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A theory of regime change on the Texas Coastal Plain

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ABSTRACT

The adaptive cycle, a seminal component of resilience theory, is a powerful model that archaeologists use to understand the persistence and transformation of prehistoric societies. In this paper, we argue that resilience theory will have a more enduring explanatory role in archaeology if scholars can build on the initial insights of the adaptive cycle model and create more contextualized hypotheses of social-ecological change. By contextualized hypotheses we mean testable hypotheses that specify: (1) the form of the connections among people and ecological elements and how those connections change; and (2) the resilience-vulnerability tradeoffs associated with changes in the networks and institutions that link social and ecological processes. To develop such a contextualized hypothesis, we combine our knowledge of the prehistory of the Texas Coastal Plain (TCP), mathematical modeling, and the concept of panarchy to study why human societies successfully cope with the interrelated forces of globalization, population growth, and climate change, and, sometimes, fail to cope with these interrelated forces. Our hypothesis is that, in response to population growth, hunter-gatherers on the TCP created increasingly dense social networks that allowed individuals to maintain residual access to important sources of food. While this was a good strategy for individuals to maintain a reliable supply of food in a variable environment, increasingly elaborate social networks created a panarchy of reachable forager-resource systems. The panarchy of forager-resource systems on the TCP created a hidden fragility: The potential for the failure of resources in one system to cascade from system-to-system across the entire TCP. We propose that this occurred around 700 years BP, causing a 6000 year old ritual and mortuary complex to reorganize.

1. Introduction

The adaptive cycle model is a seminal component of resilience theory, and this model is applied by an increasing number of archaeologists to understand the complex trajectories of change documented among prehistoric societies (e.g., Bradtmöller et al., 2017; Marsh, 2016; Gronenborn et al., 2014; Rosen and Rivera-Collazo, 2012; Widlok et al., 2012; Zimmermann, 2012; Thompson and Turck, 2009; Nelson et al., 2006; Peeples et al., 2006). This research has the potential to link archaeology with broader research themes in the study of complex adaptive systems. Yet, the history of theory in archaeology is littered with concepts and models that practitioners initially find useful, but then abandon because, although initially stimulating, the concepts fail to generate testable hypotheses that advance research (e.g., cybernetics). A legitimate question is whether the adaptive cycle model is *initiating* a body of research that will continue to generate testable hypotheses that have an enduring impact on archaeological research and theory?

In this paper, we argue that the use of resilience theory in archaeology is at a critical juncture. The adaptive cycle model is stimulating and provides a general, cross-cultural framework to understand social-ecological change (Solich and Bradtmöller, 2017) but is ultimately too general to sustain long-term research agendas. We illustrate one way to build on the insights of the adaptive cycle model to develop more contextualized hypotheses that explain the persistence and transformation of human societies. By "contextualized hypotheses" we mean hypotheses that build upon the adaptive cycle model to specify: (1) what, how and why networks of people and ecological elements change and (2) resilience-vulnerability tradeoffs associated changes in the networks and institutions that connect social and ecological processes (see

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Fitzhugh et al., 2016 for a similar approach). To illustrate one such contextualized hypothesis, we propose an explanation for the growth and reorganization of a mortuary and land use complex on the Texas Costal Plain (TCP).

2. The benefits and limits of the adaptive cycle model

Resilience theory has entered the archaeological literature through the use of the adaptive cycle model (e.g., Bradtmöller et al., 2017; Gronenborn et al., 2014; Rosen and Rivera-Collazo, 2012; Thompson and Turck, 2009; Nelson et al., 2006; Peeples et al., 2006). The adaptive cycle describes a set of phases that systems go through, though not necessarily in a linear sequence: Growth, Conservation, Release and Reorganization (the classic Fig. 8 diagram illustrated by Bradtmöller et al., 2017). The phase names are descriptors of three dynamic properties of a system: the connectedness of entities, the potential of the system to process energy (capital) and the resilience of the system. The classic adaptive cycle model is defined by potential and connectedness in particular; with the conservation phase exhibiting a high degree of coherence (lots of connection between entities) and high potential (lots of capital). For example, in a mature patch of forest the plants and animals are more connected than in a patch that was just burned. Similarly, the mature patch of forest has more biomass and a higher rate of respiration than a patch that was recently burned. The power of this model is that it provides a ready made, general device for making sense of well described patterns in the archaeological record.

Over the last 10 years a critical mass of research has accumulated that uses analogical reasoning to relate the adaptive cycle model to the archaeological record (Gronenborn et al., 2014; Rosen and Rivera-Collazo, 2012; Thompson and Turck, 2009; Nelson et al., 2006; Peeples et al., 2006). When we say that archaeologists use analogical reasoning we mean that, in Wylie's (1985) terminology, researchers have developed relational analogies. A relational analogy is a comparison between a source, the adaptive cycle, and subject, patterns in the archaeological record that seeks to establish relevance. Relevance means that rather than simply saying archaeological phase *X* is equivalent to phase *Y* of the adaptive cycle, researchers have attempted to establish whether the dynamics described by the adaptive cycle model can also be inferred from patterns in the archaeological record. This body of work has been a productive intellectual step. Although analogical reasoning is maligned by some, analogical reasoning is the first step to applying theory developed in one context (the adaptive cycle was developed to describe the dynamics of ecosystems) to a new context (the archaeological record) (Hesse, 1966). Indeed, archaeologists have been leaders in identifying the benefits and limits of applying the adaptive cycle to human societies (Bradtmöller et al., 2017; Nelson et al., 2006).

2.1. Analogical reasoning and adaptive cycles in archaeology

This is not a review of each paper in the growing body of research that applies the adaptive cycle to the archaeological record (Bradtmöller et al., this issue provide an excellent synthesis). Rather, we review two studies that illustrate the analogical reasoning that often underlies the use of the adaptive cycle to interpret the archaeological record. The use of analogical reasoning is a productive research strategy up to a point, but the adaptive cycle is too general to be tested and rejected as an explanatory model—which was never the point. The model was proposed as a framework for organizing interdisciplinary research on issues of sustainability; a framework useful for building more specific models amenable to critical evaluation. Thus, the need for lower-level, more contextualized hypotheses to build upon insights afforded by the adaptive cycle model.

Working in the Southwest US in the Eastern Mimbres archaeological region in modern day New Mexico, Nelson et al. (2006) argue that the Mimbres culture area experienced a period of aggregated settlement coincident with a high degree of conformity in how potters made pottery (a famous style known as Mimbres Black-on-white). This period of aggregation ends around 1130 BCE, and the end of this period has been called a reorganization (Hegmon et al., 1999; Nelson, 1999). Reorganization in this case refers to how farmers used the landscape (Nelson, 1999), with families moving into small, dispersed hamlets, and, in some cases, remodeling “field houses” into more permanent residences after 1130 BCE. This Reorganization Period lasts from 1150 to the early 1200s BCE (Hegmon et al., 1999, pp. 147). Given the well developed archaeological systematics of a Mimbres Classic Phase and Reorganization Period, Nelson et al. (2006, pp. 410, 426) create a relational analogy between the adaptive cycle and the archaeological systematics in the Eastern Mimbres area. The Mimbres Classic, they assert, corresponds to the Conservation Phase of the adaptive cycle and the Reorganization Period to the Reorganization Phase of the adaptive cycle (Nelson et al., 2006, pp. 410). This initial analogy is based on the fact that the Mimbres system appears aggregated (and presumably has more capital) and was more connected (at least in terms of potters' conceptions of how to make decorated ceramics) during the Classic and less aggregated and connected during the Reorganization Period.

In Wylie's terms, if Nelson et al. (2006) had stopped here, they would have been creating a simple analogy with no basis for inferring that the causal dynamics that underlie the adaptive cycle were at work in the prehistoric Mimbres case. However, they go further in their reasoning to consider the relevance of the adaptive cycle. They do this by reasoning expectations for the archaeological record that should empirically distinguish the Conservation Phase (Mimbres Classic) from the Reorganization Phase (Mimbres Reorganization Period) of the adaptive cycle. For example, Nelson et al. (2006, pp. 411) state:

“RT [Resilience Theory] suggests that K-phase growth is often characterized by increasing investment in a limited number of strategies and sometimes hypercoherence. These developments limit the resilience of social institutions and the ecosystems of which they are a part and thus contribute to eventual release and reorganization (Redman, 2005). This perspective suggests that in the period prior to reorganization most house-holds would have been organized in the same way and most would have pursued a limited number of strategies; that is, there would have been little inter and intrahousehold diversity. In contrast, the consequent reorganization would have been characterized by a diversity of forms and relationships (Holling, 2001), contributing to a greater degree of flexibility” (brackets ours).

Nelson et al. (2006) conclude that diversity along three dimensions, household configuration, resource selection, and storage, was actually higher during the Mimbres Classic (by analogy the Conservation Phase) than the Reorganization Period (the Reorganization Phase). This work demonstrates both the power of the adaptive cycle model to create analogies and the limitation of the adaptive cycle: it is too general. For example, Nelson and colleagues expectation that as connectivity increases, diversity decreases is not supported by their data. One reason for this incongruence between expectation and data is that the *‘connectivity of what-to-what’ and ‘how connectivity changes’* are as important as the fact that connectivity increases or decreases (Scheffer et al., 2012). The Mimbres Classic may have seen a high degree of connectivity among potters sharing ideas about design, but not necessarily among agricultural land holding groups. Similarly, entities (potters) may become increasingly connected in a symmetrical manner, each interacting with more potters more frequently, or in an asymmetrical manner, with only one or two potters interacting with more potters and more frequently. The differences in how connectivity changes can have significant effects on the resilience of a system to social or ecological change (Scheffer et al., 2012).

In short, using the adaptive cycle as an analog for the prehistoric social-ecological systems in the Mimbres area was a first step in a research program. Subsequent work by the same authors has sought to contextualize how connectivity (social networks), mobility strategies, population size and the selection of different resources *interact* to generate shifting resilience and vulnerabilities to climate change and social movements (Nelson et al., 2016; Anderies and Hegmon, 2011; Hegmon et al., 2008).

Thompson and Turck (2009, pp. 268) use the adaptive cycle as a heuristic for understanding the archaeological record. Again, they equate phases of the adaptive cycle with well established patterns of settlement and material change in the archaeological systematics of the south Georgia Coast, USA. From earliest to most recent, the Georgia coast follows conventional archaeological systematics for the Eastern US: Late Archaic, Early Woodland, Middle Woodland, and Late Woodland. Thompson and Turck (2009) describe the Late Archaic as a period of time that experienced the Growth and Conservation Phases of the adaptive cycle, and the transition from Late Archaic to the Early Woodland Period in the archaeological systematics as the Release Phase of the adaptive cycle. The subsequent archaeological periods of the Middle and Late Woodland are analogous to the Reorganization and Growth Phases of the adaptive cycle (Thompson and Turck, 2009, pp. 268–273).

For example, during the Late Archaic foragers resided in locations along the coast that resulted in the accumulation of large shell and trash middens. Thompson and Turck (2009, pp. 268) plausibly infer that these archaeological signatures are consistent with lower residential mobility and more delayed return economic relationships. Their argument that the Late Archaic is the Conservation Phase of the adaptive cycle makes the additional assumptions that denser settlement, more continuous use of sites, etc. correspond to increases in connectivity between social and ecological units and higher potential or accumulation of social and ecological capital. In contrast to the Late Archaic, Early Woodland settlements along the coast no longer contain shell middens and are more ephemeral (Thompson and Turck, 2009, pp. 269–270). Thus, Thompson and Turck (2009, pp. 270) argue that there was a reorganization in land use and the Early Woodland corresponds to the Reorganization Phase of the adaptive cycle. They further argue that a rapid decline in sea level triggered the reorganization. Their assumption is that the higher connectivity and potential during the Conservation Phase lead to a loss of resilience and, thus, a decline in sea level shocked the system into a reorganization because of a lost capacity to absorb the shock (Thompson and Turck, 2009, pp. 270).

This application of the adaptive cycle is productive; it allows us to observe that context matters. Thompson and Turck (2009) assert that the rapid decline in sea level triggered the Early Woodland reorganization of hunter-gatherer economies. This is a starting point for specifying relationships between the forms of connectivity created by hunter-gatherers, the local resilience of resources to harvest pressure on the Georgia Coast and the effects of sea level decline on various resources. One cannot assume that sea level decline is automatically a shock to hunter-gatherer societies. To evaluate Thompson and Truck's (2009) proposition, one must show how the resilience of hunter-gatherer social-ecological systems is affected by different forms of increasing connectedness (e.g., asymmetrical social networks vs. symmetrical), and how the resilience and vulnerability of forager-resource systems changes in response to changes in the climate and demography of populations.

In sum, the adaptive cycle model is a useful heuristic for understanding well established archaeological patterns. This is a first step to apply resilience theory to archaeological questions. However, in order for resilience theory to have a more sustained impact on archaeological research, we argue that research must take another step, and build on the insights of the adaptive cycle to create more contextual theory. Contextual theory is simply a theory that explains how the three properties of a system (resilience, connectivity and potential) are related and determine whether a social-ecological system persists or transforms in a given context. The contextual theory is more specific, focuses on resilience-vulnerability tradeoffs and how forms of connectivity change. Thus, such a theory is amenable to further testing. In the following sections, we propose how changes in demography, the form of social networks, and land use strategies may have lead to shifting resilience and vulnerability in the ecological context of the TCP and, thus, social change.

3. Biogeography and archaeology of the TCP

The biogeography on the TCP provides the template upon which the evolution of human subsistence and social networks occurred. The ecological structure of the TCP lends itself to the development of a simple insurance market for human foragers. On the TCP, foragers could harvest food from three types of habitats (or production loci): Coastal, riverine, and terrestrial. These habitats were distributed within two biogeographical zones, a Coastal Zone and a Riverine-Savanna Zone. The Coastal Zone is a 50 km wide strip that includes estuaries, bays, barrier islands, coast lines, and river mouth production loci. The Riverine-Savanna Zone extends inland from the Coastal Zone to an elevation of about 60 m above sea-level. Below 60 m in elevation, the rivers of the TCP are more sinuous with wide floodplains, oxbow lakes and sloughs that contain both freshwater fish and shellfish, as well as terrestrial resources.

Based on ethnohistoric descriptions of the Karankawa Native Americans and archaeological research, Ricklis (2004, 1996), Hall (2000) and Campbell (1983) describe the seasonality of resource exploitation in the Coastal and Riverine-Savanna Zones. In the Coastal Zone, estuaries offer a variety of mollusks and fish, but key predictable resources are the redfish and black drum that spawn in the shallow bays in the fall and late winter. *Thus, the productivity of food in estuaries and bays peaks during the winter.* Riverine habitats on the TCP foster abundant freshwater resources, particularly spawning fish in the spring. Hall (2000, 1998) describes these riverine settings as natural catfish farms and emphasizes the abundant mast crop (e.g., pecans, acorns, walnuts) in the fall. The Spaniard Nuñez Cabeza de Vaca (1983) observed that in 1533–1534 the Native American group referred to as the Mariame moved along the lower Guadalupe River exploiting fish, pecans, deer, roots, and occasionally bison. In the summers, they traveled 100–200 km to harvest prickly pear (Campbell, 1983; Campbell and Campbell, 1981; Tomka et al., 2009). *Importantly, these inland habitats (riverine and terrestrial) peaked in productivity during the late spring, summer and early fall.*

Finally, at longer time-scales, the productivity of estuaries is affected by processes such as salinity, up-welling currents, and water temperature in the *Gulf of Mexico*, while terrestrial and freshwater resources are affected by changes in rainfall and temperature over the land. In other words, the controllers of the productivity in the Coastal and Riverine-Savanna biogeorgraphic zones are different and create heterogeneity in the availability of food across time-scales (i.e., seasons, years and decades).

3.1. TCP mortuary and land use patterns

For more than 6000 years, hunter-gatherers on the TCP developed and maintained cemeteries at which the dead were interred along with important ritual items such as shell pendants and stone pipes. The culture history of the TCP has been detailed by several excellent works (Ricklis, 2012, 2004; Hester, 1995). Though there is variation in the local sequences on the TCP, in general, TCP mortuary sites were first used in the Early Archaic period (8500–6000 BP) (Hard and Katzenberg, 2011; Ricklis, 2012), with continued use during the Middle Archaic period (6000–4000 BP). The highest number of components are recorded during the Late Archaic (4000–1150 BP) and Late Prehistoric I (1150–700 BP) (Ricklis, 2012, pp. 137–138). Based on regional syntheses, there are three major patterns documented in the TCP mortuary record.

First, all of the largest and the oldest mortuary locations on the TCP are in the Riverine-Savanna Zone (Fig. 1a). Human stable isotope data from the oldest documented cemeteries indicate that individuals buried between 7000 and 3000 years ago were getting food from both the Riverine-Savanna and Coastal Zones, using estuary, freshwater, and terrestrial habitats (Hard and Tuross, 2012; Hard and Katzenberg, 2011). This pattern is consistent with what one would expect if hunter-gatherers were using both zones to maintain a consistent supply of food, in spite of environmental change over seasons, years and decades. For example, the TCP experienced a series of climate changes from sea level rise (caused by glacial melt) and/or increased aridity throughout the Holocene. Punctuated periods of sea level rise disrupted the productivity of estuaries and bays with flooding and increased the salinity of estuaries. In turn, the increase in salinity impacted the food chain and disrupted the availability of coastal resources (Ricklis, 2012; Ricklis and Blum, 1997; Ricklis and Weinstein, 2005). Rapid sea level rise occurred in the region between 7900 and 7500 calibrated years before the present and again from 6800 to 5900, followed by slow rise, with modern sea-levels attained by 3000 BP (Anderson et al., 2014; Ricklis, 2012; Ricklis and Blum, 1997). Paleoenvironmental sequences for the region suggest relatively moist conditions prior to 7000 BP (Nordt et al., 1994) as moisture from the *Gulf of Mexico* brought a summer monsoon pattern of rainfall farther east than modern conditions (Barron et al., 2012). A dry period ensued from 6500 to 4500 BP, with peak aridity ca. 5800 BP (Nordt et al., 1994; Ricklis, 2012). Moisture increased, although conditions remained highly variable following 4500 BP (Ricklis, 2012). The use of both Riverine-Savanna and Coastal resources by individuals interred at sites such as 41VT1 suggests that hunter-gatherers responded to declines in the productivity of estuaries due to sea level rise or declines in the productivity of terrestrial and fresh water resources, due to aridity, by shifting where they resided on the landscape to cope with long-term fluctuations in the productivity of resources in distinct biogeographic zones (Ricklis, 2012; Ricklis and Blum, 1997; Ricklis and Weinstein, 2005).

Second, the available evidence points to increasingly settled

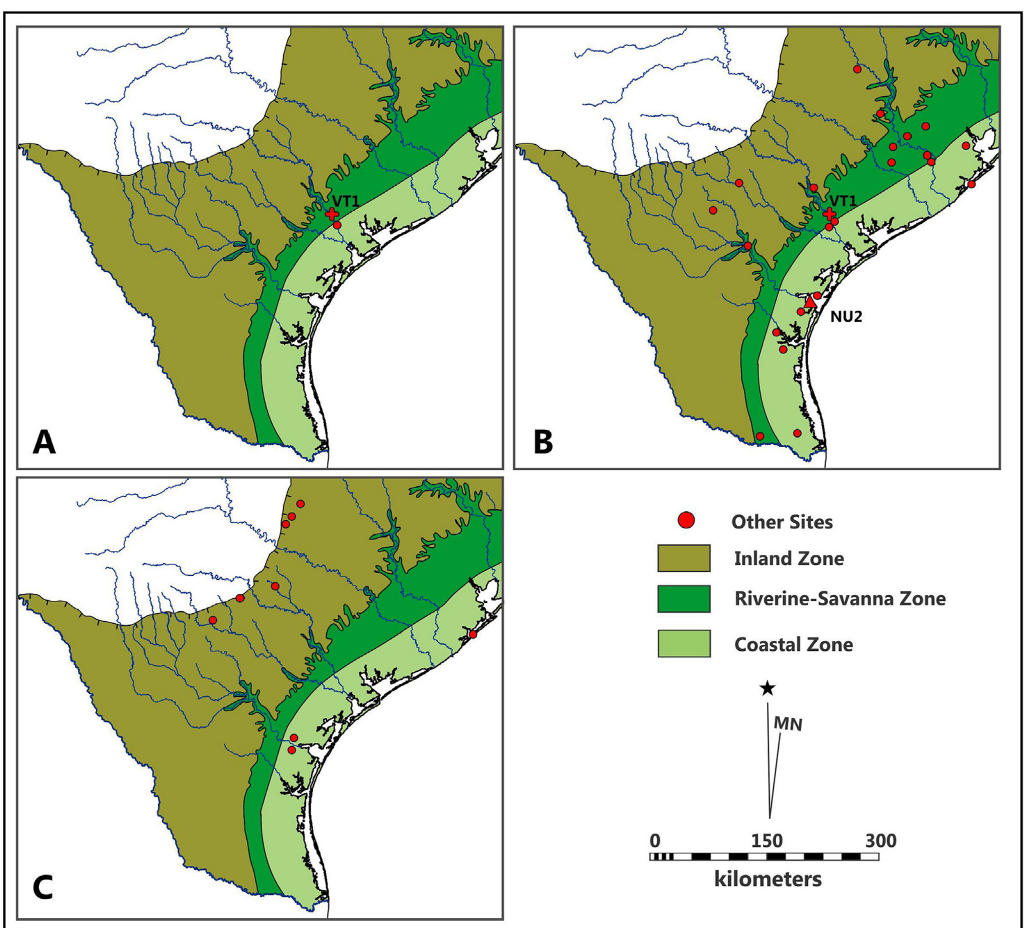

Fig. 1. Cemetery locations by time period and biogeographic zones on the TCP. Map a—mortuary sites that date from 7000 to 3000 cal. BP; map b—mortuary sites that date from 2999 to 701 cal. BP; map c—mortuary sites that date to younger 700 cal. BP.

populations and more hardened conceptions of territorial ownership on the TCP between 3000 and 700 BP (Ricklis, 2012; Hall, 1998, 1995; Story, 1985; Hester, 1981). Indeed, archaeologists working on the TCP argue that the proliferation of mortuary locations is a mark of territorial behavior (e.g., Hard and Katzenberg, 2011; Perttula, 2001; Taylor, 1998; Hall, 1995, 1981; Huebner and Comuzzie, 1993; Hester, 1981, 1969). Between 3000 and 800, sea level reached its modern level, and barrier islands along the coast were in place allowing estuarine ecosystems to become highly productive. Moisture levels also increased allowing terrestrial and riverine productivity to increase. During this period, the number of cemeteries on the TCP proliferated, peaking at about 1000–800 years ago (Ricklis, 2012) (Fig. 1b). Human bone isotope evidence from individuals interred in TCP cemeteries indicates that after 3000 years ago, the average lifetime diet of individuals became more specialized (Hard and Katzenberg, 2011; Mauldin et al., 2013), concentrating on resources within particular biogeographic zones.

For instance, individuals began to specialize their diet on either freshwater fish in the Riverine-Savanna Zone, complimented by terrestrial foods such as acorns, and individuals began to specialize on marine fish and shellfish in the Coastal Zone. This trend of increasing specialization is exemplified at two mortuary sites. At the longest used cemetery on the TCP, 41VT1 (VT1 for short), after 3000 years ago, the diet of individuals became heavily biased toward freshwater fish, nuts, and cactus (Hard and Katzenberg, 2011). The VT1 cemetery is 30 km from the coast (Fig. 1b)! At a large cemetery site called 41NU2 near Corpus Christi, Texas, most individuals were interred around 1000 years ago. Stable isotope data indicate that these individuals' mean diets were heavily biased toward marine fish and shellfish rather than freshwater resources (Hard and Katzenberg, 2011). Individuals interred at this site lived less than 30 km from productive freshwater fishing locations (Hard and Katzenberg, 2011) (Fig. 1b)! These distances are trivial when one considers that the median distance moved per year is nearly 200 km among contemporary hunter-gatherers (Binford, 2001; Kelly, 2013).

Coincident with specialization on resources within well-defined biogeographic zones, TCP mortuary sites document an increase in the exchange of ritual and ceremonial items among burial populations (Ricklis, 2012; Perttula, 2001; Hester, 1981). Between 3000 and 1000 years ago, individuals buried in cemeteries within the Coastal and Riverine-Savanna Zones were exchanging shell pendants, stone pipes, engraved bone, and shell beads, among other things (Ricklis, 2012; Perttula, 2001; Hester, 1981). Moreover, based on a visual inspection of the presence and absence of grave goods and burial positions (e.g., flexed, semi-flexed), Fig. 2 illustrates that grave goods and burial patterns are more similar within river valleys (Ricklis, 2012, pp. 141). For example, Ricklis (2012) notes that both along the coast and inland cemeteries along the Rio Grande (Area 5 in Fig. 2) had abundant bone beads and olive-shell beads and tinklers. Conversely, along the Nueces River, stone pipes and conch shells dominated the burial goods assemblages of both coastal and inland cemeteries. These patterns are suggestive that *individuals were developing social relationships that would allow them to maintain access to complimentary resources, even if that access was only called upon relatively infrequently (e.g., a couple of times a decade)*. This would make sense because the productivity of estuaries and river valleys are controlled by different biophysical processes that are unlikely to cause resource failures simultaneously, holding all else equal. However, a formal network analysis has not been conducted (see below).

Finally, about 700 BP, the regional mortuary complex reorganized. Why this occurs is unknown and debated. The reorganization of the regional mortuary complex is coincident with the beginning of the Toyah Phase. During the Toyah Phase, mortuary locations decreased from dozens to a mere handful of locations on Galveston Bay and deep in the interior of Texas (Fig. 1c). Cemeteries in the Riverine-Savanna Zone were abandoned. Further, there is potential evidence of a drop in population after 700 BP. This evidence is a drop in the frequency of recovered radiocarbon dates, and a shift in the diets of individuals buried on Galveston Bay that looks like the dietary patterns of people who lived around 4000 BP, suggesting a breakdown in territorial restriction (Hard and Katzenberg, 2011; Mauldin et al., 2013). During this time of reorganization, migrating foragers may have moved into Central and South Texas, bringing the key technological traits of the Toyah Phase (beveled knifes, blade technology and bone-tempered pottery), displacing local groups (Prewitt, 1985), or the changes may simply represent the spread of a technology among local groups on the TCP (Black, 1986; for a review see Kenmotsu and Boyd, 2012). Regardless of whether this new archaeological complex represents a migration of people or diffusion of technology, there is clearly a reorganization of how hunter-gatherers used the TCP at this time.

The decline of the mortuary complex is also coincident with a climate change, in particular, an increase in the variation of annual rainfall. Tree-ring chronologies indicate much higher fluctuations in rainfall after 700 BP (Mauldin et al., 2012). In fact, North America experienced two megadroughts from 731 to 703 BP and 677–650 BP that impacted populations in western and eastern North America (Cook et al., 2016; Benson et al., 2007; Stahle et al., 2007) and, presumably, the study region. Periods of drought and rainfall variability, by implication, created more uncertainty in the productivity of terrestrial foods. Long-term declines in moisture may have reduced the productivity of river valley resources, including both terrestrial and freshwater resources. However, the cemeteries on the TCP were focal points of ritual and land use over millennia that saw many severe changes in climate. Why would the climate changes of the 13th-14th century potentially trigger major social reorganization and not earlier climatic changes? We hypothesize that the answer lies in the evolution of territorial strategies and exchange networks in response to population growth. This trajectory of social change may have set forager-resource systems up, so to speak, for cascades of resource failure and precipitated rapid social change.

4. Our hypothesis

Our goal is to develop a hypothesis that explains the three major patterns identified above: (1) the development of territorial restriction in conjunction with the expansion of mortuary locations on the TCP; (2) increased investment in exchange relationships; and (3) the reorganization of the TCP mortuary and land use system. Our hypothesis combines a consumer-resource model know as the Gordon-Schaefer model developed in resource economics (Clark, 1976; Gordon, 1954; Schaefer, 1957) with the concept of panarchy drawn from resilience thinking. We first outline our hypothesis and then detail the logic of the hypothesis, explicating the importance of panarchy and resilience for understanding social change on the TCP. Finally, we outline research questions useful for testing our hypothesis.

In sum: 7000 years ago societies on the TCP were modular groups of human foragers with a land use and ritual pattern focused around one of a few major cemeteries. These cemetery locations were major nodes in a regional social network that were only weakly tied together by the exchange of information and mates. This modular organization was resilient to episodes of climate change and sea level rise over a 4000 year period because individuals had low cost access to complimentary resources in coastal estuaries and inland along river valley bottoms (Hard and Katzenberg, 2011; Ricklis, 2012). However, 3000 years ago the

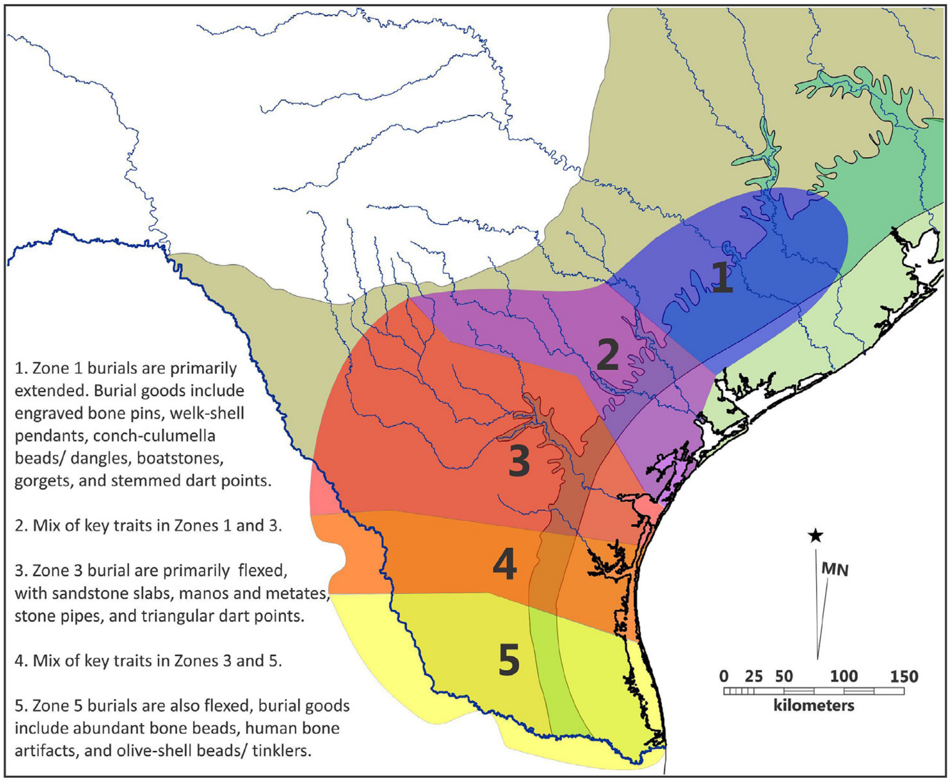

Fig. 2. Regions of shared burial traits over resource zones on the TCP after Ricklis (2012, pp. 141).

climate improved, sea level stabilized, and population growth spiked. Current evidence (see above) suggests that human foragers coped with this spike in competition by developing territorial systems around major cemetery locations and invested in social networks that increasingly became essential for individuals to maintain access to complimentary resources in river valleys and coastal estuaries.

We propose that between 3000 and 700 BP populations in distinct biogeographic zones on the TCP created increasingly connected forager-resource systems as regional "insurance markets" developed to accommodate the risks associated with territorial restriction and periodic failures of distinct resource bases. By forager-resource system we mean that humans and the resources that they exploit are coupled in a feedback of harvest decisions on a resource base and the state of the resource base on the future decision making of individuals. An increased investment in social networks, in response to population growth, would have allowed individuals to maintain residual rights to complimentary resources and off-set risk, but the networks, we propose, lead to a hidden vulnerability at the level of the entire regional system: The ever closer coupling of forager-resource systems, across levels of organization, and the potential for sudden cascades of social change. The cascades of social change occurred around 700 BP and hunter-gatherer social-ecological relationships reorganized on the TCP.

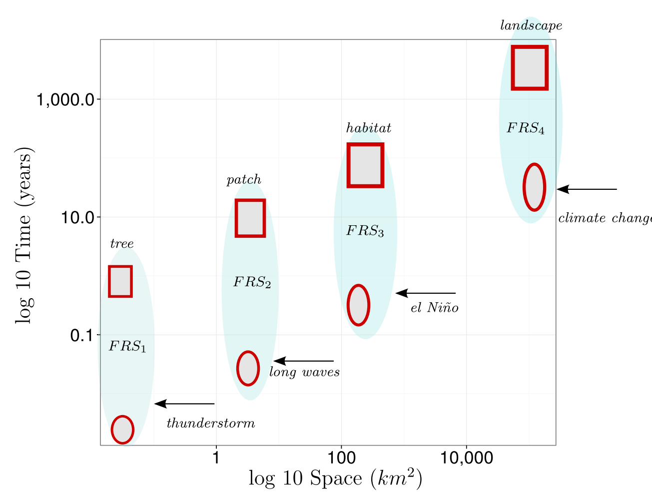

Fig. 3. Nested hierarchy of ecosystems, decisions and forager-resource systems after Peterson et al. (1998). The rectangles are ecosystem structures. The circles are decisions associated with each ecosystem structure. The blue shaded ovals represent forager-resource systems (FRS) operating at different scales of space and time. The arrows illustrate the kinds of disturbances that hit a FRS. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.1. *Panarchy*

Panarchy is the idea that social-ecological systems are nested over scales of space and time (known as a nested hierarchy) *and* that these nested systems are connected by processes that cross-cut levels of organization (Holling and Gunderson, 2002, pp. 75). For example, Fig. 3 illustrates an abstract, nested hierarchy of forager-resource systems. The log 10 of space defines the x-axis and the log 10 of time defines the y-axis. The rectangles are levels of ecological organization that foragers can use/modify. Moving from left-to-right on the graph, at a scale of a few square meters we find individual plants. At the scale of tens of square kilometers we find patches composed of many non-human organisms. And so on up the space-time hierarchy we find habitats, which are collections of patches, and landscapes, which are collections of habitats.

This hierarchy of ecosystem structures is a core framework of ecological theory (Odum and Barrett, 2002; Orians, 1980). The thing that makes the concept of panarchy distinct from a simple nested hierarchy is the textual discontinuity hypothesis (TDH) (Holling and Gunderson, 2002; Holling, 1992). The TDH proposes that the composition of ecosystems is controlled by three to five variables that operate at distinct scales of space and time, which leads to what Holling calls the entrainment of ecological communities into distinct levels of organization. Systems at larger and slower levels of organization constrain the dynamics of systems at smaller and faster levels. The entrained systems at lower levels change faster than systems at higher levels and provide experiments that are critical for the whole panarchy to continue to evolve (see also Cascalheira et al., 2017). The importance of this view of nature for our discussion is that the panarchy defines a biophysical template upon which human foragers make decisions. This is not to say that foragers don't effect the template, they do. Our emphasis here is on the decision hierarchy that foragers face as a consequence of ecological entrainment and the formation of a panarchy.

The ovals on Fig. 3 represent the scale of space and time at which human foragers make decisions. Again, moving from left-to-right, in forager-resource system #1 (FRS_1), individual foragers must simply make a food choice. That is, which blackberry do I pick? In FRS_2, foragers must make a patch choice. That is, which resource do I target today, blackberries or wild onions? Moving up the hierarchy foragers must make habitat choices about where to locate their residences this month and landscape choices about where to locate a series of residences this year. To make this a bit more concrete, consider the following example. By interviewing elderly informants, Binford (1983, pp. 380–381) elicited the different scales of space and time over which Nunamuit foragers made decisions about foraging and residence. Binford describes a nested set of foraging units that scale in space and time: the foraging radius, the logistical radius, annual territory and life-time territory. The foraging radii and logistical radii compose the annual range and foragers move between such units over weeks to months. The lifetime range is the sum of all annual ranges that foragers use and, at least in this case, informants expected to cycle through 4.5 annual ranges over a period of 45 years. In this example, the annual range decision corresponds to FRS_4. Foragers use a landscape (ecological structure) that changes over 100s-to-1000s of years, while their foraging decisions about which section of a landscape to use changes at the time scale of a decade.

Binford's description of the Nunamuit provides a nice point of departure because the system he describes is one in which the foragers would have been highly mobile over all levels of the forager-resource system panarchy. The level of mobility over the levels of the panarchy is obviously something that varies from forager society-to-society. Among the Southern Pomo of modern day California, for example, the annual range was synonymous with the life-time range of foragers (Gifford, 1923). The key point, as Holling (1992) notes, is that the panarchical structure of human-resource systems provides a template on which human foragers build their strategies for finding food, mates or esoteric knowledge. The panarchy template provides a starting point for understanding how the adjustment of foraging strategies leads to shifting resilience and vulnerability when individuals are confronted by environmental change.

4.2. The resilience and vulnerability of a forager-resource system

Resilience-vulnerability tradeoffs are common in social-ecological systems. For instance, building an irrigation system may make the production of crops more resilient to annual variations in rainfall but also more vulnerable to large floods that occur at the time-scale of decades that wipe out the irrigation infrastructure (Anderies, 2006). Our hypothesis for the increase in territoriality on the prehistoric TCP and eventual reorganization of the territorial and mortuary system rests on understanding resilience-vulnerability tradeoffs in forager-resource systems within the context of the panarchy framework.

One way to identify resilience-vulnerability tradeoffs is by studying non-linear dynamical systems models of social-ecological systems (Scheffer and Carpenter, 2003). Freeman and Anderies (2012) have built such a model to study the process of land use intensification in a forager-resource system. The model is scaled to the level of the habitat (i.e., FSR_3 in Fig. 3) and illustrates an important resilience-vulnerability tradeoff. When population density increases, foragers make their supply of food more resilient by simply working a bit harder (intensification). This is effective in the short-run, but creates a novel vulnerability: foragers may unexpectedly end up in a degraded ecosystem.

Fig. 4 summarizes the long-run dynamics of the model (Freeman and Anderies, 2015, 2012; Freeman, 2014). This figure is known as a bifurcation plot. The plot illustrates how variation in a parameter (in this case population density) changes the global structure of a non-linear dynamical system. In the model summarized by Fig. 4, there are two long-run, stable harvest states or attractors that foragers can occupy: A high productivity state and a degraded state where individuals just maintain biological function (a kin to a “poverty trap”). These states emerge from the reciprocal interaction of individual behaviors and the structure of a resource base.

Population density ‘controls’ the structure of the system (Freeman and Anderies, 2012). Moving from left-to-right, Fig. 4 illustrates that at low population densities, the forager-resource system has one stable harvest attractor. As population density increases, modeled foragers invest more of their time budget in the harvest of resources, at equilibrium, to obtain their desired level of food, and the strategy of working harder to obtain more food is effective. Working harder to increase one's supply of food, however, decreases the resilience of the productive attractor and precipitates the emergence of a repellor and degraded attractor, also known as multiple stable states (see Fig. 5).

The concept of multiple stable states is a paradigm for explaining changes in ecological systems that are dichotomous and

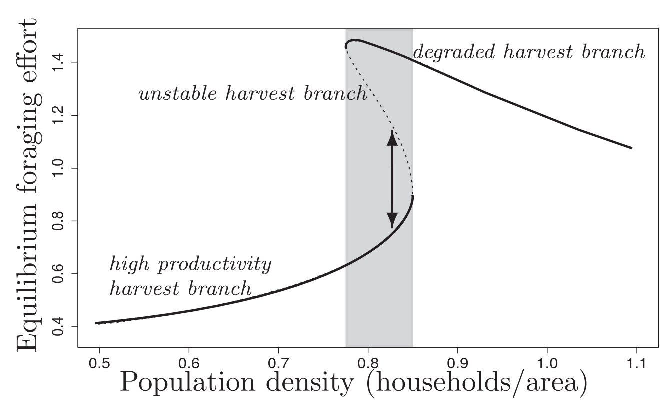

Fig. 4. Summary of model dynamics. The lower solid line represents all stable, long-run highly productive harvest states (i.e. low effort is required to meet energy needs) as a function of population density. The dashed middle line shows all unstable states. The top solid line shows all stable, long-run degraded harvest states (high effort is needed to just stay alive). The gray area is a “window of vulnerability” that defines the parameter space for which a perturbation can cause the system to flip between the productive and degraded harvest branches. See Scheffer (2009) for very readable background on how such plots are used to analyze dynamical systems models of social-ecological systems.

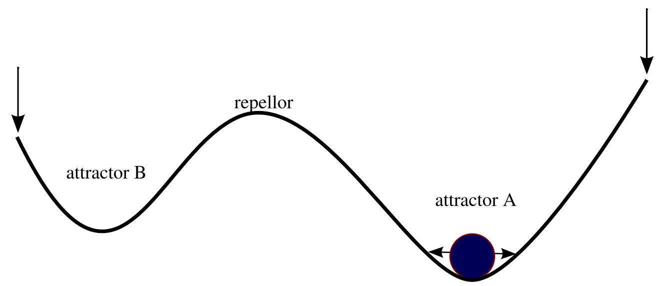

Fig. 5. An example stability landscape. The global structure of the system consists of two attractors and one repellor. The ball represents a particular moment in time at which a system could exist. The arrows pointing down on each end of the landscape are forces (e.g., population density) that can change the global structure of the system.

punctuated rather than smooth and continuous (e.g., Lever et al., 2014; Lade et al., 2013; Scheffer et al., 2012; Staver et al., 2011; May et al., 2008; Janssen et al., 2003; Anderies et al., 2002). When multiple attractors emerge, the resilience of the system becomes important. The resilience determines the risk of a so-called variance induced critical transition, which is when a shock can flip the system from one attractor to another.

For example, when population density enters a critical range, a "window of vulnerability" is generated (gray region in Fig. 4). In this window of vulnerability, environmental shocks, such as a drought, can reduce resource density, induce foragers to increase their harvest effort, which further reduces the density of resources and causes the system to rapidly "flip" into the degraded attractor. Fig. 5 provides a metaphor for these dynamics. Attractor A is the productive attractor. As long as a perturbation (immigration event or drought) does not shock biomass too hard, the system will remain in attractor A. However, if a perturbation hits the system too hard, foragers may suddenly flip into attractor B. The emergence of multiple stable states means that a transition from the productive to degraded attractor can be punctuated (i.e., occur much more rapidly than a model without multiple stable states would permit) and difficult for individuals to anticipate because of the uncertainty generated by the feedback between past foraging decisions and the current state of a resource base (Freeman and Anderies, 2012, pp. 431).

When foragers occupy a system that has multiple stable states, they face a commons dilemma. A commons dilemma occurs when it is in the short-run interest of every forager to increase their harvest effort, for example, in response to a drought, but doing so means that everyone experiences a cost (flipping into the degraded state). As noted above, such a transition may be difficult to anticipate. When it is difficult to anticipate such a transition, the ability to know where other foragers are located on the landscape is paramount because those foragers are a potential perturbation, which may generate a critical transition from the productive to the degraded state.

Our argument is that the emergence of common pool resource dilemmas stresses the ability of foragers to update their information about the state of resources in an environment (Freeman and Anderies, 2015). In such an ecological setting, individuals either continue to harvest resources in an uncoordinated manner and risk experiencing a "tragedy of the commons" or cooperate to manage the pressure on various resource locations limiting who, when and where resources may be harvested via investment in ownership. The cooperation option requires individuals to reduce the number of levels of the panarchy that they use and become less mobile, but it also decreases the amount of effort that individuals must invest in the collection of information and increases the reliability of the information that individuals have on the location of others. Although it is costly to develop and maintain ownership rules, such rules decrease the complexity of information that individuals must collect and interpret to reliably plan how to use a landscape and avoid the fitness costs associated with a tragedy of the commons.

For example, Hitchcock and Ebert (2006, 146–147) tell us:

> "prior to the seasonal breakup of hunter-gatherer groups, the localities to be occupied by various family units were surveyed. The resources available in the area to which people might move were assessed carefully, as were the current states of occupancy, use and sentiments about resource sharing among groups that had rights to that area. Once this process was complete, the relative advantages and disadvantages of the alternative places were exhaustively discussed prior to reaching a consensus on what options should be perused."

Sharing accurate information is not a trivial matter. In a mobile hunting and gathering society, mistakes that result in the transmission of faulty or irrelevant information may not be seen as a mistake at all but, rather, a lie. In his study of mobile, high latitude foragers Brody (1981, 175) observes,

> "among the Inuit, Beaver, and many other hunting peoples there is a great hostility towards any unreliability about resource harvesting activities. It is striking that in some hunting peoples' languages there is no clear distinction between making an error in judgment and telling a lie. In a society where information about the land and its animals can make the difference between life and death, there cannot be much tolerance for errors of judgment."

In sum, the loss of resilience in many habitat-level forager-resource systems has the consequence of making it difficult to plan how to use a landscape because habitat-level systems may flip from one state to another. The development of territoriality reduces the risk of flipping and allows foragers to plan how they will use a landscape with more certainty.

4.3. *Putting the pieces together: social change on the TCP*

The adaptive cycle model places emphasis on the effects of increasing connectivity and energy potential (capital) on the resilience of a system or nested systems within a panarchy. Rather than use the adaptive cycle as an general analog for complex adaptive systems, we have begun to develop a more contextualized theory of regime change relevant to forager-resource systems on the TCP. One of the main differences between our contextual approach and the adaptive cycle is that our theory focuses on resilience–vulnerability tradeoffs associated with different strategies for obtaining food, given the biophysical template of the TCP. Our hypothesis can be thought of as a set of resilience–vulnerability tradeoffs that shifted over time on the TCP.

1. From 7000 to 3000 BP foragers on the TCP moved seasonally between Coastal and Riverine-Savanna resource zones. This strategy was resilient to seasonal changes in the productivity of food in the different zones. But this strategy was vulnerable to increases in population density that could make the transmission of information less reliable and the ability of foragers to plan a sequence of residential moves more difficult.
2. From 3000 BP to about 700 BP population growth and, as a consequence, increases in population density, lead to the emergence of multiple stable states and the emergence of common pool resource dilemmas where none had existed

previously in many habitat-level forager-resource systems. Under these novel conditions, foragers who began to maintain residences on highly productive resource locales also made their supply of food resilient to errors in judgment about how to sequence residential moves and the time costs of moving to locations that do not have the resources that one expects. However, while residential stability and territoriality may have made foragers resilient to uncertainty generated by foragers moving around in an uncoordinated manner on the landscape, territoriality would have made foragers more vulnerable to local resource shortfalls caused by seasonality and climate variability. Thus, it was in the self-interest of individuals to invest in social networks that allowed them to maintain residual rights of access to resources in alternative biogeographic zones.

3. Our proposition is that the establishment of denser social networks by individuals to maintain residual access to alternative resource zones created ever more tightly coupled forager-resource systems, and, thus, the potential for the dynamics of one habitat-level forager-resource system to cascade from system-to-system across the entire TCP. Succinctly, the development of an insurance market to "share risk" among individuals led to a situation in which forager-resource systems became increasingly connected into a ridged panarchy of nested systems. The exchange of ritual and symbolic items to establish residual rights to territories and "share risk" is documented among modern hunter-gatherer groups. For example, Wiessner (1983) documents how San hunter-gatherers who "share risk" also engage in the exchange of symbolically important arrows. In addition to the ritual exchange of goods, hunter-gatherers often establish reciprocal access to alternative territories through the exchange of mates and marriage alliances (e.g., Hart and Pilling, 1965). These social connections on the TCP helped individuals maintain a robust supply of food but made the whole set of linked systems on the TCP vulnerable to cascades of regime flips due to the emergence of multiple stable states (as described above).

When the climate changed around 700 years ago, forager-resource systems experienced cascades of critical transitions to a degraded harvest attractor and individuals could no longer maintain a robust supply of food. First, groups whose diet focused on terrestrial resources experienced the critical transition to the degraded attractor; these folks called upon social connections to gain access to alternative territories, inadvertently causing a cascade of flips across the TCP. In response, many foragers simply departed from the existing system of institutions and the mortuary system ceased, especially in the Riverine-Savanna Zone.

4.4. Predictions for testing the hypothesis

The concept of panarchy assumes that forager-resource systems at the habitat scale are equally reachable. This means that systems are equally connected to each other and a flip in one habitat scale system has the potential to cascade to every other system. This is a strong assumption because social networks can have very different topologies (Chen, 2014; Bodin and Crona, 2009; De Weerdt and Dercon, 2006; Janssen et al., 2006). Two fundamental questions, then, are: How did the topology of social networks on the TCP evolve over time, and did the topology evolve in such a way that the dynamics of habitat scale forager-resource systems became increasingly reachable? Fig. 6 illustrates four ways that social networks on the TCP could have been organized.

We predict that between 7000 and 3000 BP networks looked like picture (a), a modular organization of social groups. Similarly, our hypothesis predicts that after 3000 BP social networks on the TCP began to look ever more like picture (d). In picture (d) all potential forager-resource systems on the TCP became interwoven in a complex, interlocking set of social relationships. This state could be analogized to the K phase of the adaptive cycle because connectedness would be high. However, social networks could have evolved on the TCP to look like pictures (b) and (c). If this were the case, our hypothesis would miss the mark. We can evaluate this prediction by conducting a formal network analysis—which has never been done on the TCP—of grave goods and aDNA. Archaeologists have explored similar ideas in farming societies using decorated ceramics as an indicator of social connections (e.g., Borck et al., 2015; Rautman, 1993). In the case of the TCP, we should see that grave goods become more similar over time, both within river valleys and across river valleys, as the number of mortuary sites increases. This would indicate increasingly connected and reachable forager-resource systems.

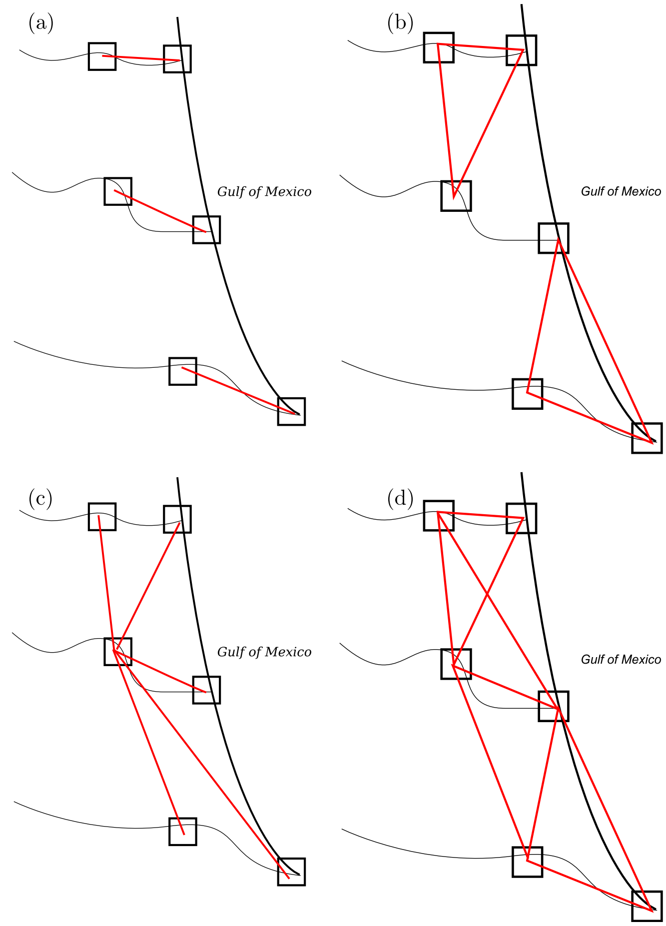

Fig. 6. Potential network structures on the TCP. The concept of Panarchy implicitly assumes picture (d).

Fig. 7 illustrates preliminary evidence that exchange networks on the central portion of the TCP cross-cut resource zones and river valleys (i.e., the networks look like Fig. 6d). Fig. 7 is an illustration of how we can begin to evaluate our network predictions. We developed this figure by constructing a similarity matrix for the presence and absence of burial items, such as beads, that may be reflective of exchange relationships (the data are available in the supplemental file and Ricklis, 2012, Table 5.3). Because this is a concept illustration based on preliminary data synthesis efforts, we have limited our data exploration to sites with Late Archaic and Late Prehistoric I components (though some sites have additional

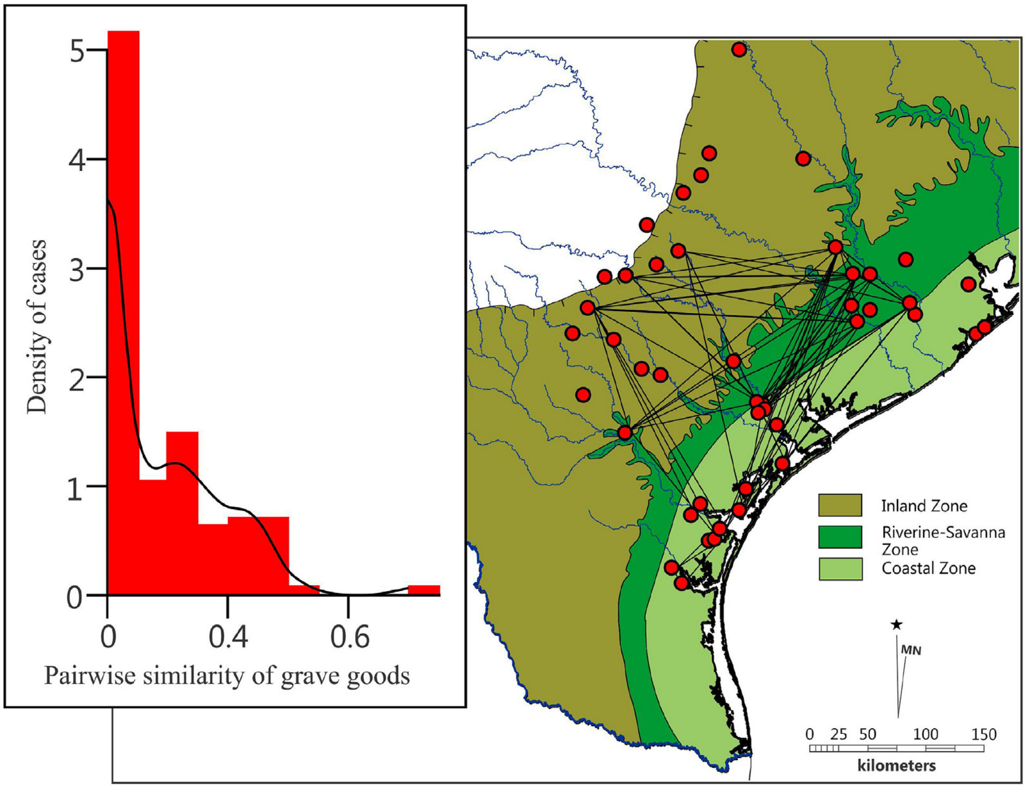

Fig. 7. Potential Late Archaic and Late Prehistoric I grave good exchange networks. The histogram displays the distribution of pairwise similarity scores for all sites in the sample.

components). We have used a grave goods similarity score of 0.33 or higher as evidence of a potential connection, in terms of exchange, between populations buried in particular cemeteries. This means that each site shares 1/3 or more of the same potential exchange goods. This type of analysis adds information on the pairwise similarities between sites that is not captured by Fig. 3. Moving forward, we plan to conduct an analysis with better temporal control and at the level of individuals, as well as sites; analyze normative traits like burial position in addition to exchangeable goods; develop a bigger sample of sites (e.g., including sites from along the Rio Grande); and calculate network statistics.

We also predict that population density increases after 3000 BP and declines coincident with the reorganization of the mortuary complex. This prediction follows from the logic of the forager-resource model presented above. Population density controls the resilience of a forager-resource system. In order for our hypothesis to be consistent with the data, we should observe that the summed probability distribution of radiocarbon dates signals increasing population density on the TCP in conjunction with the increasing similarity of grave goods noted above after 3000 BP.

Finally, we predict that warfare was minimal prior to the reorganization of the mortuary complex and evidence of warfare increases after the reorganization of the mortuary complex. This prediction follows from the logic of our hypothesis that social connections were made to maintain access to complimentary resource bases. We postulate territorial sharing akin to what Cashdan (1983) has called social boundary defense. However, we also postulate that a regime change takes place precisely because the social sharing of territories allows a bifurcation in one system to cascade from system-to-system. We suspect that the reorganization that followed was based more on territorial defense through violence, as observed in the ethnohistoric record of the TCP. Again, we can evaluate this by observing the frequency of individuals in the burial record who display traumatic injuries, such as skull fractures and embedded projectile points. We should simply see higher per capita evidence of violence after 700 BP relative to the period between 3000 and 700 BP.

5. Conclusion

We either learn from our ancestors or we face the challenges of a globalizing planet undergoing rapid population growth and climate change hamstrung by our ignorance of the past. Globalization is a process that creates networks of human economies, social systems and ecosystems, channeling the flow of people, resources, diseases and pollutants across the boundaries of ‘local’ systems to create a tightly connected ‘global’ system. As a consequence, the development of sound policy depends on our ability to understand the dynamics of human systems that become increasingly connected over time. Archaeology has a central role to play in understanding the causes and consequences of the combined roles of globalization and ecological change in the persistence and transformation of human societies. However, to fill this role archaeologists need interdisciplinary frameworks and theories that are useful for understanding the archaeological record but also are relevant beyond archaeology. Resilience thinking provides one such framework.

A seminal component of resilience theory is the adaptive cycle. To date, most archaeologists have used this model to create analogies between the phases of the adaptive cycle and established archaeological systematics. This has been a productive first step. Such studies demonstrate the usefulness of the adaptive cycle for organizing our thoughts and beginning to focus on connectivity, capital and resilience as dynamic properties of systems. However, the adaptive cycle is too general to ever be falsified in a Popperian sense. In order for resilience theory to have an enduring impact on archaeological theory, we argue that we must begin to move beyond analogical arguments that use the adaptive cycle as an interpretive device that gives meaning to the archaeological record. In this paper we have proposed one way to move forward. It will no doubt not be palatable to everyone. But we hope that our paper moves the discussion forward over the long-term role of resilience theory in archaeology and how to translate archaeological findings into knowledge that is meaningful across disciplines.

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