. External change (e.g., climate change or catastrophic loss of populations) pose little problem for this explanatory framework, but internally generated (evolutionary) change is anathema.

A promising bridging approach is the recently developed theory of niche construction. Laland and O'Brien (2011:191) define niche construction as "the process whereby organisms, through their activities and choices, modify their own and each other's niches." Upon reflection, it might seem obvious that spider webs, bird nests, and brick buildings serve adaptive purposes for their architects while also altering environments and creating new opportunities, dependencies, and constraints for themselves and other organisms. When considered as a co-evolutionary process in which people and other organisms iteratively alter the characteristics of their selective environment and experience changing selective pressures as a result, niche construction provides a formal way of studying human ecodynamic co-evolution. Within this context, Laland and O'Brien (2011) use the concepts of 'cultural niche construction' to refer specifically to the way that people modify environments, in part, on the basis of cultural beliefs and practices. Bruce Smith (2007) shows how the food production "revolution" can be understood as an outcome of human modification of environments that ultimately led to fundamental changes in human economies and organizations, though he explicitly tries to distance niche construction theory from the principles of human behavioral ecology.

We suggest that these two approaches, HBE and niche construction, are complementary and that they could be integrated into a more comprehensive theory of human ecodynamics. Even so, the reductionism inherent in the "ultimate" evolutionary logic guiding HBE and to a lesser extent niche construction is unacceptable to many scholars on theoretical grounds, especially in its neglect of symbolic or cultural considerations. From a practical perspective, behavioral and evolutionary reductionism may miss important structural causes conditioning macro-evolutionary ecological change. For behavioral ecologists, the position that such processes should be explained reductively is recognized as a methodological assumption (Winterhalder and Smith, 1992). Other theoretical traditions focus on examining structural factors that may guide the evolution of systems irrespective of or, more likely, in concert with the actions and motivations of strategic and evolutionarily designed agents within them. Prominent among these for ecological anthropology are historical ecology and resilience theory.

2.3. Historical ecology

Historical ecology traces the complex relationships between our species and the planet we live upon, charted over the long term. It is a term new to both ecology and to history; practitioners take the term ecology to include humans as a component of all ecosystems, and the term history to include that of the Earth system as well as the social and physical past of our species. Historical ecologists adopt a holistic, practical, and, often, dialectical perspective on environmental change and on the practice of interdisciplinary research. They draw on a broad spectrum of evidence from the physical and biological sciences, ecology, the social sciences and the humanities. As a whole, this information forms a picture of human-environment relations over time in a particular geographic location. The goal of historical ecologists is to use scientific knowledge in conjunction with local knowledge to make effective and equitable management decisions. (Crumley, 2007:16).

From foundations laid in the 1970s and 1980s (see Crumley, 1998), historical ecology came to the fore in the mid-1990s with two thematic volumes, the first edited by Carole Crumley (1994) and the second by William Balée (1998). According to Crumley (1998: xii), the goal was a "renewed effort to foster collaboration in two crucial social science disciplines (anthropology and geography) and among several hybrid fields (e.g., environmental history, environmental sociology, human ecology, landscape ecology) that seek to mend the divide between the two cultures." The two cultures are those of the sciences and the humanities caricatured by Snow (1959), and the differences between them continue to plague efforts to unite social and environmental scholarship (see Barash, 2005; Crumley, 2007:15–16). Naturally, any success in understanding — and therefore effectively managing—human-environmental processes requires an equal measure of environmental science (biological ecology, climate change, geology, hydrology, oceanography, etc.), and knowledge of human social processes and what motivates human behavior (cultures, ideologies, politics, economics, etc.). Social science occupies the middle ground between natural science and humanities, yet is itself mostly divided into camps on either side of the 'two cultures' rift.

As proposed by Crumley and Balée—if not closely followed by later practitioners—the "historical" in historical ecology refers to notions of 'historical process' developed in the humanities and social sciences through the influence of Hegel and Marx, among others. The core principle is that history (the changes in social and environmental configurations and relationships through time) is the product of dialectic interactions between agents, human and non-human, that transpire in particular places and times, driving change. In other words, history is the outcome of cumulative small and large interactions and responses, in the human context often driven by individual beliefs and motivations but conditioned by the 'hard' realities of their situation in particular socio-environmental configurations. This notion of social change is consistent with the concept of 'structuration' advocated by Anthony Giddens (1984) and taken up by post-processual archaeologists in the late 1980s and since (Johnson, 2010). The "ecology" in historical ecology refers to the scientific understanding of relationships between organisms, including humans, in environments that drive adaptations and evolution of populations, communities and ecosystem structures through time. It emphasizes the materialist basis of dynamic, co-evolved, co-dependent systems of biological life and culture.

Combined, 'historical ecology' emphasizes the importance of historical contingency in spatial and temporal contexts for shaping integrated human-environmental systems. Under this framework, anthropologists, ecologists, geographers, environmental historians and others have shown how landscapes from the tropics to the poles carry histories of past human activities and indeed how few landscapes today can be said to be devoid of human influence or considered "natural" (Dunning et al., 2002; Heckenberger et al., 2007; Maschner et al., 2013; Normand et al., 2017; Urgenson et al., 2014). Ecosystems are dynamic and unstable, and explaining their states at any given time or place requires knowledge of prior states and the variables that have affected them over time. Unlike some approaches to social and ecological systems of the past, historical ecologists commonly focus less on the development of broad, abstract explanatory generalities, in favor of more detailed and place-based study of the contingent causes of landscape change. This is not to say that they reject insights drawn from general theory. These are necessarily employed in explanatory models of local landscape change. A related tenet of historical ecology is recognition of the reciprocal (dialectic) relationships inherent in human cultural and environmental co-evolution. Humans are seen as active agents in ecological change not passive respondents to external environmental forces (Erickson, 2008: 160). In this way, historical ecologists have recognized practices of Indigenous resource management in environments long thought (by outsiders) to have been "wild" and "natural" (Balée, 1994).

Archaeologists have been drawn to historical ecology as a framework for the study of long-term, human-environmental change. In the context of the post-processual critique, environmental archaeologists were attracted by the effort to embrace both materialist and cultural influences in the unfolding of place-based, human-environmental histories (Hegmon, 2003). It did not hurt that these are histories that archaeological evidence is well-suited to address, and indeed—in many cases—that only archaeology is in a position to document (Van der Leeuw and Redman, 2002).

2.4. Resilience theory

Where ecological anthropology and archaeology turned to history, landscape and dialectics, biological ecology (under the framework of complex and non-linear adaptive systems) took up the question of ecosystem resilience to disturbance (e.g., Holling, 1986). The concept of resilience, including its formalization in resilience theory (RT), has since become influential in many studies of human ecodynamics. Resilience is frequently defined as the capacity of a system to tolerate disturbance maintaining or returning to the same basic properties and functions without shifting into a differently organized system (Holling, 1986). Resilience frameworks are an outgrowth of 'disturbance ecology' and the collapse of equilibrium models, which treated systems as relatively simple and closed; that saw change as linear and deterministic;

and that advocated management practices which support simplification and stability (Gunderson and Holling, 2002; Holling, 1973). Equilibrium models guided the establishment of resource management policies in the mid to late 20th century in the U.S. and elsewhere and remain embedded in management practices even today. As such, management strategies seek to promote harvests of "nature's excess production with as little fluctuation as possible" (Holling, 1973:21; see also Holling and Meffe, 1996) by promoting estimates of 'maximum sustainable yields.' Resilience theory represents a paradigm shift in ecology. Systems are viewed as complex, change as non-linear, and—-given the indeterminate nature of future events—the best management practices are those that seek persistence in system *relationships*, rather than stability per se. Contemporary resource managers are trying to adjust to this new understanding under the banner of 'ecosystem-based management' over conventional 'species-based management' practices (Belgrano and Fowler, 2011; Levin et al., 2009; McLeod and Leslie, 2009).

While RT has its origins in 20th century ecological theory, it has found broader application to a variety of complex social systems, in areas such as healthcare, urban planning, and more. Likely one reason RT has currency across such disparate fields is that it incorporates humans—their social and political structures—as components of complex system models. Thus RT focuses on *Social-Ecological systems* (SESs), or the coupling of 'human-natural systems,' in conceptualizing questions related to food, human health, the environment, global climate change, and so forth (e.g., Abramson et al., 2015; Bottom et al., 2011; Folke et al., 2010; Urgenson et al., 2010; Walker and Salt, 2006).

One thrust of RT has been on modeling the dynamics of SESs as historical process by means of the *adaptive cycle* (illustrated by the figure eight panarchic loop), wherein a SES moves through four main phases: growth, conservation, release, and reorganization (Holling, 2001; Gunderson and Holling, 2002). As modeled, cycling need not occur in a fixed and regular direction, and SESs can interact across multiple scales and operate at different rates. So conceptualized, nested SESs combine to introduce complexity and contingency to system histories. Considering SESs in this way addresses the paradox of change and persistence that characterizes complex adaptive systems, potentially accounting for patterns of so-called punctuated equilibria in both biological and cultural evolution.

Resilience 'thinking' (see Walker and Salt, 2006) is appealing as a way to frame stability and change in complex coupled human-environmental systems according to relatively intuitive models (e.g., the adaptive cycle, the 'ball and basin' metaphor). Adaptive cycle models, for example, suggest new ways of framing enduring questions of long-term change observed archaeologically, such as how cultural complexity increases some times and then declines or "collapses" at other times, or how communities persist through some environmental downturns but are destroyed by others of similar scale. For example, Nelson et al. (2016) compare the resilience of SESs in Greenland and the American Southwest in the face of extreme and rare environmental events (drought in the Southwest; cooling in the North Atlantic). They document community vulnerability to food shortage before environmental crises and then cultural response after the crises, finding "major social changes and food shortfall followed climate challenges in the highest vulnerability loads" (2016:302). Communities with relatively resilient food systems (e.g., diverse portfolios of foods, social networks, storage) were less affected by extreme events. Besides scholarly insights, their study has clear implications for how ancient records can contribute to modern disaster management policy.

Despite its appeal, the application of resilience theory in archaeology remains limited (Bradtmöller et al., 2017; but see examples by Redman, 2005; Nelson et al., 2006; and Thompson and Turck, 2009). Debate continues about whether resilience theory provides truly explanatory insights or simply a new way of describing patterns of stability and change (Bradtmöller et al., 2017). At least in some applications, adaptive cycle models have been used primarily as a post-hoc, descriptive tool. This is true, for example, where cultural units (e.g., 'Solutrean,' 'Early Woodland') are assigned to a distinct phase in the adaptive cycle, and then specific socio-ecological factors are proposed that may have caused the SES to shift from one domain to another. We suggest the most fruitful avenues in RT research will be in expanded theorizing about the mechanisms that underlie complex system changes drawing on HBE, niche construction, political ecology and similar frameworks (see Bradtmöller et al., 2017; and Solich and Bradtmöller, 2017, for examples along these lines).

Often resilience research seems to describe the resilience of coupled systems themselves, under the expectation that a resilient system supports resilience of its components (e.g., human communities). We note here, in passing, that it is sometimes unclear in these applications whether the relevant target of analysis is or should be the human population, its economic organization, socio-cultural lifestyle, non-human taxa influenced in part by human interaction, or the larger, coupled human-natural system in which these SES components are situated. That analytical ambiguity is a common feature of complex system analyses, and it is one of the reasons some prefer to explore mechanisms at less aggregated scales (e.g., HBE).

2.5. Human ecodynamics

In this already crowded field of alternative approaches to the study of long-term human-ecological interactions, we turn now to explore human ecodynamics itself. The term "ecodynamics" appears in the ecology literature starting in the late 1960s (Gannutz, 1971; Hansen and Reed, 1969). Perhaps the earliest application of the term to human social processes is by evolutionary economist Kenneth Boulding, in an ambitious tome called *Ecodynamics*: *A New Theory of Societal Evolution* (Boulding, 1978). In that work, Boulding asks why human social and cultural institutions have a tendency to grow in complexity at odds with the then-current principles of ecological equilibria. His answer, after much dissection, is "disturbance" (destabilizing elements), a conceptual shift paralleled, and no-doubt influenced, by the same turn in mainstream ecology discussed above (Worster, 1994). Similar in some respects to the encompassing social evolutionary approaches of contemporaries in anthropology and archaeology (e.g., Flannery, 1968; Sahlins and Service, 1960; White, 1959), though citing none of them, Boulding sought to expose generalizable structural principles at the nexus of social change. Unlike some of his contemporaries, Boulding embraced an 'agnostic evolutionism,' envisioning social change as emerging continuously through the complex and undirected interactions of physical, biological, and social factors, each at once structuring the evolution of other parts and being structured by them. Boulding's approach foreshadows much in H.E. research as it is practiced today. This includes:

- viewing human social change as embedded in and contributing to human-environmental interactions;
- seeking understanding through examination of patterns of systemic relationships;
- including both "natural" (physical and biological) as well as "social" (psychological, ideological) dimensions in any comprehensive description of social evolutionary process; and
- rejecting evolutionary teleology and embracing a contingent understanding of socio-ecological evolution.

Without explicit reference to human dimensions, ecodynamics appears again a decade after Boulding's book as the organizational framework for a volume entitled *Ecodynamics*: *Contributions to Theoretical Ecology* (Wolff et al., 1988). Papers in that volume reflect the general trend in ecology toward more mathematical modeling and simulation, conservation, and especially non-linear 'complex ecological systems' discussed earlier.

The first paper embracing an archaeological approach to ecodynamics was by James McGlade (1995; see also Van der Leeuw and McGlade, 1997), who proposed a 'human ecodynamic' framework, but without reference to Boulding's earlier use of the term and indeed without Boulding's social-evolutionary focus. McGlade was inspired by contemporary trends in ecological theory, and his view of human ecodynamics emphasized non-linear dynamics arising from nested scales of socio-natural relations and the unpredictable creativity of disturbance/perturbation (like Boulding). Crucial to McGlade's framework is the view that humans are integral parts of the environment, not external actors outside of nature. His work explicitly breaks from 1960s-era cultural ecology and systems theory archaeology, which viewed cultures as coherent adaptive units, human ecosystems as homeostatic, and that classified the 'environment' as distinct from 'subsistence' and from other discrete parts of human-related phenomena. To McGlade, human-environmental interactions are simply irreducible, a position at odds with behavioral ecology and perhaps some niche construction approaches. Archaeology should focus on reciprocal, co-evolutionary relationships between humans and the 'environment' or 'socio-natural systems.' The paper is also notable for its effort to promote mathematically intensive non-linear modeling focused on the mutually constructed relationships of coupled natural and social dynamics. In this pioneering archaeological work, we already see some of the dominant concepts that will carry through most subsequent applications of human ecodynamics: nonlinearity, disturbance, historical contingency, resilience and sustainability, which echo and combine themes also raised in historical ecology and resilience theory.

McGlade's (1995) paper presented a rather abstract vision of H.E. research goals with relatively little pragmatic guidance for archaeologists interested in using it. Those who took up the torch since have tended to approach the subject more concretely, emphasizing the dynamic relations between physical (climate change, natural hazards, etc.), ecological (nutrient cycling, predator-prey relations, population fluctuations), and social (economic, technological, organizational, political, and ideological) processes. Patrick Kirch's adoption of the concept in the early 2000s provided an influential catalyst. He used it to frame the evolutionary analysis of pre-contact Hawaiian socio-ecosystems, with attention to climate, soil ecology, agricultural technologies, population, and the political strategies of elites (Kirch, 2005, 2007; Kirch et al., 2004, 2007). A number of subsequent papers and projects adopted the human ecodynamics label. Many were funded under the U.S. National Science Foundation's (NSF) 'Coupled Natural and Human Systems' program (CNH, initially a subprogram of the 'Biocomplexity in the Environment' initiative; Baerwald et al., 2016). Many of these projects were developed to synthesize decades of archaeological and ecological research in targeted landscapes and emphasized the integrated modeling of human and natural system co-evolution. While H.E. research is in no way limited to large, well-funded efforts, most published references to the term come from those projects. This fact suggests both that realizing the goals of a synthetic, long-term H.E. research program is laborious and expensive, but also that the term's initial fluorescence is at least partly linked to its relevance to funding initiatives as it is a self-realizing research paradigm (see McGovern, 2014:214).

Many of the CNH and thematically related projects have led to comparative theoretical, methodological, and substantive syntheses across multiple projects (e.g., Alberti et al., 2011; Nelson et al., 2016). To give a sense of the kinds of research recently generated under the topic of human ecodynamics, Table 1 lists the human ecodynamics (or 'coupled natural and human systems') research efforts funded by the NSF CNH program. These are particularly representative of the direction of H.E. research, given the targeted nature of the funding program and the large budgets that allowed unusually comprehensive, interdisciplinary efforts within coordinated research programs.

A common theme in the H.E. research projects listed in Table 1 and otherwise is the effort to study the causal relationships between past climate, ecology, geography, human settlement, demography, mobility, economy and other cultural dimensions of their respective regions, such as political and social organization. These projects often draw on large datasets (making well-studied areas some of the first such targets) and use computational models in various ways to flesh out predictions, facilitate data integration and develop experimental scenarios. Studies run the gamut of temporal, economic and socio-political variation in human history, from the Pleistocene to late Holocene, hunter-gatherers to agriculturalists/pastoralists, mobile to sedentary, egalitarian to hierarchical, and organizationally simple to complex. Locations of research projects cover terrestrial and maritime environments, continents and islands, tropical latitudes to the subarctic.

Of course, H.E. projects are not limited to large-scale, interdisciplinary collaborations supported by the CNH program, or other research agencies in the U.S. or abroad. A number of smaller-scaled or otherwise funded studies fall under the umbrella of H.E. research (e.g., Corbett et al., 2010; Katzenberg et al., 2012; Müller et al., 2016; Weber et al., 2011, 2013; West et al., 2012). The Čḯxʷicən Project, about which this special issue is dedicated, is another in this growing list of H.E. case studies. Importantly, one way smaller-scale projects, including those linked to heritage management, or 'compliance' archaeology can be incorporated into H.E. research is through coordinating efforts and synthesis of 'big data' (see Section 4.7 below). Research coordination efforts (e.g., Integrated History of People on Earth or IHOPE [ihopenet.org]; Global Human Ecodynamics Alliance [gheahome.org]; North Atlantic Biocultural Organization or NABO [nabohome.org]), are excellent examples of such networks that illustrate how integrating results from disparate, relatively small-scale projects can contribute to broad comparative syntheses, directly applicable to H.E. research.

2.6. Comparing human ecodynamics and allied frameworks

In the previous four Sections (2.2–2.5), we sought to characterize several concepts popular in the archaeological study of human-environmental interactions. Upon reflection, while human behavioral ecology, niche construction, historical ecology, resilience theory, and now human ecodynamics are defined around some unique explanatory goals and/or methodological commitments, they also overlap in numerous ways. HBE is probably the most formally circumscribed of these approaches with its strong theoretical commitment to individual-level Darwinian explanatory modeling. Niche construction provides a way to view how human (and non-human) behaviors could change socio-ecological systems through the engineering of new niches, and it may be an interesting theoretical mechanism to bridge scales from individual-level actions to system 'evolution'. Of the remaining three concepts, resilience theory is the next most formally defined conceptually, and the adaptive cycle model provides a key orienting framework.

Outside of the formal resilience theory framework, many archaeologists use the concept of resilience as a framing tool to explore the relative effectiveness of past community adaptations within socio-ecological contexts. In these cases, theoretical attention is sometimes drawn to relationships between "natural" variables (e.g., "natural" hazard exposure, climate change, and scales and predictability of ecological variability) and "social" variables (e.g., demographic patterns, mobility, residential organization, economic practices, social networks, hierarchies, and inter-group hostilities). These variables are often considered in terms of their relative implications for the welfare of economic, social, and cultural systems (Campbell and Butler, 2010; Fitzhugh et al., 2016; see papers in Harrison and Maher, 2014). These archaeologists attempt to track ways socio-ecological systems confer greater or lesser resilience to the well-being of the individuals, communities, and populations they include.

Historical ecology and human ecodynamics are probably the least formally defined of the concepts reviewed above. In one of the papers in which Kirch promoted the term 'human ecodynamics,' he explicitly points out the 'heavy intersection' between H.E. and historical ecology, while also acknowledging the influence of complexity and resilience

Table 1
Examples of integrated human ecodynamics projects between 2000 and 2015.

Project title	Themes explored	References
Human ecodynamics in the Hawaiian ecosystem	Agroecology; paleodemography; political centralization	Kirch et al., 2004, 2007; Ladefoged and Graves, 2008; Ladefoged et al., 2009; Vitousek et al., 2004
The village ecodynamics project	Hydrology, agroecology; paleodemography; domestication (turkey)	Kohler et al., 2007, 2008, 2012; Varien et al., 2007
Long-term coupled socioecological change in the American Southwest and Northern Mexico	Resilience; standardization; climate change; ecology paleodemography; identity	Nelson et al., 2011, 2012
Land-use and landscape socioecology in the Mediterranean Basin	Intensification; residential mobility; environmental change	Barton et al., 2010, 2011, 2013
The Kuril Biocomplexity project	Climate change; marine ecology/biogeography; colonization; social networks; abandonment; geological hazards; political economy; resilience and vulnerability	Fitzhugh, 2012, 2018; Fitzhugh et al., 2011, 2016; Gjesfjeld, 2015; Gjesfjeld and Phillips, 2013
The Sanak archaeology project	Climate change; marine ecology/biogeography; paleodemography; resilience	Maschner et al., 2009; Misarti et al., 2011; Reedy-Maschner and Maschner, 2012, 2013
Comparative island ecodynamics in the North Atlantic	Colonization; climate change; natural hazards; human impacts and ecological management; agropastoral and marine economies; resilience and vulnerability	Ascough et al., 2014; Brewington et al., 2015; Harrison and Maher, 2014; McGovern, 2014; Smiarowski, 2014

theories:

> *In addition to sharing with historical ecology an emphasis on the contingent long-term histories of landscapes, human ecodynamics incorporates concepts such as hierarchy, resilience, self-organization, and nonlinear causality* (*Gunderson and Holling,* 2002; *Nicolis and Prigogine,* 1977; *O'Neill* et al., 1986). *While drawing heavily on the legacy of a largely qualitative and descriptive environmental archaeology, human ecodynamics thus moves the field toward quantitative approaches and the use of dynamic, nonlinear models.* (Patrick V. Kirch, 2007:8)

Clearly, 'human ecodynamics' is a concept closely allied and overlapping in application with related frameworks proposed to study complex human-environmental interactions and long-term histories. With historical ecology, it shares and draws inspiration from theoretical currents of mainstream ecology, anthropology, geography, sociology, and related disciplines. The research falling under these two labels shares the foundational premises: 1) that humans are part of the environments and ecosystems in which they engage; and 2) that the component social and natural subsystems co-evolve through mutual interaction and bi-directional influences. These premises themselves do not form a singular and coherent theoretical framework or model for research as such, and for that purpose, different researchers have tapped into theoretical inspiration from across the spectra of science and humanities, from Darwinian behavioral ecology to Hegelian dialectics.

On the basis of early programmatic statements, historical ecology may be said to have been defined uniquely around a human/non-human Hegelian dialectic in which landscapes come to inscribe the 'dialogic' histories of interacting natural and cultural processes. By the same token, a core and somewhat unique element in human ecodynamics, not central in early historical ecological framings, is the emphasis on mathematical modeling, especially in the development of coupled human and "natural" system models. Interestingly, the themes raised by those identifying with historical ecology today are somewhat different from those highlighted by Crumley and Balée in early formulations. In particular, dialectical models of history are not mentioned in Armstrong et al.'s (2017) list of the top 50 questions in historical ecology. Apparently more materialist, ecological models have claimed prominence under the banner of historical ecology. In any case, the outcome of these shifts is the reduction of any significant differences between the practice of historical ecology and what might be otherwise defined more generally as human ecodynamics research.

Conceptually, both human ecodynamics and historical ecology view social and natural systems as coupled, inextricably bound entities. Humans *are* nature. Given this perspective, one might expect that the unit of study should be the socio-ecological system or SES. In practice, however, to explain *changes* in coupled human-natural systems, scholars from both camps generally divide the components of the SES into sub-units of analysis; and these sub-units generally break down along the traditional social-natural divide.

For example, researchers wishing to understand ways coastal SESs changed over the Holocene would consider key variables that likely guided those changes, such as sea level, ocean productivity, human population size, technology, the marine and terrestrial resource base, abrupt environmental forces such as tsunamis, and so forth. Research could focus at varying spatial and temporal scales, depending on the question and available records. Scholarship would model, then try to evaluate, the importance of these variables, using standard practices. For example, faunal analysis would document changing animal use—-whether certain resources were used sustainably or not, the extent the animal resource base was independently affected by bottom-up ocean conditions (e.g., food and/or habitat availability) or top-down (e.g., human and non-human predation and habitat alteration) ecosystem forces. We might study the landform history—trying to determine the role of coastal processes (currents, availability of sediments) vs. human deposition of shellfish, for example, in constructing that landscape—or the extent to which the two forces were intertwined. We could create proxies for human population size using radiocarbon models (see Section 4, below), and then study how trends reflected changing ocean productivity, changing technology, regional trade networks, and so forth.

This scenario highlights an important paradox. Embracing the concept that humans and nature are inextricably bound still allows for, in fact can demand, that we create conditional units of analysis for the variables of interest that often still fall into "natural" and "cultural" categories. This process is part of what is required in establishing cause and effect relationships.

While these analytical steps may appear to push this scholarship back to environmental determinism, key ideas in the human ecodynamics/historical ecology framework mitigate this. Thus, change in SESs is non-linear and complex, and is the result of the dynamic interaction of variables and historical contingency. Moreover, these frameworks give humans agency, as strategic actors, in structuring their responses to socio-ecological conditions and, as a result, affecting their own historical trajectories.

In sum, the scholarship of human ecodynamics and historical ecology have different intellectual histories, but they have converged on topical foci and goals—namely research into long-term ecological change in human/non-human dynamics; and rely on broadly similar premises. We grant that there are places of divergence in scholarship but suggest the differences are in emphasis rather than substance. Indeed, many of the scholars cited in Table 1, under human ecodynamics, have also published on the same themes under historical ecology (e.g, Kirch and Hunt, 1997 vs. Kirch, 2007; McGovern et al., 2007 vs. McGovern, 2014).

3. Common goals & questions of human ecodynamics research

Despite their different histories, theoretical inspirations, and terminology, there is much common ground in the approaches outlined above, both in terms of goals/questions and methods (see Section 4). Here we provide a brief overview of some common questions pursued in the name of human ecodynamics research. With limits on space, we can only highlight a few examples, emphasizing research in coastal settings (our primary area of expertise and the most relevant literature for the Č́íxʷicən site discussed in this special issue).

3.1. Archaeology of natural hazards

There is a long history in archaeology of studying catastrophic external events, both abrupt (e.g., earthquakes, volcanoes) and more gradual (e.g., severe drought, onset of the Little Ice Age, sea level rise), given the obvious potential for ecosystem perturbation, which may have directly or indirectly affected past peoples (e.g., Baumhoff and Heizer, 1965; Sheets and Grayson, 1979). In some areas, such as coastal Peru, people faced convergent catastrophes, including extreme *El Niño/Southern Oscillation* events, earthquakes/tsunamis, and volcanic eruptions (Mosley, 1999; Sandweiss and Quilter, 2012). Understanding how people on the edges of human existence, both in terms of these extreme events or geographically challenging environments (Arctic, deserts), have adapted and survived is a central focus of much H.E. research (e.g., Cooper and Sheets, 2012; Harrison and Maher, 2014).

Recent research in anthropology and archaeology has begun to unpack the concept of "catastrophe" to show that while these are natural events, their impacts are mediated by various social variables, such as subsistence strategy, settlement pattern/mobility, population density, territoriality, infrastructure/technology, and previous experiences (e.g. Reycraft and Bawden, 2000; Grattan and Torrence, 2007; Oliver-Smith, 1996). Many studies highlight the resilience, adaptive ability, flexibility and continuity of foragers facing dramatic natural events. Losey (2005) found few effects (in terms of diet or settlement patterns) of the massive 1700 CE Cascadia Zone earthquake on northern Oregon coastal communities. The resiliency observed in North Pacific foragers may have been possible because of their mobility, extensive territory, and widespread kin networks (e.g., Fitzhugh, 2012; Fitzhugh et al., 2016; Johnson, 2002; Saltonstall and Carver, 2002). In his summary of Indigenous Caribbean response to hazards such as hurricanes and floods, Cooper (2012) argued that complex belief systems, transfer of ecological knowledge over generations, settlement locations, house structures, diverse food procurement strategies and social networks all contributed to resiliency. Vanderhoek and Nelson (2007), by contrast, find that the unique conditions surrounding the frequent catastrophic volcanic activity of the Aniakchak volcano on the Alaska Peninsula prevented prehistoric settlement prior to 2200 years ago, despite settlement in adjacent regions as far back as 9000 years ago. Clearly there are limits to human resilience, something many H.E. projects have attempted to measure.

3.2. Humans in bottom-up, top-down, and integrated SESs

Beyond extreme events and environments, those working on human ecodynamics research themes have all been interested in how people both affect, and are affected by, their natural environment. Indeed assessing the relative roles of 'bottom-up' versus 'top-down' ecological drivers over time has been a major focus of scholarship. Recent studies in coastal areas have focused on assessing changes in resource availability, diet, or settlement strategy during the late Pleistocene/Holocene transition (e.g., Barton et al., 2013; Fisher et al., 2010; Reitz et al., 2015), the Medieval Climatic Anomaly (MCA) and Little Ice Age (LIA; e.g., Jones et al., 2017; Monks, 2017; Rindel et al., 2017; West, 2009). Others have investigated the effects of human hunters removing apex predators from an ecosystem, such as sea otters in the Aleutians (Simenstad et al., 1978) and Loco shells in Tierra del Fuego (Jerardino et al., 1992), or locally overharvesting large mammals or birds (e.g., Broughton, 1994; Nagaoka, 2002). Scholars do not always agree on these impacts given the difficulty in parsing out human hunting from climatic effects on animal populations (Rose, 2004). In some cases, scholars have diagnosed 'sustainability' or stability in harvesting over time, supporting the idea that communities with intimate local ecological knowledge may manage or otherwise limit their impacts on critical subsistence resources (Braje et al., 2017; Butler and Campbell, 2004; Campbell and Butler, 2010; Erlandson et al., 2008, 2009; Etnier, 2007; McGovern et al., 2007; McKechnie et al., 2014).

Recent research in human ecodynamics strives to treat humans as part of (not external to) the ecosystems they model, given the irreducibility of people in their environment (see Simenstad et al., 1978 for an early version of this point). In the Pacific Northwest coast, integrated anthropological and archaeological study has revealed intensive ways that wild resources were managed through habitat alteration (niche construction), such as the creation of clam beds and anthropogenic burning (e.g., Deur and Turner, 2005; Lepofsky et al., 2017). Dunne et al. (2016) used a highly-resolved food web network model to explore the implications of adding humans as prey-switching omnivores and find that without technologically intensive predation on 50% or more of the taxa, the system would remain largely sustainable in the face of human harvesting.

4. Methodological contributions to the study of human ecodynamics

The questions just reviewed, common to H.E. research in a broad sense, require robust methods to address with any confidence. Several methodological developments have helped to operationalize H.E. research. While these methods are not unique to H.E., their availability is crucial to our ability to answer questions about long-term human ecodynamic change. In particular, developments over the last several decades have dramatically improved chronological inference, paleoecology and paleoclimate reconstruction, human paleodemography, migration mapping, and dynamic socioecological modeling. Particularly relevant developments include refinements in radiocarbon and luminescence dating, isotope bio- and geo-chemistry, paleogenomics, computational modeling, data management, and comparison/synthetic analysis of large datasets from multiple projects (so-called 'big data').

4.1. Chronological inference

While for at least a century archaeologists and others have recognized the importance of studying the interactions of climate, physical environment, ecology and culture change in tandem, efforts have been hampered by limitations on integration due to incomplete and imprecise chronologies. Until recently, archaeologists ran few dates and only used them to supplement typological dating within culture historical systematics. The result was imprecise chronologies of change and a limited ability to compare archaeological and paleoecological/climatic proxy sequences. For their part, temporal control for paleoclimate and paleoecological reconstructions are normally based on a limited number of age estimates that are used to interpolate age models through the sequences. With rare exceptions then, regional syntheses must assume imprecision and correlation (between individual paleoenvironmental proxy records and between them and archaeological records), falling back on 'wiggle matching' and coarse-scale interpretation. As a result, small sample sizes, sampling protocols, and instrumental errors limited chronological precision of human-environmental accounts. For those dependent on radiocarbon dating for most chronological assessments, the refinement of AMS radiocarbon instrumentation and better pretreatments have tightened precision and enabled dating of smaller samples (Kutschera, 2005). In turn, this has allowed dating of short-lived specimens that can increase accuracy. Improved calibration datasets and protocols for both terrestrial and marine samples (Ramsey, 2009; Reimer et al., 2013; Stuiver and Braziunas, 1993) further strengthen the comparability of data from different contexts, sometimes dated by different methods. Innovations in other chronometric techniques such as single-grained optically stimulated luminescence (OSL) are also helping improve chronological inferences for both paleoecological and archaeological records. As much as anything, larger chronology budgets have made it possible to date paleo-sequences at higher resolution, identifying date inconsistencies, stratigraphic disturbance, and sampling errors and facilitating better interpretations of sequences. Large chronological datasets also enable statistical analysis of human settlement duration and intensity at local sites and across regions, which is the basis of a current growth industry in population modeling.

4.2. Population dynamics

Population trends are critical for many long-term human ecodynamics studies. The density and distribution of people across a landscape influence human effects on ecological processes and, of course, those ecological processes have direct effects on the sustainability of human populations who depend on them for food, water, raw materials, and shelter. For many H.E. projects, population dynamics are placed at the nexus of the modeled socioecological relationship, and a primary goal is understanding how population fluctuations may have occurred in relation to changes in climate, prey availability, crop productivity, or other factors. As a result, reliable measures of population change are necessary.

"Archaeological demography is the investigation of the structure and dynamics of past human populations using the broad spectrum of evidence provided by the traces of human activities and remnants of material culture in the archaeological record" (Chamberlain, 2009: 275). Archaeologists often seek to estimate relative population levels in the past based on the assumption that some quantifiable attribute or attributes like sites, houses, burials, or artifacts varies in proportion to populations. Quantification of one or more such attribute as it changes through time can be used as a 'temporal frequency distribution' (*tfd*) that can be interpreted to represent change in relative population through time.

Radiocarbon date samples have been the archaeological target of choice for a fluorescence of recent paleodemographic models (Chamberlain, 2009; Rick, 1987; Williams, 2012), or study of human settlement duration and intensity (Hutchinson et al., this issue). Radiocarbon datasets have a distinct advantage over other archaeological attributes because they simultaneously encode chronology and something about relative human activity on the landscape. Nevertheless, variables that undermine the reliability of 'dates as population data' include: 1) small numbers of dates in a local or regional dataset (low numbers bias); 2) differential loss of archaeological sites in the past (preservation bias); 3) uneven sampling of archaeological deposits and dates (sampling bias); and 4) changes in modes of living during the interval under study that alters the rates of per capita production of the archaeological attribute (cultural bias) (Brown, 2015). Where these factors are controlled, radiocarbon *tfds* make excellent population trend proxies (Fitzhugh et al., 2016).

Methods for quantifying and interpreting large regional radiocarbon data sets are developing rapidly. Whereas little over a decade ago, population models were built on histograms of uncalibrated dates, today summed probability distributions (*spds*) dominate the literature (Bamforth and Grund, 2012; Tremayne and Brown, 2017; Williams, 2012) and both modeling procedures and interpretations are becoming more sophisticated (Brown, 2015, 2017; Crema, 2012; Crema et al., 2014; Shennan, 2013). Importantly, paleodemographic change is influenced by a complex array of factors, including changing rates of fertility, mortality, in/out migration, and intra- and inter-population interactions, each potentially influenced by and influencing environmental developments in the region in question (Lee and Tuljapurkar, 2008, Lee et al., 2009). Coupled with high-precision dating, radiocarbon modeling can provide a well-resolved picture of fluctuating population size. The task becomes trying to explain demographic trends through close comparison with paleoenvironmental and social changes (including hazards like earthquakes, volcanic eruptions, population movements, market expansions, disease transmission, and so on: Fitzhugh et al., 2016).

In addition to radiocarbon-based models of paleodemography, complementary methods are developing rapidly in paleogenomics that may soon add independent data on population dynamics and relatedness. Where human remains can be ethically sampled, for example, demographic information on relatedness can be derived from the ancient DNA (aDNA) of preserved human samples (Harpending et al., 1998). Population bottlenecks can also sometimes be identified in isolated populations from studies of aDNA diversity (Chan et al., 2006), which could also provide key insights about human demographic crises and possible causes in socioecological variables.

4.3. Paleoenvironment and paleoclimatic inference

Paleoclimate research has been integral to the Earth sciences for well over a century (Bradley, 1985; Butzer, 1964) and was influential in the establishment of the scientific discipline of geology in the 19th century (Grayson, 1984). Since that time, climate scientists have learned to make increasingly detailed paleoclimatic inferences from proxy evidence, such as geomorphic features (e.g., glacial moraines, river terraces and wave-cut coastal benches) and preserved plant and animal remains (e.g., pollen, insects, marine diatoms as well as the remains of larger organisms) recovered from stratified sediments and quantified as evidence for those changes. Late 20th century developments in geochemistry and the accumulation of multi-proxy records from tree rings, corals, marine, lake and ice cores around the world have increased the ability to study aspects of climate change more or less continuously through time in different regions and connect them to develop pictures of global changes (Cubasch et al., 2013; Masson-Delmotte et al., 2013). Studies of stable isotope fractionation, especially of oxygen (O) isotopes in biological, sedimentary, and glacial ice archives, have also been critical in paleoclimate interpretations (Chappell and Shackleton, 1986; Grootes et al., 1993).

The accumulation of proxy climate data has led to revisions in the understanding of the pace of climate changes (they are often abrupt) and revealed greater spatial variability in regional and local effects than previously appreciated. This, in turn, has revealed problems in facile application of paleoclimate records from one region to represent climate implications for local ecosystems and cultures in other regions. In the absence of robust local proxies, presumed global records, like the Greenland ice sheet proxy records, have sometimes been compared uncritically to environmental and cultural changes in distant regions (Jones and Mann, 2004). Unfortunately, good proxy records with suitable time depth and temporal resolution are still too few and spatially disparate to provide solid inferences for many local regions. For this reason, H.E. projects often must include the independent development of local/regional proxy records. It is increasingly recognized that paleoclimate and paleoecological proxies drawn from archaeological deposits themselves are ideal for many H.E. purposes because the climate and ecological inferences can be tied directly to changes in human variables without the use of age models and correlations over distance

(Sandweiss, 2017).

Paleoclimate series typically track local changes in temperature and precipitation based on changing micro-plant and animal communities, organic growth rates, stable isotopes, minerals, and greenhouse gas concentrations, among other proxies. Of course, paleoclimate inference depends on establishing that the proxy measure in question changes in a predictable way because of climate change. Even with good proxy climate series, interpreting the relationship between climate and socio-ecological dynamics requires strong inferential arguments. When the goal is better understanding of socioecological dynamics, it is vital to move past generalized climate trends to consider how those trends would manifest at the scales relevant to the SESs under investigation (Sandweiss, 2017). Advances in global climate models (GCMs) that incorporate key features of solar insolation, Earth topography, hydrology, oceanography, and atmospheric circulation in concert has made it possible to assemble multiple paleoclimate proxy records into ensemble models and predict how past climate dynamics should have varied spatially in the past (e.g., Collins et al., 2006). The availability of spatially resolved dynamic climate models, in principle, allows researchers to develop models and hypotheses about regional climate variability and its effects on local ecosystems and people. With improvements in climate theory, computing power, and inclusion of new proxy data sets, we can expect regional climate models (RCMs) to become increasingly precise and appropriate for use in modeling the behavior of regional to local scale variables in SESs (Rummukainen, 2010).

4.4. Foodweb dynamics

Any study of long-term human ecodynamics requires robust data on changing environments in the past. Archaeologists have long collaborated with paleoecologists, who study changing communities of plants and animals, to better understand the evolution of local/regional ecosystems. In the 1960s and 1970s, biochemists discovered that heavy isotopes of carbon (C) and nitrogen (N) are metabolized differently than their lighter, more abundant counterparts and 'bioaccumulate' in successively higher trophic levels in the food web (DeNiro and Epstein, 1978, 1981). Differences were also seen in the photosynthetic pathways of terrestrial plants, including important cultivars such as maize (van der Merwe, 1982), as well as marine vs. terrestrial organisms (Schoeninger and DeNiro, 1984). These differences are reflected in the concentrations of C and N (and a host of other elements) in body tissues, including bone collagen. This allows for the reconstruction of food web dynamics from ancient (archaeological and paleontological) samples, and has been used extensively in recent decades to investigate human diets (Newsome et al., 2004; Schoeninger, 2009) and ecological relationships among the prey species upon which human populations depended (Burton and Koch, 1999; Newsome et al., 2010; Misarti et al., 2009; Szpak et al., 2009).

The study of marine food web dynamics has also benefited greatly from the pioneering field research of Jim Estes (sea otters, kelp, urchins—Simenstad et al., 1978) and Robert Paine (intertidal ecology—Paine, 1966). Their extensive field programs were subsequently bolstered by the development of rigorous quantitative models, which have the capability of examining ecological dynamics by virtually adding or removing one or more key components of the system (Christensen and Pauly, 1992). Importantly, these applications can explicitly include humans as part of that system (Dunne et al., 2016; Simenstad et al., 1978).

4.5. Tracking trade/social networks

For much of the history of archaeological practice, migration and mobility in pre-literate societies was inferred from relative similarities in the styles of artifacts, houses, burials, and biological traits—imprecise and largely speculative methods at best. Recent developments in archaeochemistry have made it possible to map movements of artifacts, people and animals/plants from source areas to the location of their archaeological deposition. For example, trace element analysis has been found effective in discriminating the sources of obsidian and other minerals in lithic artifacts and pottery, which in turn allows us to test hypotheses about degrees of movement and trade throughout a region (Gjesfjeld, 2015; Gjesfjeld and Phillips, 2013). When geographic variability is known in isotopic strontium (Sr), oxygen (O) and lead (Pb) across terrestrial landscapes, the same isotopes in human, non-human animal and plant tissues from archaeological deposits can be compared to map the net displacement of adults from the locations of their childhoods (Price et al., 2002; Shaw et al., 2010; Turner et al., 2009). Likewise, spatial gradients in C and N have been used to infer migratory pathways of various prey species that formed the foundation of coastal subsistence economies (Burton and Koch, 1999). Future developments in the combined use of chemical and molecular evidence promise dramatic expansion of our abilities to map past movements (e.g., Brown et al., 2013; Nielsen et al., 2017), with concomitant benefits for our understandings of past SES dynamics.

4.6. Computational modeling

Advances in computational modeling have been essential to many recent human ecodynamics projects. At its core, H.E. research seeks to account for the evolution of complex human behavior patterns and/or complex adaptive systems. Quantitative modeling of variables seeks to represent the effects of that behavior on system dynamics. Anthropic variables such as food choice, mobility, social organization, and technology are often integrated with environmental parameters and dynamics in simulations and other modeling endeavors (e.g., Barton et al., 2011; Kohler et al., 2012). Various approaches to complex systems modeling are well-suited to tracking dynamic feedbacks of multiple variables, including those related to environmental change. Most computational modeling used in H.E. research relies on optimality logic (that individuals or groups would operate in certain ways to maximize benefits), with the understanding that such models are not "true" as much as they create a standard against which the empirical record can be measured (Barton et al., 2011). Often the discrepancy between the modeled result and the archaeological pattern is where real insights emerge. Human agency and historical contingency are often built into the models, countering the critique that computational models are overly deterministic (McGlade, 2014). In fact, one of the key features of dynamic models is that they represent systems as interconnected and integrating, which also contradicts the critique that optimality models are overly deterministic.

Within H.E. research, agent-based models (ABMs; a.k.a. individual-based models/IBMs) have perhaps seen the most use. ABMs are a class of models for simulating the actions of autonomous agents (e.g., individuals or groups), given relatively simple rules, or constraints that are fed into the model, such as initial group size, age profile, food requirements, technology, trade networks, climate conditions, and so forth. ABMs draw on game theory, evolutionary programming, and Monte Carlo methods to simulate the behavior of complex systems. As with any modeling, the simulation effort is not the end or goal of scholarship, but rather what is of interest is the *comparison* of the results of simulation with the archaeological/ecological record. To the extent the two are aligned, we can gain insights on the 'rules' that guide complex socio-ecological systems. And, as noted above, discrepancies point us to components of the cultural system for which we still lack understanding. Kohler et al., 2012 have used ABMs to elucidate the socio-ecological factors behind the growth, expansion and collapse of villages and broader social systems in a part of the prehispanic United States Southwest between the 9th–13th centuries CE. Barton et al. (2011) use an ABM to highlight the dynamic forces—including changing land use and technology, climate change, biological evolution—-which led to the disappearance of Neanderthals and expansion of modern hominins in western Eurasia during the late Pleistocene. Beyond ABMs, d'Alpoim Guedes et al. (2016) showcase the use of niche or species distribution modeling to help explain the spread of early farming in Europe and the distribution of wild ancestors to maize, which is key to earliest farming in Mexico.

4.7. Digital archiving and the birth of big data

Starting in the late 20th Century, science communities and funding agencies began developing the infrastructure for greater data standardization, more explicit data management practices, digital archiving, and the development of online data assimilation platforms for aggregating, analyzing and synthesizing those data. The first big push came with the development of GENBANK in 1982 as a platform for archiving and accessing genetic sequences (NIH, 2008). Although GENBANK was initially used primarily/exclusively by modern geneticists, the growth of aDNA studies in support of (or in conjunction with) archaeological analyses has definitely capitalized on the existing database structure. Within more classically historical sciences, the North Atlantic Biocultural Organization (NABO) was one of the first major efforts to systematize coding of zooarchaeological data in 1992 (McGovern et al., 2018). Since that time, major federal funding organizations, like the National Science Foundation (NSF), and publication outlets have established requirements and guidelines, funded archives, and worked with research community to develop best practices for digital archiving of data (Atici et al., 2013).

While the initial thrust of the advocacy behind this move was preservation and accountability, H.E. research has been facilitated by the meta-analytical potential of these developments. For example, digital archives, like the Canadian Archaeological Radiocarbon Database (CARD) is now serving as a digital repository for all North American archaeological 14C dates (see Hutchinson et al., this issue). Archaeological paleodemography requires the accumulation of the most comprehensive radiocarbon datasets available for a given region, and CARD's centralized online database makes it possible to assemble data for demographic analysis from potentially hundreds of project archives. Other notable developments include the Neotoma Paleoecological Database (Williams et al., 2018), which was itself an expansion of the FaunMap vertebrate paleontological database (FAUNMAP Working Group, 1994; Graham and Lundelius Jr., 2010) but now serves as an online repository for a wide range of paleoecological data including pollen, diatoms, insects, etc. Open Context (opencontext.org) and the Digital Archaeological Record (tDAR, core.tdar.org; Kintigh, 2006) are both archaeology-specific databases and web platforms that serve primarily as a repository for data and unpublished metadata (field notes, excavation photographs, etc.).

5. Contributions of Indigenous knowledge to human ecodynamics research

H.E. research is relevant to any socio-ecological context regardless of scale, location, or social context. However, for those projects focused on the human-environmental dynamics of subsistence-oriented communities, especially where descent communities remain in place and continue to live in intimate connection with the environment and to claim sovereignty over the natural resources and cultural heritage of ancestral territories, it is both beneficial and essential to work closely with those communities.

In the past three decades, archaeologists in many parts of the world have committed to working collaboratively with descent communities in the regions where they conduct research. This trend has emerged in reaction to the colonial heritage of earlier archaeology and anthropology and the desire for research to more directly benefit local and often Indigenous communities. This shift has been accelerated by landmark legal decisions in countries like the United States (e.g., NAGPRA) that legislate consultation and encourage collaboration. Moreover, many archaeologists, anthropologists, and ecologists believe that partnering with local and descent communities is an ethical obligation—at the simplest level, it is the right thing to do because we owe something to the people and places where we work. At a more pragmatic level, researchers know that partnering with local communities is often necessary for accessing sites and opportunities for future study.

Beyond these reasons, engaging with Indigenous knowledge holders and communities is important because it increases the information, perspectives, and potential benefits of research. Many Indigenous communities retain some degree of traditional lifestyle, often involving the use of knowledge about the ecosystems in which they have been embedded for generations. For these reasons, the understanding of human ecodynamics can only be improved with increased Indigenous engagement.

5.1. Local and traditional knowledge as a bank of socio-environmental information

Over the past few decades, anthropologists, archaeologists and environmental scholars have shown a growing appreciation that locally based knowledge systems can represent sophisticated understanding of the dynamics of local environmental conditions. The terms 'traditional ecological knowledge' (TEK), 'local and traditional knowledge' (LTK), and 'Indigenous knowledge' (IK) have been used to refer to the accumulated wisdom of groups with deep connection to and dependence on their surroundings (Berkes, 2009; Hunn, 1993; Stump, 2013). Where university-trained ecologists and anthropologists from outside the region cumulatively might spend several years in the field and study various forms of collected evidence, those who grow up, interact, and base their livelihoods in daily engagement in the local environment gain deep and practical understanding of the socio-natural systems of relationships in which they are embedded. Where communities persist in place and that wisdom is passed down through the generations, communities can accumulate knowledge over decades, centuries and, in some cases, millennia (Cruikshank, 2014; Thornton et al., 2010; Turner et al., 2013). Such knowledge often encodes information about both frequent and infrequent perturbations and regime shifts in climate and ecosystem, as it does about the range of social opportunities and hazards experienced in the past (Minc, 1986). We prefer to use the term 'local and traditional knowledge' or LTK in this context because it refers to the two core features of this knowledge, its local or place-based context, which is key to the intimate experiences that generate and reinforce it, and its inter-generational transmission primarily, though not necessarily, through oral modes of communication. The term 'Indigenous knowledge' becomes salient when referring to how this knowledge comes to be framed in relation to what is sometimes called 'Western Science' or in the effort to bridge academic and Indigenous scholarship (see Stump, 2013).

LTK is important to environmental social science, and H.E. research more specifically, in at least two ways. The first engages LTK as a source of *expert information* about the socio-ecological structures and processes encoded in that knowledge. Academic and agency-based ecologists and environmental anthropologists often collaborate with LTK scholars to supplement field observations. In the context of colonialist histories, in which outside scholars have often failed to appreciate or respect Indigenous people or their expert knowledge, bringing LTK into research studies validates the expertise of Indigenous scholars, enables development of bi-directional learning, and makes for better scholarship. Because the most experienced holders of LTK are also usually full-time practitioners of environmentally embedded livelihoods—or retired elders, inclusion of LTK insights in the academic study of local human ecodynamics usually requires dedicated effort on the part of the research team. When done well, which is difficult, such work has yielded valuable insights (e.g., Gonzalez, 2016; Lepofsky et al., 2017; Lightfoot et al., 2013; Silliman, 2008; Welch et al., 2011). Unfortunately, because Indigenous communities around the world have been victims of repeated appropriations of land, resources, and rights, the rush by outside researchers to record Indigenous knowledge has also triggered concerns about misuse of information and career profiteering, perpetuating the colonialist mode (Brush, 1993). These are serious ethical concerns that are overcome only with the development of trust and the respectful negotiation of protocols for the use of and credit for LTK before a study begins (Atalay, 2012; Colwell-Chanthaphonh and Ferguson, 2008; Nicholas and Bannister, 2004).

5.2. Local and traditional knowledge as adaptive mechanism

A second dimension in which LTK is important to H.E. research concerns the processes of its formation, how it works in different cultural settings, and the extent to which it comes to encode adaptive information (and for whom or what). These questions fall squarely in the fields of environmental and cognitive anthropology (Hunn, 1993).

Indigenous knowledge systems are forms of scientific knowledge not fundamentally different in derivation than so-called Western Science (Brush, 1993). They are systems that *work* in practical terms, systems that make sense of empirical observations and enable effective predictions, even if they do so according to cultural logics that are foreign to outsiders. Like ecosystems, knowledge systems are products of the eco-social histories through which they are shaped. Understanding how and to what extent LTK comes to be effective in guiding adaptive solutions, and for whom (individual, communities, and societies), should be one of the core theoretical concerns of an anthropology of human ecodynamics. To our knowledge, archaeologists have largely ignored this question of mechanism (but see Stump, 2013), focusing instead on how Indigenous knowledge systems seem to work.

Some of the most promising research is being done through ethnographic fieldwork. For example Eduardo Kohn (2013), in his book *How Forests Think*, presents a rich ethnographic account of the socio-ecological logic of the Runa of Ecuadoran Amazon. Kohn makes sense of how the Runa understand the jungle as a web of social interactors embedded in relationships with each other. Humans, dogs, jaguars and other beings negotiate these relationships through acts of interpretation with life or death consequences (human or animal? predatory or prey? spirit? family?). In the process, the jungle comes alive as a system of interconnected but changeable relationships of meaning situated, not simply in the heads of people, but in the histories of interactions that change how they think about those relationships. Through this account we can begin to imagine how SESs might evolve in ways that include biological imperatives, cognitive principles, adaptation, and emergent systemic properties.

If people living intimately with "nature" become experts in it, then it only makes sense that they might be able to diagnose negative human impacts and devise ways to mitigate or even reverse those impacts if so motivated. This logic is behind the push to explore ‘sustainability’ in SESs. A rigorous debate has surrounded the question of whether or not Indigenous communities tend to be ‘conservationists’—that is, to put environmental preservation above short term personal gain (Alcorn, 1993; Balée, 1994, 2013; Berkes, 2017; Erickson, 2008; Kalland, 2003; Lepofsky and Caldwell, 2013; Redford and Stearman, 1993; Smith and Wishnie, 2000). Even so, it is not hard to see how small populations with intimate LTK could recognize the personal advantages of a sustainable relationship with their natural resources and environment. Archaeological cases contribute to these debates by showing how communities, with presumably effective LTKs, have sometimes adversely and sometimes beneficially altered their environments or left evidence of sustainable strategies that mitigated overuse (Brewington et al., 2015; Broughton, 1994; Etnier, 2007; Groesbeck et al., 2014).

6. Conclusions

Human ecodynamics research today is a reflection of the theoretical history of ecology and ecological anthropology, insights on human entanglements in ecological processes, new methods, and political and ethical perspectives on how to direct socio-ecological insights toward desirable future environmental and social outcomes. Increasingly, this is done in collaboration with traditional knowledge experts and Indigenous communities. Having reviewed the history and application of the human ecodynamics concepts and related frameworks, we are now in a position to directly address the questions first posed in the introduction.

6.1. Where does the H.E. concept come from? What are its influences? What, if anything, separates H.E. from related frameworks such as historical ecology or resilience theory?

Human ecodynamics has emerged from a variety of overlapping frameworks and constructs in ecology, ecological anthropology, historical ecology, resilience theory and similar perspectives. Evolutionary economist Kenneth Boulding was likely the first scholar to use the term in the late 1970s, and even in its early uses, human ecodynamics was already associated with key elements of its current meaning, inspired by shifts in the interpretive fabric of ecological and social theories. Since McGlade (1995) brought the term to archaeology, it has been used primarily by archaeology-centered studies of past human-environmental interactions, embracing elements of environmental and post-processual archaeologies. Since that time, human ecodynamics has paralleled and overlapped research efforts defined under the historical ecology framework, and while there are differences in how the two terms were introduced, they now are generally treated as synonyms. One might therefore comfortably speak of historical ecology as a research framework for the study of human ecodynamics, positing one as in a disciplinary context (perhaps properly an “inter-discipline”), and the other a subject of interdisciplinary study. One could advocate for the reverse framing as well. The argument would be polemic at best. Concepts from resilience theory are incorporated into both frameworks, further emphasizing overlap across all three frameworks.

‘Human ecodynamics’ particularly draws attention to the *dynamic* nature of socio-ecological systems, aptly capturing the expectation that these systems respond actively and responsively to internal and external influences, shifts in structural configurations, and unanticipated, chance confluences of factors whose combinations matter more for the status of ‘the system’ than any single variable in isolation. Dugmore et al. (2012) demonstrate this point well in showing how Norse Greenlanders were able to adapt to a range of climate variability through the onset of the Little Ice Age, but failed to cope with similar scale perturbations when additional, unrelated factors co-occurred.

6.2. Does H.E. contain a defined theoretical or methodological commitment and dedicated set of practitioners?

In response to Holm's query quoted in the Introduction about whether H.E. has a unifying interpretive theory or model, the short answer is “no.” H.E. is theoretically agnostic and open to different conceptual frameworks appropriate for explaining different aspects of socioecological change. Theoretical assumptions and propositions cannot all be correct in every instance, and we do not advocate an open-ended, anything-goes, theoretical pluralism. Nevertheless, we suggest that H.E. should be viewed as a subject of study and not a paradigm; human ecodynamic-related questions can be explored through any theoretical framing that seems relevant to a given question or interpretive issue. This makes the topic fertile ground for comparing the effectiveness of different approaches and providing a rich interpretive diversity. Nagaoka and Wolverton (2016:473) make a similar point in discussing the benefits of ethnobiology as a framework for zooarchaeological research. They suggest that subject-centered orientations can be less divisive than one often finds in the polemic ideological landscape of discipline-centered communities like Archaeology and Anthropology. We are not as convinced that subject-based identities are necessarily freer of dissent on theoretical and methodological issues than other ways of framing research. But certainly, a lack of theoretical specificity is advantageous for a subject with a potentially diverse array of research questions about systems affected by a range of forces. It also may be the case that the most divisive epistemological and ontological debates have been excluded by the way H.E. research has attracted or repelled potential practitioners.

Even though it may be untethered to any specific theory, H.E. research has tended to share several common principles, for example embracing dynamism and challenging determinism. H.E. research also tends to recognize historical contingency, human agency, and the key notion of social-natural systems (that humans are not separate or isolated from the environment). Many scholars rely on optimality models for predicting a range of human behaviors; some extend this to computer modeling. Many embrace the analytical concepts of complexity and engage in systems thinking.

As with theory, human ecodynamics has no specific claim on methods of practice, per se. Even so, the study of human-environmental interactions and change has been fundamentally shaped and—in its current form—made possible by a range of methodological advancements in paleoecology/paleoclimate, molecular zooarchaeology and archaeobotany including isotopic ecology and aDNA analyses. These methods are often paired with synthetic paleodemography, made more robust—if not less controversial—by the accumulation of large radiocarbon data sets and the development of methods for modeling changes in the intensity of archaeological deposition and arguably, population. With the ability to connect climate, ecology, demography, mobility and exchange through archaeological deposits, it is increasingly possible to correlate social and ecological variability within the same stratigraphic settings, reducing the dependence on correlations between proxy series, such as lake pollen or glacial cores, over great distances.

With these improved methods and data sets informing interpretations about environmental, demographic, and social dimensions of the past, it is possible to identify patterns and ask questions about human resilience to environmental and social influences. It is also possible to reverse the question and ask about the resilience of non-human populations and ecosystems to human perturbations due to factors such as human immigration, increased density, technological change, adoption of domesticates, changes in political organization, urbanization, and warfare.

6.3. Is the human ecodynamics term useful in other ways, for example in facilitating interdisciplinary collaborations?

Our overview should make clear that human ecodynamics captures and summarizes a frame of reference that has yielded a flurry of productive, interdisciplinary research into integrated human-environmental change. This flurry has been led by archaeologists, who have drawn willing collaborators from other fields into the fray. The resulting scale and scope of interdisciplinary research has been possible for several reasons. First, the unique availability of large funding packages from NSF CNH initiative and other funding streams, created a unique catalyst to develop human ecodynamics case studies and advance the theory and methods around the dynamics of socio-ecological system change. Second, H.E. research has benefited from the growth of large-scale digital databases and coordinating research networks—that allow for the opportunity to synthesize records from multiple small-scale projects. Both scales of projects have hugely benefited from methodological advances in disciplines outside of archaeology—geosciences, genetics, and more.

6.4. What can Indigenous knowledge contribute to human ecodynamics research?

As archaeologists today are aware, many Indigenous and local communities are culturally and spiritually committed to maintaining lifestyles in landscapes and ecosystems long part of their cultural heritage. These groups have robust and intimate knowledge about the ecosystem processes, variabilities, and dynamics often inaccessible to outside research methods. They have insights into environmental histories and cultural responses in the past (e.g., Crowell, 2016). Community historians and leaders are also keenly aware of the hazards of socio-ecological change and often eager to document long-term histories of natural and cultural change to better prepare for the future and to support traditional claims whose violation only undermines community resilience in today's complex globalized world. Collaborative human ecodynamics research is a way for outside archaeologists and their collaborators to help serve these goals and participate pragmatically in the research of a “usable past” (Stump, 2013), that is, where communities see an interest in pursuing such research.

6.5. How can human ecodynamics research contribute to society?

Archaeologists are increasingly eager to put their understanding of the past to use in the present. H.E. research and the synthesis of what Nelson et al. (2016:299) call “completed experiments in human ecodynamics” is a key way to make these contributions. From local to global scales, H.E. is often promoted as a source of long-term information on integrated socio-ecological changes that should be relevant to contemporary society. There are at least three general ways that H.E. can make contributions to our contemporary world. First, understanding of human ecodynamics can contribute to issues in contemporary conservation and habitat management. Historic collapses of the stocks of herring (McKechnie et al., 2014; McKechnie and Moss, 2016), sea otters (Larson et al., 2002, 2012; Springer et al., 2003), and elk or the ‘out-of-control’ deer populations across eastern North America (e.g., Wolverton et al., 2007) can best be understood by comparison to long-term case studies in human ecodynamics, drawing on zooarchaeology, paleoclimate research, and land use evidence. More broadly, human ecodynamics themes run through the core of what archaeologists today consider to be the most important *grand challenges in archaeology* (Kintigh et al., 2014). These include issues of resilience, complexity, mobility and human-environmental interactions. Third, as part of historical science, H.E. research can affect change in cultural values, through the perspective of ‘disclosure’ (e.g., Borgmann, 2000, as cited in Wolverton and Lyman, 2012). According to this philosophical concept, humans mainly make sense of the world through day-to-day experiences and those accumulated over a lifetime. The vastness of time and space—as understood from geology, paleobiology, and archaeology—are not readily ‘disclosed’ to the human imagination. To the extent that historical science helps people conceptualize deep time and worlds beyond their own lives, such scholarship can promote a shift in values, especially regarding the impact of current actions on the future. The thinking goes: if we can change the way people feel about the past, we may be able to get them to think differently about their impact on the present and the future. How can H.E. research begin to address this need? A starting place is to devote more resources to translating scientific understanding from H.E. research into formats that engage the broader public, which can take a range of forms. If we agree that engaging the public about human-environmental history is important, then there is a clear need for more incentives to support such engagement (from research funding agencies, professional organizations, and agencies that fund archaeological mitigation).

In closing, we are optimistic for the future of H.E. research, carried out as such or under the banner of historical ecology or any other related term. As archaeologists, it is invigorating to collaborate with scholars and students with different training and experiences on questions that require our mutual engagement. H.E. research gives us the opportunity to cross the artificial but ingrained natural and human divide. It is not easy, but it is intellectually rewarding and holds significance for a globalized society facing dramatic climate change, resource management crises, endangered lifestyles, and social unrest.

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