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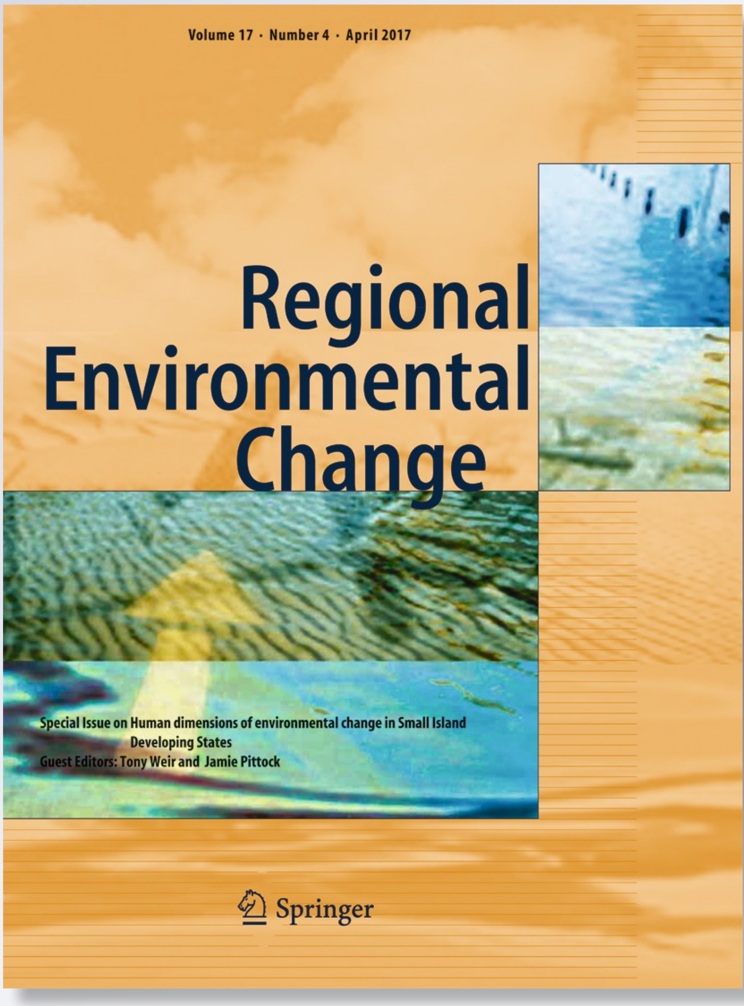
Regional Environmental Change

ISSN 1436-3798
Volume 17
Number 4

Reg Environ Change (2017)
17:1205-1215
DOI 10.1007/s10113-016-1096-y



Springer

Reg Environ Change (2017) 17:1205–1215
DOI 10.1007/s10113-016-1096-y

REVIEW ARTICLE

Looking to the past to shape the future: addressing social-ecological change and adaptive trade-offs

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Received: 10 April 2016 / Accepted: 14 December 2016 / Published online: 28 January 2017

Abstract Paleoecological and paleosocial synthesis, meaning the examination of data and patterns derived from past social and ecological systems, provides an important long-term perspective on adaptive strategies and their consequences. Data and analyses from extended timescales (centuries, millennia) have yet to be routinely incorporated into adaptive capacity studies; this has limited our ability to adequately consider adaptation and sustainability from a long-term perspective. In this study, we examine three cases of successful adaptation in the past drawn from various regions of northern North America and from various times spanning the last 13,000 years. These cases involve different degrees and kinds of environmental and social conditions, changes and triggers. Exploring their specific circumstances provides insights into the role of ecological, technological and social change in producing adaptive capacity and confronting sustainability challenges. Two implications of these case studies are explored. First, we outline how paleoecological and paleosocial approaches can be used to refine measures of adaptive capacity. Second, we argue that community-based observing networks are a deep time-vetted strategy for managing resources sustainably and that implementing similarly local and decentralized practices in modern contexts will aid in achieving sustainable resource management into the future.

Keywords Adaptive capacity · Community-based observing · Paleoecological · Paleosocial · Sustainability · Synthesis

Editor: Will Steffen.

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Using paleoecological and paleosocial synthesis in the study of sustainability and adaptive capacity

There are many adages concerning how the past can guide the future in both Western and non-Western societies. In recent years, studies outlining how we might draw on data from the past to make decisions about our future have appeared, typically in scholarly discussions of climate change, sustainability, vulnerability and resilience (e.g., Anderies 2006; Diamond 2005; Nelson et al. 2016; Schoon et al. 2011). In our efforts to mobilize data on the past to address the current and future social and ecological change, it is important to move beyond generalities and be specific about the approaches and methodologies that can be productive.

Examination of a wide diversity of cases and contexts will help to illuminate the many factors that contribute to adaptive capacity in human and ecological systems in the past (Nelson et al. 2010, 2016; Oldfield 2006). Paleoecological and archaeological studies can add greatly to the potential repertoire of cases to consider. The data they provide, which we refer to as paleodata, offer a uniquely long-term perspective that opens up the study of both causes and consequences of socioecological change (Sandweiss and Kelley 2012). They can also contribute in some specific cases to more fine-grained analyses, providing a multiscalar approach in space and time.

In this paper, we contribute to the broader objective of using the past to guide the future by considering three cases of adaptation in deep time: two in the North American Arctic and one on the Northwest Coast of North America. From these case studies, we draw specific lessons in terms of how successful adaptations have played out, arguing that: (a) maintaining a diverse cultural repertoire enhances flexibility in times of instability, (b) adaptation is not a stable plateau but rather a constantly changing set of practices and adjustments to local conditions, and (c) decentralized management of ecological knowledge provides a useful way to manage and sustain ecologies in small-scale contexts.

The rationale for the specific regions and timescales covered by our case studies is threefold. First, past research on adaptive capacity has often focused on large-scale societies, such as ancient state systems, or on intensive farming economies, both of which alter their environments in substantial ways (e.g., DeMenocal and Cook 2005; Dearing 2008; Diamond 2005; Tainter 1988). Our case studies come from small-scale hunter-gatherer societies. Second, northern regions are highly sensitive to the kinds of climate change and social pressures on resources that are now emerging. Third, small-scale societies like those that form our case studies are germane to developing solutions that are also small-scale. While climate change, ecological deterioration and resource depletion are global scale issues, we argue that part of a global solution will be implementing new practices at local scales (Westley et al. 2011).

In this paper, we first review the nature of paleoecological and paleosocial data and the possibilities these offer for studying adaptive capacity in the past. Second, we present the case studies, highlighting the particular variables that we interpret as important for producing adaptive capacity in these specific contexts. Third, we use the cases to further refine the variables potentially useful in adaptive capacity studies, focusing on those that are highlighted by our case studies.

What are paleoperspectives and how can they be used?

Paleodata, meaning data derived from or pertaining to past ecological and social systems, come in many forms. We divide paleodata into two components. First, paleobiophysical data describe the conditions and dynamics of past ecosystems and natural environments. This category includes any data that provide an indication of the state or dynamics of the natural world in the past. The kinds of data that are particularly important for reconstructing past environmental conditions include lake sediment cores, isotope assays and fossil animal or plant remains (Gillson and Marchant 2014; Sandweiss and Kelley 2012). Humans (and our pre-human ancestors) have been part of their environment for millions of years, and so these data can be obtained from both paleontological and archaeological contexts.

Second, paleosocial data are material remains that document past human lifeways, organizational practices or adaptive strategies. Archaeological remains are primary in this regard and can provide a record of subsistence practices, social organization, ideology and political dynamics. Most inferences from paleosocial data pertain to basic subsistence and provisioning activities (for example, the faunal records contained in archaeological middens). However, data that illuminate past social organization can be readily obtained, as when using the size of ancient houses and settlement layouts to infer household or community organization (e.g., Coupland et al. 2009; Grier and Kim 2012).

The resolution of paleodata varies, but yearly or decadal scale data are now available for some archaeological and paleontological locales (Sandweiss and Kelley 2012). For example, in the US Southwest, dendrochronological dating using tree rings allows generation of a date for the establishment and abandonment of ancient pueblo communities to the specific calendar year (Towner 2002). In Japan and elsewhere, varve analysis, meaning the study of fine sediment layers in lake bottoms derived from yearly runoff, allows for the reconstruction of annual climate and ecological conditions in the surrounding ecosystem (Nakagawa et al. 2012).

Such fine-grained data are incredibly useful, but are not always critical. Most archaeological data are in fact quite coarse grained. These coarser data usefully track long-term processes that play out at a scale of centuries or millennia. Archaeological data therefore offer the opportunity to study processes at multiple scales (Grier and Kim 2012; Carballo et al. 2014). Paleodata provide a means to understand the ecological, technological and social conditions in the past, but, germane for our purposes here, also provide a window into how past challenges and perturbations in lifeways have been handled in specific contexts. Investigating the relative timing of social and ecological change can reveal whether social changes occurred as a response to changing ecological conditions or in advance of exogenous changes (e.g., Nelson et al. 2016; Sandweiss and Kelley 2012).

Paleodata can reveal factors that were important in successful adaptation but which we may be unable to see or measure from our present vantage point. There may be deep time-vetted adaptive strategies that will remain unrecognized if we restrict our knowledge base to the last 30 or even 100 years. These novel factors can be incorporated into models for how ecologies may change in the future and how we may pro-actively respond to such changes (Gillson and Marchant 2014; Higgs et al. 2014).

The theoretical background

In the study of adaptive capacity and sustainability, the consideration of ecological, technological and social variables and their interactions is critical on both theoretical and methodological grounds. Following wider currents in the social sciences, human geographers, anthropologists (including archaeologists) and paleoecologists have devoted significant effort to proposing and evaluating models for how social and ecological variables are coupled (Costanza et al. 2007; Nelson et al. 2010; Schoon et al. 2011; Tainter 1988). These models have explicitly coupled human and natural systems in various ways. In situating our argument, we briefly touch on some major theoretical positions that have been utilized to situate our argument. In doing so, we limit the discussion primarily to anthropological and social science approaches to the study of recent small-scale societies and past societies as documented archaeologically.

A prominent position in the study of small-scale societies has been that of human behavioral ecology. This approach has focused on developing robust ecological models for how humans should behave under certain behavioral assumptions and ecological constraints (Bird and O'Connell 2012). Behavioral ecology situates humans in their environment much as non-human animals have been modeled and studied in ecology (Bettinger 2009; Foley 1985; Winterhalder and Smith 2000). Humans are viewed as organizing themselves spatially and temporally on landscapes to optimize the costs of resource acquisition. In the formal application of prey choice and patch choice models, humans are expected to evaluate alternatives optimally choose their prey in order to reduce search and handling costs relative to the caloric return of the resource. Strategies are adjusted as natural conditions and resource availability change in a way that produces successful response to changing conditions.

While these approaches have both revealed and clarified adaptive strategies and decision-making in specific ecological contexts, they do have important limitations. First, human decisions are driven only in part by concerns of optimality. Most humans in fact operate under cultural preconceptions about what is possible, which shapes their choices (Trigger 2006). Second, humans rarely have the scope of ecological knowledge implied by formal behavioral ecology models and regularly encounter situations where they must act on the basis of limited information, without a clear sense of the trade-offs and consequences over the long term. In recent years, efforts to more holistically characterize the recursive elements of human–environment relationships and the nature of traditional ecological knowledge have opened up a wider range of possibilities in the application of behavioral ecology approaches (Cronk 1991; Orr et al. 2015:116–117).

A second approach, that of historical ecology, posits that historical factors, both natural and cultural, must be incorporated into analyses of change (Ballée and Ericson 2006; Crumley 1994, 2006; Szabo 2010; Thompson 2013). In part, this is an ecological statement that there is no "normal" or homeostasis in ecologies, but rather that there are diachronic, historically derived elements to what we tend to see as timeless or natural synchronic conditions (Higgs et al. 2014). A second important element of historical ecology is that humans are, and likely always have been, important drivers of change in ecosystems. In historical ecology, human decisions and practices interact with natural trajectories of ecological change to create complex and dynamically coupled histories—context is key.

Also of more recent genesis is the theoretical cannon of political ecology. While encompassing a diverse set of objectives and approaches, political ecologists operate under the premise that the political elements of decision-making and the unequal distribution of power in human societies have an important and often dominant role in shaping ecologies (Bryant 2015; Forsyth 2003; Orr et al. 2015; Paulson et al. 2003; Robbins 2012; Vayda and Walters 1999; Whitehead et al. 2007). Policies and political machinations and tensions affect how resources are harvested and managed and often result in less-than-ideal outcomes from the perspective of sustainability (Robbins 2012). The advantage of political economy is that it places human actors in the foreground of any analysis. However, political factors should be considered in the context of a specific problem or analysis, and the degree to which they play a role in determining outcomes should be empirically established rather than assumed a priori

The focus of analysis in political ecology has been on capitalist societies and recent/modern states (Orr et al. 2015). In the study of small-scale and pre-industrial societies, politics has been embedded in human–ecology relationships through the perspective of political economy (Spriggs and Earle 2015; Halperin 1989). While political economy is seen as having strongly Marxists roots, more broadly its objective is to focus our attention on material processes and the very intimate and direct relationship of small-scale and pre-industrial societies with their ecologies. All economies are social as well as material processes (Halperin 1989), and politics operates in the economics of all societies, even the so-called egalitarian hunter-gatherers (Angelbeck and Grier 2012).

All three approaches outlined here provide important insights into the workings of small-scale societies. Accordingly, we must work to establish the role of ecology, history and politics in specific cases. Importantly, paleodata do provide, however, a unique opportunity to put history back into the equation at scales that are longer than those typically considered in many forecasting-focused computational and predictive models, as we show with the three case studies that follow.

Examining adaptive capacity in the past: three case studies

Having argued for a role for paleodata both theoretically and empirically in examining adaptation and socioecological change, their causes and effects, and their consequences, we now turn to three cases that highlight how employing paleodata can inform the study of adaptive capacity. For the case studies, we adopt two key definitions. Sustainability is defined in social-ecological system terms as the persistence through time of the institutional structure(s) supporting resource acquisition and management and includes the resource units, the resource system, the governance system and the users, along with the outcomes of interactions between these components (Ostrom 2009). Adaptive capacity refers to the ability of a social-ecological system to absorb shocks to or changes in its external and internal parameters yet retain its integrity—this is synonymous with the concept of resilience in social-ecological systems (Folke et al. 2003, Armitage et al. 2009). These definitions are largely consistent with current ideas in sustainability science literature (e.g., Alessa et al. 2015; Anderies et al. 2013; Nelson et al. 2010; Schoon et al. 2011; Smit and Wandel 2006). Specific elements of such definitions remain contentious (Redman 2014), though these debates are beyond the objectives of this paper to address.

In the discussion that follows, we take a synthetic approach, drawing on data from existing studies to establish several points concerning adaptation in small-scale societies. We briefly consider the archaeological and paleoecological record of Alaska during the Late Pleistocene and early Holocene, and the North American central Arctic during the mid-Holocene. These two cases illustrate how the maintenance of a diverse cultural repertoire of potential solutions promotes adaptive capacity. The second illustrates how adaptation was not simply a stable state or plateau, but rather a flexible set of practices, even in a region where adaptations were previously viewed as stable over the long term (Armitage et al. 2009).

We then consider in more detail the Coast Salish case of the Pacific Coast of North America, which provides an important window into organizational possibilities based on decentralization. These three cases vary in terms of the importance of ecological, technological and social factors in shaping the way adaptive challenges were confronted and resolved, illuminating how these factors operated on their own and in concert (Table 1).

Table 1 Critical factors (marked with +) involved in producing and/or addressing adaptive challenges in the three case studies

	Type of factor		
	Ecological	Social	Technological
Case Study			
Alaska in the Late Pleistocene	+		+
Coast Salish of the Northwest Coast		+	+
Paleoeskimo of the Canadian Arctic	+	+	

Alaska in the Late Pleistocene

The archaeological and paleoenvironmental records of Alaska offer a window into human adaptive strategies over the last 14,000 years. Multiple lines of paleobiophysical data have been used to reconstruct late glacial and post-glacial conditions, including oxygen isotope-derived paleoclimate reconstructions from Greenland ice sheets (Fiedel 2013), fossil pollen and charcoal primarily from Alaskan lake sediment cores (Higuera et al. 2008; Viau et al. 2008), and fossil beetle analyses (Elias 2001). These have been coupled with paleosocial data, including lithic (stone) tool kits and faunal records recovered from archaeological sites (Potter 2008). Settlement locations and land use strategies have also been documented, particularly along the river valleys of central Alaska, providing an indication of the organization of communities and societies in the distant past (Goebel and Buvit 2011; Graf and Bigelow 2011; Hamilton and Goebel 1999).

Combined, these data provide a window into adaptive strategies following deglaciation near the end of the Pleistocene. The Younger Dryas period (12,900 to 11,600 years ago) of the Late Pleistocene involved a return to much cooler conditions following a warmer period that initiated deglaciation around 14,000 years ago (Graf and Bigelow 2011). Reconstructions of climate conditions show that the Younger Dryas event had varying impacts across Alaska, but that overall the early occupants of Alaska likely encountered rapid and significant climate and environmental change at the end of the Pleistocene and through the early Holocene (Fiedel 2013; Graf and Bigelow 2011).

The Late Pleistocene period in Alaska has been traditionally viewed as a focused big-game hunting adaptive strategy that appears in the archaeological record just after 13,500 cal BP (Goebel 1999; Hamilton and Goebel 1999;

Potter 2008). Megafauna (mammoths and other large-bodied herbivores) were hunted with large bifacial chipped stone tool technology, an adaptation that persisted for several 1000 years. Microblade technology has been argued to have appeared as much as five or six centuries later, perhaps brought to Alaska through a second migration of people from Siberia (Graf and Bigelow 2011; Hamilton and Goebel 1999). Much more variability in the archaeological record of Alaska has been recognized in recent years, however (Graf and Bigelow 2011; Potter 2008). Microblades have been found in numerous sites in Alaska contemporaneous with larger bifacial technology, suggesting a much more complex set of technologies were utilized to negotiate the Late Pleistocene environment of Alaska.

Microblade technology involves chipping small blades (<2 cm) from obsidian and other stone material and setting these into bone armatures to create projectile and other tools (Elston and Brantingham 2002; Goebel 2002). Microblades may offer several advantages. First, larger stone implements tend to become brittle and break in colder conditions, while bone tools with small inset stone blades remain flexible under such conditions. Second, access to raw tool stone may have decreased in more snow-covered landscapes of the Younger Dryas. Microblade production makes very efficient use of raw tool stone, mitigating raw tool stone shortages. Third, it may have been better suited to hunting the fauna available in Younger Dryas conditions (Binford 1979; Hiscock et al. 2011). Fourth, because of its efficient use of raw toolstone, microblade technology may have served to facilitate mobility (Kuhn and Elston 2002; Torrance 2002; Yi et al. 2013).

Whatever the case, microblades are not the dominant stone tool technology in Late Pleistocene sites in Alaska. They in fact have very limited representation or are absent in many of the earliest Alaskan archaeological sites; the technology increases in prevalence with the onset of the cooler conditions of the Younger Dryas (Graf and Bigelow 2011:443–445). This pattern does indicate that microblades appear to have been retained as a long-standing technological option to meet changing environmental and climate circumstances. Early Alaskan peoples curated cultural knowledge of microblades as a potential solution even when it was not their primary evolving technology, despite the costs of doing so. Microblade technology fluoresced after the younger Dryas to meet changing social and ecological circumstances. Throughout the Holocene, the importance of microblade technology varies, but it does not disappear and is employed when and as needed to address new and changing ecological circumstances (Mason et al. 2001; Potter 2008).

The situation with Later Pleistocene/Early Holocene technology underscores two lessons. First, successful adaptation to unforeseeable conditions can be greatly assisted by retaining a repertoire of technological solutions as a knowledge pool, providing the flexibility to meet sustainability challenges. Second, solutions to problems of adaptation can be gained through applying existing and long-standing technologies in new circumstances. This suggests that the development of new technologies *per se* is one way in which adaptive challenges can be overcome. Investing in the maintenance of a diverse knowledge pool (including curating technological knowledge) provides flexibility in the face of change. Conversely, overspecialization into technological niches can limit potential responsiveness in a changing world, in part because it limits flexibility (Hiscock et al. 2011).

Paleoeskimo adaptations in the Canadian Arctic

Paleoeskimo groups inhabited some of the coldest regions of the Canadian Arctic archipelago and the northern continental mainland between 4000 and 1000 years ago. Much like in Late Pleistocene Alaska, they were organized into small groups of relatively mobile hunter-gatherers. The core area of Paleoeskimo habitation in the Foxe Basin of Arctic Canada, an area approaching 250,000 sq km, has long been viewed as a region that supported stable human occupation for 3000 years (Maxwell 1985:81–82; Murray 1999). Areas peripheral to Foxe Basin saw significant flux in settlement, being abandoned and re-occupied in concert with changing ecological conditions. The stability of habitation in the core area has been equated with a successful and stable adaptation for three millennia.

However, a recent comprehensive study by Savelle and Dyke (2013, 2014) has shown significant variation rather than stability in the organization of settlement in this core area through time. Using a greatly increased sample of radiocarbon dates and archaeological sites, they address the reality of the putative 3000-year unbroken continuum (Savelle and Dyke 2014:262). Throughout the region, episodes of population shifts and abandonment of local areas are evident, suggesting a constant adjustment to local resource and climate conditions.

Their results force a reconsideration of our view of the situation both empirically but also conceptually. Paleoeskimo groups were successful by any measure; it is difficult to characterize 3000 years of adaptation in some of the harshest conditions on the planet as unsuccessful. But their successful strategy involved constant, fluid and continuous responsiveness rather than a static organizational plateau. Moreover, the transition within the Paleoeskimo period between what is termed Predorset and Dorset cultures involved significant shifts in material culture style, habitation structure preferences and diet (seal vs. walrus) preferences. Yet, the technology was fundamentally similar across this transition. The Paleoeskimo cultures at the end of the period were quite different than those evident at its beginning, emphasizing how the continual adjustment of adaptation is an historical process.

Coast Salish of the Northwest Coast of North America

Exogenous factors, including climate and associated ecological changes, have loomed large in explaining how human societies have changed over the last 2 million years (e.g., Burroughs 2005). The relationship is often considered to be very direct. However, paleodata provide us with examples of situations in which social change occurred in the absence of significant exogenous ecological triggers. These situations are critical to recognize. When climate and ecology play a limited role, the role of social adaptation in confronting sustainability challenges comes into sharper relief.

On the Northwest Coast of North America, ecological change throughout most of the Holocene was much less dramatic than that experienced in the Late Pleistocene and early Holocene. On the whole, climate and ecological changes have been limited over the last 5000 years in the area known as the Salish Sea (Grier et al. 2009; Lepofsky et al. 2005; Lucas and Lacourse 2013). This region includes the Strait of Georgia in southwestern British Columbia, Puget Sound in northwestern Washington State and the Strait of Juan de Fuca.

The area did, nonetheless, experience dramatic social changes over the last 5000 years. These changes involved the emergence of cultural complexity, which included the development of permanent settled villages, large multi-family cedar plank houses, class-based social inequalities and property and resource ownership systems (Ames and Maschner 1999; Grier 2014; Matson and Coupland 1995). These characteristics are atypical for peoples that did not practice staple agriculture.

Indigenous Northwest Coast peoples existed in an extremely productive and diverse environment, but this productivity was not without its variability across seasons and over space (Moss 2011, 2012). Higher population densities that emerged in concert with settled village life around 2000 years ago likely exacerbated the impacts of this variability. Sustainability challenges arose due to high local population densities and the sensitivity of certain marine and terrestrial resources to harvesting pressure. Similar population pressures on coastal resources have been documented in many areas of the generally abundant Pacific Coast of North America (Broughton 1999; Broughton et al. 2010; Rick and Erlandson 2008).

There were also significant social demands on resources, with elevated production driven in part by an elite class of individuals who attempted to build their own prestige and external alliances through the conspicuous consumption of resources (Ames 1995; Angelbeck and Grier 2012). It is therefore useful to examine how sustainability challenges were met in the Salish region. What were the strategies that were employed? What was the role of ecological, social and technological factors in producing sustainability and adaptive capacity over the long term?

The dataset that bears on these issues include archaeological and paleoecological data from long-standing village locations, as described in Grier (2014) and Grier et al. (2009). These locations have been the focus of settlement in the Coast Salish region for as much as 5000 years (Grier 2014). Analysis of village locations from the southern Gulf Islands reveals that adaptation to changing circumstances, particularly ensuring resource access for expanding permanent communities, was through technological investments in large-scale resource harvesting infrastructure. Clam gardens, fish weirs and engineered wetland systems were increasingly employed in order to ramp up food production (Grier 2014; Lepofsky et al. 2015).

However, all technologies are implemented in a social context, with consequences and trade-offs, and are only successful as a solution if the social and institutional arrangements exist to capitalize on that technology (Angelbeck and Cameron 2014). This point is made clear with the large-scale resource production facilities built and used by the Coast Salish over the last few 1000 years (Grier 2014; Lepofsky et al. 2015). These facilities required large-scale labor organization and long-term coordinated efforts to keep them working, and the timing of the emergence of large corporate groups (i.e., the large multifamily households), perhaps not unsurprisingly, coincides with the appearance of large-scale resource production facilities.

These simultaneous changes suggest social relationships in Coast Salish society had to adjust to operationalize these new technologies. Specifically, new social institutions coalesced that could operate at a scale commensurate with the technology. This is not a causal statement, however. The capacity to organize in that manner had to exist prior to such changes, and the changes that were made had some intended and unintended consequences.

Ownership and property systems documented for recent Coast Salish societies likely emerged as a means to regulate economic production. Large infrastructure is recorded ethnographically as having been controlled by high-status individuals who managed when and how production occurred (Richardson 1982; Suttles 1951). Under conditions of high population densities and social demands on resources, production cycles and access to resources were regulated to avoid overexploitation.

Decentralized control was a key to managing the system (Angelbeck and Grier 2012). Resource locations were owned by those situated in close proximity to the resource. This promoted local and intimate monitoring of changing ecological circumstances and resource harvesting pressures. Resource owners were linked over large regions by social institutions that circulated ecological information, such as the renowned Northwest Coast potlatch (Trosper 2002, 2009).

The Coast Salish case underscores that climate change (and ecological change more generally) is not always a key driver or perhaps even critical variable in all cases of change in human societies. This holds for small-scale societies with a very intimate relationship with their environment, such as the Coast Salish. While social and natural factors are routinely coupled, social factors can be the dominant element in structuring change.

Interestingly, despite the efforts to ensure sustainability through structured resource access, Coast Salish societies included dramatic social inequalities, with differences in wealth and status beyond those typically seen in societies lacking centralized governments (Angelbeck and Grier 2012). This inequality was a trade-off, in that it was a consequence of the unequal access to resources created by ownership systems designed to promote sustainability (Grier and Angelbeck 2017). In this respect, decisions that improve ecological sustainability can have detrimental effects down the road for sustainability in the broader social sense, in that social practices implemented to sustain ecologies can be detrimental to human equity and overall human well-being.

Implications for sustainability and applications to current challenges

There are several lessons and implications that emerge from the preceding case studies and conceptual discussion. In this section, we consider these with the intent of clarifying the role of paleodata and its analysis in research methodologies and potential policy applications.

The case studies above raise several issues concerning adaptive trade-offs and the interactions of ecological, technological and social variables in producing adaptive capacity. In the Alaskan case, the solution to external ecological change involved implementing existing technologies in new ways. In the Paleoeskimo situation, recurrent adjustments to ecological change and potential resource depression produced adaptive capacity. In the Coast Salish case, the key problem derived not from external climate-induced ecological perturbations but rather from increasingly place-based populations requiring new technological and social approaches to achieve sustainability (Grier 2014).

These observations fuel a consideration of adaptive capacity and how we might measure it in three respects: (1) how we identify factors that produce adaptive capacity, (2) the methods for developing yardsticks (or indices) to measure adaptive capacity and (3) conducting analyses of how various components of adaptive capacity work together in specific contexts to generate adaptive flexibility and the capacity to accommodate change (Nelson et al. 2016).

Adaptive capacity indices (Yohe and Toi 2002) were developed to provide a systematic synthesis of key social, biological and physical indicators that allow for targeted yet coordinated responses under changing conditions. The goal of adaptation in this context is to sustain desired livelihoods and well-being (Alessa et al. 2015). ACIs have frequently been approached using theory-driven indicators that combine primarily economic and ecological information to provide a management tool (UNISDR 2005).

Most ACIs operate at the national scale and are consequently less applicable to individual communities or regions seeking to develop adaptive strategies as an iterative, ongoing process (Tremblay et al. 2008; Vincent 2007). Nevertheless, there are emerging efforts to develop ACIs from a community partnership approach incorporating indicators that are central to livelihoods and well-being (Brooks et al. 2005; Alessa et al. 2015).

A useful outcome of analyzing paleodata is the possibility to refine and expand our view of adaptive capacity and the way it can be measured and assessed through ACIs. In a recent study, Nelson et al. (2016) consider the vulnerability to severe climate shocks (or "rare climate challenges") of seven historical and archaeological cases in the desert US Southwest and North Atlantic. Both can be thought of as small scale—the North Atlantic colonies of Greenland, Iceland and the Faroe Islands being mostly semi-isolated colonies of a medieval nation state, and the US Southwest in that these societies were not organized into centralized, regional-scale polities.

Nelson et al. (2016) developed eight measures of vulnerability, with vulnerability effectively being an inverse measure of adaptive capacity in that if a system is vulnerable, it has little adaptive capacity. Their measures include availability of food, diversity of available and accessible foods, health of food resources, social connectivity, storage, mobility, equitability of access to resources and physical barriers to resource access. Several of these are social conditions, and several are ecological conditions.

These coarse variables work for establishing common conditions (vulnerabilities, in this case) across disparate cases and consequently establishing the resilience of systems to rare climate challenges. Our case studies suggest potentially fruitful ways to further refine several of these variables. For instance, in the Coast Salish case the social networks that existed were decentralized and peer-to-peer.

Such networks were instrumental in circulating resources, and so the nature of social networks, whether hierarchically integrated as in nation states or decentralized, as in Coast Salish societies, may be important to distinguish in studies of adaptive capacity. A centralized, hierarchical system, while efficient in making decisions (Johnson 1982), can act to restrict access to resources, impairing equitability and making a system more vulnerable (Grier and Angelbeck 2017).

Several additional observations are worth amplifying. Considering the Alaskan situation we reviewed, technological flexibility to address changing circumstances, and the retention of potential technological solutions in cultural practice, appears to be a potentially important variable in adaptive capacity. We note here that this variable (and other technological variables) remains absent from the analysis of Nelson et al. (2016).

In the case of the Paleoeskimo, rare climate challenges or ecological shifts were not the impetus for social change. Rather, we see small adjustments in Paleoeskimo responsiveness as central to maintaining adaptive capacity. The attention to large-scale, rare climate challenges assessed by Nelson et al. (2016) is apropos given the potential impact of current and future climate change on the modern world. Yet, it is important to consider climate events and ecological shifts of many amplitudes and periodicities in the examination and investigation of adaptive capacity.

An impetus of this is that ACIs can be of great utility in generating policy options, and small adjustments at local scales may prove pragmatically feasible compared to large structural reconfigurations in the pursuit of resilience and sustainability (Juhola et al. 2012). In both cases, paleodata allow ACIs to be vetted and weighted in terms of outcomes. There may have been approaches and strategies to social-ecological change that are deep time-vetted, but that we cannot see from our current position in the present without paleodata (e.g., decentralized networks with local control of resource access).

Studies of the organization of social networks in past societies and how these promote adaptive capacity have direct implications for modern challenges and the kinds of policy solutions that may be implemented to promote sustainability (Folke et al. 2005). The decentralized, locally focused system of resource management that emerged in the Coast Salish world over several millennia to address pressures and demands on resources was similar to the modern community-based observing and response systems—described by Alessa et al. (2015, 2016). In these practices, local knowledge of ecological conditions and variation is compiled, and these data mobilized to guide decisions and policy to promote sustainability.

In the Salish Sea, many marine resources now threatened by a combination of overexploitation and habitat degradation have been managed sustainably in the past by local groups using a decentralized system of ownership (Lepofsky et al. 2015; McKechnie et al. 2014). Both community-based observing and the Coast Salish approach to managing such resources differ markedly from current approaches in modern nations states, where centralized, hierarchical and often distantly located management structures make decisions and implement (often technology driven) policy solutions. The nation-state agencies that now manage these same Salish Sea fisheries are less connected to local ecologies and use hierarchical bureaucracies to construct policy and make decisions, seemingly in the absence of local knowledge.

Community-based observing, and the deep time-vetted strategy of decentralized management highlighted by the Coast Salish case study, highlights the possibilities for more decentralized mechanisms for engaging and managing ecologies and fostering sustainability (Kliskey et al. 2016, Virapongse et al. 2016). Institutional change toward more "on the ground" community-based data collection and control is a step toward that goal (Valdivia et al. 2010). Community-based observing therefore provides a mechanism and model for monitoring ecological change; these networks connect modern research methodologies with traditional practices (Alessa et al. 2015, 2016). This type of approach is also akin to several of the characteristics of enduring common property systems (Ostrom 2015), including collective choice arrangements and adaptive trade-offs.

Conclusions

The key import of using paleodata, in our view, comes through extracting knowledge and lessons from the past about the consequences of decisions that were made in the face of changing social and ecological circumstances. Inferring whether specific strategies promoted successful adaptation, and identifying the factors that contribute to adaptive capacity and sustainability in human and ecological systems, is critical. This paves the way for re-implementing some long-standing approaches to sustainability that are not readily visible without paleodata.

From this starting point, we see two main arenas of research emerging. First, an expanded study of paleodata provides an opportunity to investigate how human societies have successfully adapted over a longer frame of time and in a diverse set of contexts. What attributes made societies able to accommodate changes, both externally in the natural environment and in the social environment? Such factors can be extracted as generalizable relationships so that past adaptation successes can inform modern policy- and decision-making (Nelson et al. 2016; Sandweiss and Kelley 2012; Westley et al. 2011).

Climate impacts are both expressed and mediated through ecologies and are routinely addressed through technological and social processes. In this respect, it is also important to recognize that climate impacts are relevant because they have specific, demonstrable consequences for human well-being, as when ecological deterioration degrades food production potential.

To conclude, we argue that humans have made decisions and implemented new practices in the past in ways that may appear dissimilar to our modern context, but which can be adopted to inform policy and meet our own sustainability challenges. Recognition that adaptive trade-offs are local and constant, despite pan-regional and even global changes in climate and ecological conditions, will foster more dynamic solutions to issues of future sustainability and adaptive capacity.

Acknowledgements The authors are grateful for funding that supported this research from: the National Science Foundation for awards DEB 1231233 (Mountain SEON), OIA 1301792 (Idaho MILES), ARC 1355238 (CONAS), and PLR 1642847 (EyesNorth RCN), and; the University of Idaho in support of the Center for Resilient Communities. Funding awarded to Grier by the Research Institute for Humanity and Nature, Kyoto, Japan (Small-scale Economies Project, Dr. Junko Habu, PI), also greatly facilitated this study. The views expressed here do not necessarily represent those of the funding agencies. Jim Savelle and Jake Adams provided helpful comments and insights into the particulars of the Arctic case studies.

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