
Long-Term Vulnerability and Resilience: Three Examples from Archaeological Study in the Southwestern United States and Northern Mexico

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Events during the last several years—such as Hurricane Katrina, the earthquake in Haiti, the Southeast Asian tsunami, and continuing droughts in Africa—vividly illustrate the vulnerability of human society to environmental disturbances. That vulnerability lies in both the nature and magnitude of hazards in the environment and in the configurations (institutions, policies, practices) of human societies. We unintentionally play an essential role in creating our vulnerabilities. The concepts of resilience and vulnerability in coupled social-ecological systems have proved increasingly important for analyzing the human dimensions of environmental disturbance and change (Janssen and Ostrom 2006)—in the sense of this book, how people experience “hazards.” For example, strong earthquakes in some regions of the world result in limited human suffering and infrastructure costs, while in others they are massively devastating in human life and property loss. The same can be said for disease, hurricane damage, and other occurrences we think of as “natural hazards.” Human societies directly affect what a hazard is and how it is experienced.

In this chapter we illustrate the role analysis of archaeological data can play to inform our understanding of resilience and vulnerability in coupled social-ecological systems with a long-term view of the interaction between society and environment. Our research employs environmental and social information from six regions within the southwestern United States and northern

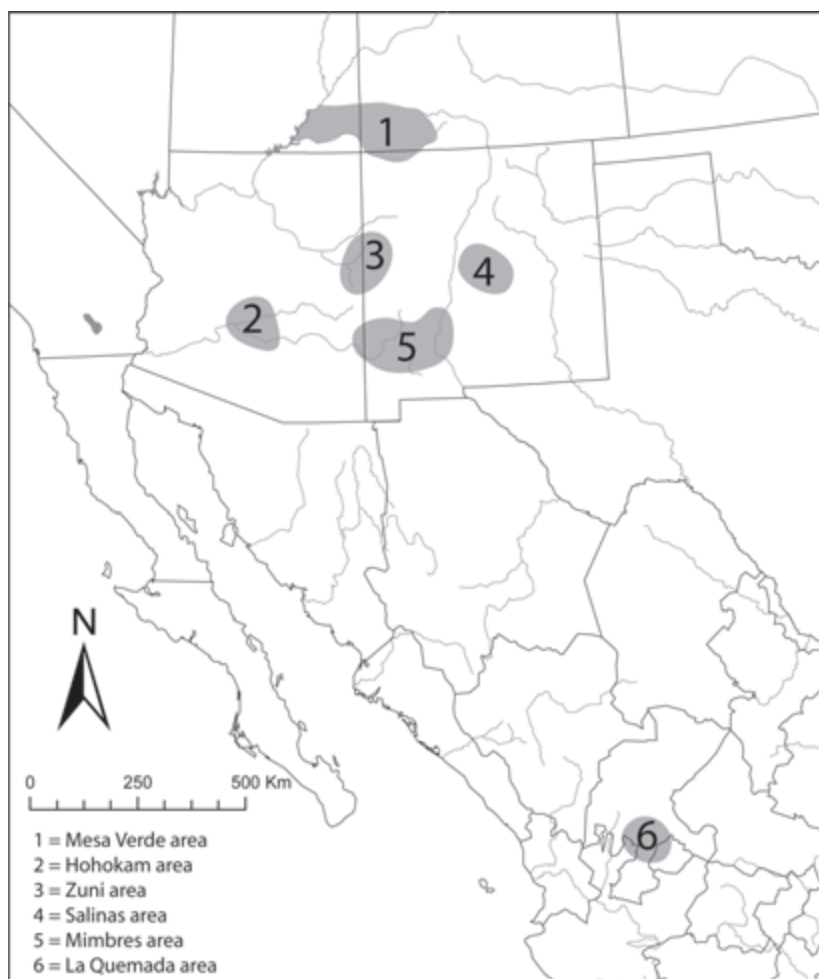
Mexico (figure 8.1) that collectively spans over a millennium. These examples address climate “hazards” directly, as well as the kinds of social pathways that can increase vulnerabilities to an array of conditions. It is the understanding of social and natural processes that can inform present decision-making, not the specific relationships evident in the past.

CHALLENGES: DEFINING AND MEASURING RESILIENCE, VULNERABILITY, AND HAZARD

If we are to assess the hazards, delineate vulnerabilities, and move toward resilient systems, one of the greatest challenges we face is to understand the dynamics of social-ecological systems. To do that requires not only an understanding of contemporary systems but also an appreciation of how dynamics play out over very long time spans. We need to understand short-term and long-term processes as well as the short- and long-term solutions for addressing the impacts of “hazards.” Our research addresses long time spans, focusing on vulnerabilities, resilience, and robustness. For this chapter we frame our work in terms of the experience of “hazards,” focusing on the social and environmental contributions to that experience.

Before exploring three examples of our work, we define the key concepts. *Resilience* is the ability of a system to absorb disturbances (such as those described as hazards) without losing identity (Folke 2006) or the capacity to absorb perturbations while maintaining essential structures and functions (Holling, Gunderson, and Peterson 2002). Similar to resilience, *robustness* highlights the ability of systems to withstand change through both flexibility and resistance. Our version of robustness incorporates many of the features of resilience but emphasizes the role social and physical infrastructure can play in fostering both flexibility and inertia in dynamic social-ecological systems (Anderies, Janssen, and Ostrom 2004). In general, *vulnerability* is a function of the exposure and sensitivity of a system to a hazard and the adaptive capacity or resilience of the system to cope, adapt, or recover from the effects of the hazard (Adger 2006: 269; Smit et al. 2001: 893–895; Smit and Wandel 2006: 286; Turner et al. 2003). There are many specific definitions of vulnerability (see Cutter 1996: 531–532 for a summary), but it is commonly understood as the “potential for loss” (ibid.: 529), the “capacity to be wounded” (Kates 1985: 17), or the “potential for negative outcomes or consequences” (Meyer et al. 1998: 239). More specifically, it is “the degree to which a system [such as a human-environment system], subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor” (Turner et al. 2003: 8074).

Scientific and policy forums on environmental change increasingly use a systems perspective to formulate policies that integrate the many dimensions



8.1. Map of the southwestern United States and northern Mexico showing the areas encompassed by the six cases. Map by Matthew A. Peeples.

of social-ecological systems (Adger 2006; Folke 2006; Janssen and Ostrom 2006; Janssen et al. 2006; Young et al. 2006). Resilience research explores multiple, open, interacting systems that move between states of stability and transformation (Holling 1973; Holling and Gunderson 2002). Vulnerability research, originating in geography and the study of natural hazards (Adger 2006), focuses on the attributes of people or groups that enable them to cope with the impact of disturbances.

Unfortunately, it is impossible to generate “absolute resilience or robustness” in social-ecological systems. Rather, we must ask, resilience of what to

what (Carpenter et al. 2001)? Any strategies humans deploy to cope with disturbances introduce fundamental tradeoffs. To develop effective coping strategies in a rapidly changing world, we must recognize that a decision to increase resilience in one dimension is likely to increase vulnerabilities in another (Anderies et al. 2007). In two of the examples described in this chapter, we address human vulnerability to climatic variability and change, specifically focused on precipitation and stream flow, and we explore tradeoffs. We contribute to an emerging literature that focuses on robustness-vulnerability tradeoffs to understand how social-ecological systems organize, cope with variation, and change (Anderies 2006; Anderies et al. 2007; Anderies, Walker, and Kinzig 2006; Janssen, Anderies, and Ostrom 2007). In the third example we specifically focus on how human social configurations can create conditions of vulnerability that influence the way people experience disturbances, climatic changes, and variability.

Following the theme of this book, we view low precipitation and variable precipitation conditions as potential “hazards” within the southwestern United States and northern Mexico to which people may be or may become vulnerable. *Hazards* can be thought of as “threats to a system and the consequences they produce” (Turner et al. 2003: 8074). We outline features of climate conditions in the southwestern United States and northern Mexico that may be potential hazards, and we explore the role of social configurations in creating hazards and preventing people from responding effectively.

ADVANTAGES OF A LONG-TERM PERSPECTIVE

We use data sequences that span millennium-long timescales in the southwestern United States and northern Mexico to assess how human societies and ecosystems interact. In this region of the world, low precipitation and variable precipitation are challenges or potential “hazards” for human occupation today and have been throughout human history. For farmers, the levels of precipitation in this region of the world are highly variable temporally and spatially and typically fall below the minimum needs of many domesticated crops (especially maize, the primary cultigen). The potential “hazards” of low precipitation and uncertain timing of precipitation can create conditions of famine whose timing can be uncertain. But the experience of potential hazards—whether they are realized and experienced as hazardous conditions—depends on a variety of social factors, from population size to the forms of physical infrastructure and social institutions. People address climatic challenges such as low and variable precipitation in various ways, from diversifying their use of resources and using a range of environmental settings, to building infrastructure (such as irrigation systems) to control the distribution of water, to settling in areas of high natural water table, which are rare (Spielmann et al. in press).

Sometimes humans build social systems that exacerbate rather than mitigate these potential “hazards” or that actually prevent people from responding to them effectively. In this chapter we examine three lessons to be learned from understanding long sequences of human-environment interaction. The first examines how diversity in food systems influences the vulnerability of human societies to food shortages as a result of low precipitation in this arid to semi-arid region. The second examines how irrigation infrastructure both mitigates variability in the temporal and spatial patterns of precipitation and creates new vulnerabilities. The third emphasizes the role of social action in creating conditions of rigidity that exacerbate the potential for climate “hazards” to impact people. These studies are published fully elsewhere (Anderies, Nelson, and Kinzig 2008; Hegmon et al. 2008; Nelson et al. 2010). All have applications to the way we think about hazards in today’s world, which we address in the final section of this chapter.

The archaeological cases we explore and compare in our studies are from the southwestern United States and northern Mexico. They include the Zuni area in northern New Mexico, the Salinas area in central New Mexico, the Mimbres area in southwestern New Mexico, the Mesa Verde area in the Four Corners of the southwestern United States, the Hohokam area in south-central Arizona, and the Malpaso Valley (occupation focused on the site of La Quemada) in Zacatecas, Mexico (figures 8.1, 8.2). All of these areas are in arid to semiarid settings* and, during the periods of study, are agriculturally based, non-state societies. They vary considerably in population size, social configurations, agricultural strategies, and social-environmental histories. Thus they provide a diverse set of cases, all situated in environmental settings that offer the same kinds of “hazards” of low and spatially unpredictable precipitation. In this chapter we discuss all except the Salinas case.

Although study of the past might appear divorced from contemporary concerns given globalization and the rapid technological change that characterize today’s world, archaeology provides a long-term, historically contextualized view of many social-ecological changes, some more dramatic than others (Redman and Kinzig 2003; van der Leeuw and Redman 2002). While the cases do not help us predict the future, they do provide natural experiments by which we can come to better understand relationships between vulnerabilities and change and examine assumptions used to make contemporary decisions about managing for change versus managing for stability. Furthermore, most of the cases we explore are what archaeologists refer to as middle-range societies—

* Average annual precipitation levels range from a low of about 200 mm (8") in the Hohokam area to a high of about 450 mm (18") in the higher portions of the Mesa Verde area.



8.2. Images that illustrate each case area. Compiled by Margaret Nelson.

they have weakly developed institutionalized hierarchies. In the contemporary world, millions of people who live in what are effectively non-state societies are faced with a variety of “hazards”—from those such as earthquakes, whose causes are purely environmental, to those that are largely social, which is to say generated by human interactions (e.g., ethnic strife), to those in which human actions have environmental consequences. Our research is relevant to those experiences.

CONTRIBUTION 1: DIVERSIFYING MAIZE-BASED SUBSISTENCE

The first example addresses the role of subsistence or dietary diversity in the capacity of systems to cope with climate “hazards” of low precipitation and variability in precipitation. This study is more fully developed in an article by John Anderies, Ben Nelson, and Ann Kinzig (2008).

The “common wisdom” or “rule of thumb” that diverse portfolios are advantageous in uncertain or variable environments is widespread. This strategy is certainly pervasive in today’s stock market, where investors are advised to maintain a diverse set of stocks or mutual funds. It is also what drives the propensity to establish trade relationships between and among cultural groups residing in different bioclimatic zones, both in the past and the present. For investments and exchange networks, the nature of the diversity matters in



8.3. Map of Mexico, with La Quemada indicated. Map by Will Russell.

addressing vulnerabilities—elements of a portfolio should have a somewhat uncorrelated performance. The higher the probability that one element (crop, trading partner, mutual fund) of the portfolio will perform well when another is performing poorly, the higher the buffering against risk. On the other hand, it is well-known that in simple feedback systems there are consequences associated with a given choice of a portfolio aimed at coping with a particular range of variability; that choice can also reduce the capacity to cope with variability outside the target range (Anderies et al. 2007). As such, general “rules of thumb” might not be all that generalizable or transferable between different “experiments.”

To explore this tradeoff, we analyzed the consequences of diversifying crops in prehispanic northern Mexico, focusing on conditions in the Malpaso Valley area around the prehispanic center of La Quemada (figures 8.1, 8.2, 8.3).

Specifically, we asked when and under what climatic circumstances would the addition of a second cultivated plant—agave—to a maize-based subsistence system allow farmers to persist in locations that might otherwise be untenable. By implication, we were interested in the conditions under which such diversification does not address the “hazard” of low and variable precipitation and may even increase vulnerability.

By 500 CE, inhabitants of the Malpaso Valley area (figure 8.3), within the modern state of Zacatecas, Mexico, subsisted on a classic Mesoamerican diet of maize, beans, and squash (Turkon 2004). If ethnographic equivalents shed light on the proportions of each, maize provided over 50 percent of the calories for this complement of crops (López Corral and Uruñuela y Ladón de Guevara 2005). During the period 500–900 CE, people spread north from population centers in central Mexico, aggregating at unprecedented scales in widely separated arable patches along the foothills of the Sierra Madre Occidental (Kelley 1971), including the Malpaso Valley. Various hypotheses have been advanced for these movements, including a diaspora following the breakup of the great city of Teotihuacan (Jiménez-Moreno 1959), climatic changes that allowed central Mexican lords to more profitably exploit the land and labor of northern Mexico (Armillas 1964), mutually beneficial alliances between the lords of central and northern Mexico (Jiménez-Betts and Darling 2000), or the pursuit of rare mineral resources (Weigand 1977). There are as yet no published paleoenvironmental data with which to evaluate these propositions.

Vulnerability to famine was almost certainly an issue for early northern Mexican maize farmers (Armillas 1964; Gunn and Adams 1981; Sauer 1963). The northern territories had lower annual precipitation, greater inter-annual variability in rainfall, and therefore greater probability of extended drought than the central regions of Mexico in which maize cultivation had originated. The abandonment of the northern regions in 900 CE has been attributed to this vulnerability to drought (Coe 1994); even today, farmers in the region report that they can only depend on good maize yields in two years out of ten (Nelson 1992).

Carl Sauer (1963) and Jeffrey P. Parsons and Mary P. Parsons (1990) point to agave cultivation as a potential buffer against famine events introduced by persistent drought, and we know agave was cultivated in prehispanic central and northern Mexican settlements (e.g., McClung de Tapia et al. 1992). This crop diversification is by no means the only possible risk-buffering strategy; other (not mutually exclusive) strategies include concentrating water resources through irrigation or terracing (e.g., Fisher, Pollard, and Frederick 1999; Howard 1993), food sharing (e.g., Hegmon 1996), mobility (e.g., Nelson and Anyon 1996), and crop storage (Seymour 1994). Moreover, agave may have been produced for reasons extending beyond subsistence—for instance, the alcoholic beverage *pulque*, produced from agave, was used in culturally important feasts (Clark and Blake 1994).

Given that agave is a perennial plant, with maturation times ranging from a few years to decades for the different species, and maize is an annual plant, the a priori arguments for cultivating agave in addition to maize as a risk reduction strategy in this arid and highly variable environment seem strong. But the general rule of thumb for diversifying in uncertain environments is unsatisfying. Climatic structures can vary significantly from place to place, with fundamentally different relationships between annual averages and inter-annual variability, for instance. Is agave equally useful in all variable environments? If not, when is it most useful? When is it least useful and potentially not worth the added costs of managing a diverse crop portfolio?

These are the questions we attempted to answer with simple models of maize and agave production and maize storage under diverse climatic conditions. Both maize and agave production are assumed to be water-limited. Variability in annual precipitation was taken to be either 20 percent or 50 percent of the mean precipitation. Mean annual precipitation ranged from levels at which maize crops would regularly fail to those at which maize yields would be maximized (yields would plateau with respect to increasing rainfall, likely because some other resource such as nitrogen or phosphorous becomes limiting). In a second set of simulations, mean annual rainfall was pegged at 70 percent of the level at which maximum yields would saturate, and inter-annual variability was allowed to range from 20 to 90 percent of this mean. Our measure of the risk-buffering potential of agave was the reduction in the experience of famine events, particularly those of long duration (three years or more) (see Anderies, Nelson, and Kinzig 2008 for further details of the model and results).

Our initial instinct, based on “common wisdom,” was that agave would be most useful in relatively harsh environments (low rainfall, where maize would be expected to fail with some regularity) with high inter-annual variability in precipitation. Our results contradicted those instincts. Specifically, agave contributed most significantly to maize farmers’ ability to survive drought (avoid famine events) when both the mean and variability of rainfall were “intermediate”—that is, rainfall was somewhere between levels that would guarantee either crop failure or maximum yields, with intermediate inter-annual variability. When variance was high, regardless of the mean rainfall, agave did not confer significant benefits. When variance was low, the most significant benefits to agave cultivation accrued in intermediate to high average rainfall conditions. Thus diversity is shown not to be an inherent good, regardless of local conditions, but rather is a conditional benefit that must be weighed against the cost of building that diversity. In this case, diversifying the cultivated resource base did not hedge against the vulnerability to famine resulting from low and variable precipitation, one of the primary hazards of farming in this area. As noted, agave may have been cultivated for entirely different reasons having to do with

its value in making a fermented beverage for ceremonial use. If that motivation accounted for its cultivation, it would have been present in the rare circumstances when it might have contributed to reducing the risk of famine.

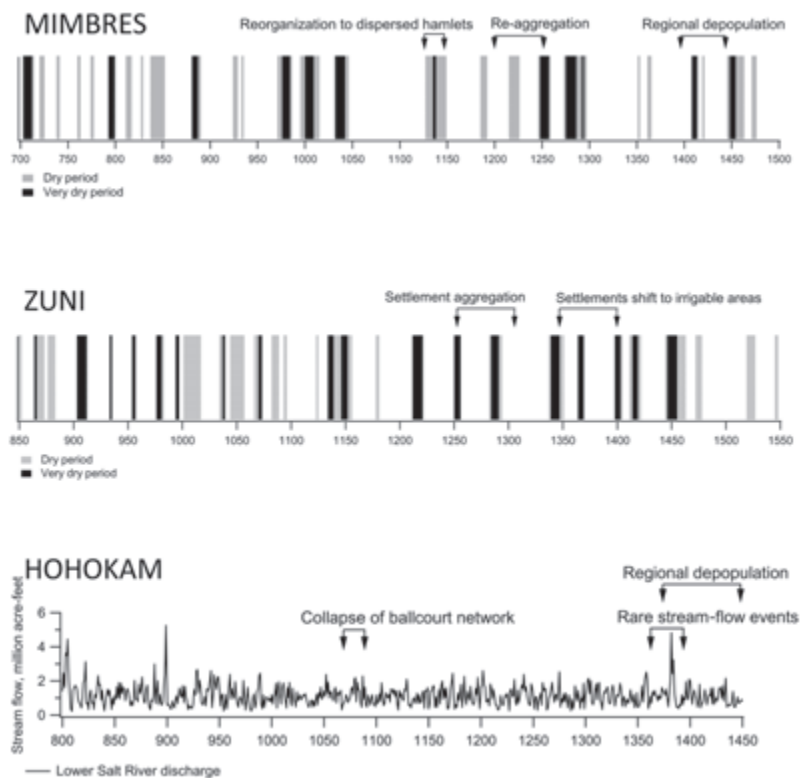
CONTRIBUTION 2: THE ROLE OF IRRIGATION INFRASTRUCTURE IN VULNERABILITY TO CLIMATE CONDITIONS

The social benefits of technological innovations, especially those leading to increases in food production, are plainly evident in the short term. This second contribution takes the development of irrigation agriculture as an example to explore how the potential vulnerabilities that can accompany this innovation may play out in the very long term (intergenerationally).

In arid and semiarid environments, some form of irrigation is nearly always necessary for agriculture, and agriculture is necessary to support anything more than the extremely low population densities that can persist with a hunting-and-gathering adaptation. Irrigation agriculture enormously increases the number of people who can be supported in a given area and enhances the robustness of that population to high-frequency spatial and temporal variability in precipitation. It does this by delivering precipitation to fields that is captured over a much larger area and—in the case of irrigation from rivers fed by snowmelt—over a much longer time. That increase in robustness, however, is accompanied by potential vulnerabilities.

1. The physical infrastructure of water-control systems may be vulnerable to destruction by rare climatic events, such as a major flood, which may make irrigation agriculture impossible for an extended period of time or render it useless when floods scour stream beds and become entrenched below the former floodplain.
2. Residents of settlements that depend on irrigation may be resistant to relocation because of their material and labor investment in the irrigation infrastructure. These place-focused long-term occupations can severely deplete local resources such as soils, animals, and plants.
3. Although productivity of irrigation agriculture makes population growth possible, long-term population growth may eventually outstrip the productive capacity of local resources, including those enhanced by the water-control infrastructure, leading to food shortages.

This second contribution (presented in more detail in Nelson et al. 2010) examines tradeoffs of robustness and vulnerability in the changing social, technological, and environmental contexts of three long-term prehispanic sequences in the US Southwest: the Mimbres area in southwestern New Mexico (650–1450 CE), the Zuni area in west-central New Mexico (850–1540 CE), and the Hohokam area in central Arizona (700–1450 CE) (see figures 8.1, 8.2).



8.4. *Periods of extremely low precipitation in Mimbres and Zuni areas and stream-flow discharge patterns in the Lower Salt River in the Hohokam area. By Scott Ingram.*

In all three of these arid landscapes, people relied on agricultural systems that depended on physical and social infrastructure of irrigation to deliver adequate water to agricultural fields. Across the cases, the scale and the nature of the investments in infrastructure varied, as did local environmental conditions.

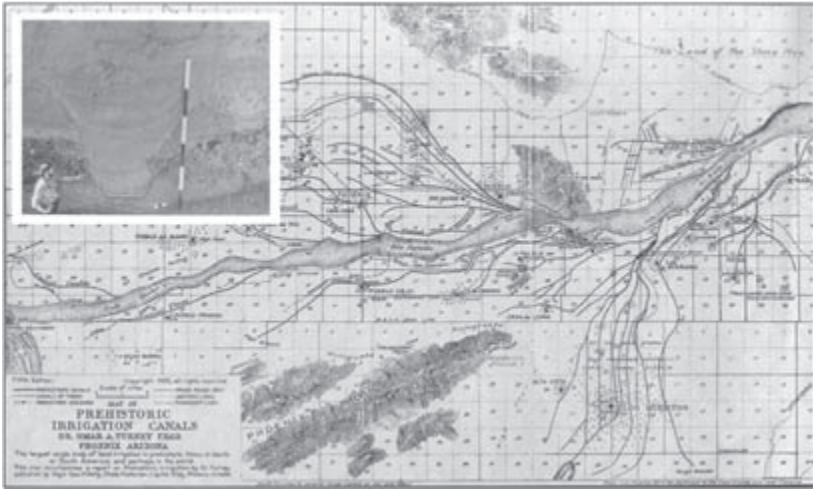
“Mimbres” refers to an archaeologically defined region in southwest New Mexico (see figures 8.1, 8.2). The subsistence economy of the Mimbres sequence is characterized by small-scale farming supplemented by hunting and gathering. Mimbres fields were primarily watered by small-scale canals feeding floodplain fields. This small-scale irrigation system increased the productivity of floodplain fields, as did the stone terracing systems on hill-slope and alluvial fan fields, ensuring more directed and abundant water and nutrient flow to field locales. Although many periods of severely low precipitation were experienced during the temporal interval discussed here, most were not associated with social transformations that are evident in the archaeological record (figure

8.4). However, an extended period of extremely low precipitation around 1130 CE coincides with the depopulation of nearly all the large villages, with emigration of the population to small settlements (Hegmon, Ennes, and Nelson 2000; Nelson 1999). Within a half-century, however, the local population and immigrants had again aggregated into new villages in the region (see “Contribution 3” below for more discussion of the Mimbres).

In the Mimbres case, the major transformation around 1130 CE was associated with a coincidence of all three vulnerabilities. Population had been growing for centuries, probably pushing (but not exceeding) the occupied areas’ sustaining capacity by that time (Schollmeyer 2009). The investments in infrastructure and a focus on floodplain farming led to a place-focused residential pattern that, by the 1100s, resulted in depletion of soil (Sandor 1992), plant (Minnis 1985), and animal resources (Schollmeyer 2009). The increasing vulnerabilities associated with these long-term social and environmental processes were realized with the occurrence of a high-frequency event—an extended period of low precipitation about 1130 CE. In this case an agricultural strategy aimed at increasing robustness to high-frequency climatic variation eventually ran afoul of long-term vulnerabilities and thus engendered a transformation to a new phase of development. Vulnerabilities to resource depletion and low precipitation led to reorganization, but practices of managing fields in diverse settings may have tempered the changes brought on by those vulnerabilities.

Our examination of the Hohokam of central and southern Arizona (see figures 8.1, 8.2) focuses on the people who lived along the Lower Salt River in what is today the Phoenix metropolitan area (for more on the Hohokam, see “Contribution 3” below). The prehistoric residents flourished in the Phoenix basin for a millennium, occupying some of the largest and longest-lived settlements in the ancient US Southwest and developing the largest network of irrigation canals in Precolumbian North America (figure 8.5). The period 800–1450 CE encompassed a cultural florescence characterized by a regional system of ceremony and exchange, followed by a collapse of the regional networks and prevailing social institutions and a long slide toward total residential abandonment (Abbott 2003, 2006; Doelle and Wallace 1991; Doyel 2000).

The large-scale irrigation technology of the Hohokam was sustained for over a millennium. Its great capacity to supply agricultural surpluses contributed to the creation of a regional-scale economy that was highly robust to local fluctuations in rainfall. But this robustness came at the cost of increased vulnerability to social and ecological perturbations at specific localities, which, because of the crosscutting interdependencies, could be felt across the region. Although people were place-focused, for centuries they acquired a wide array of resources through an extensive regional exchange network. The ca. 1070 CE collapse of the regional system and the depopulation of much of the surrounding area resulted in a dramatic increase in the Phoenix basin population (Doelle,



8.5. *The Hobokam irrigation system as mapped in the 1920s and a cross-section of an irrigation canal excavated by Jerry Howard. Map is from Omar Turney (1929).*

Gregory, and Wallace 1995; Doyel 1981; Teague 1984; Wilcox 1991) and a consequent depletion of local resources. With the replacement of the regional network with balkanized local networks, many exchanged resources were no longer available (Crown 1991) and the social relations that supported the canal systems were changed. Extreme climate events in the late 1300s—including two years of river flows higher than had been seen for 500 years (see figure 8.4)—were probably devastating to the irrigation infrastructure (Graybill et al. 2006: 117). Occurring in a context of population pressure, depleted resources, and institutional disarray, these events may well have contributed to the long-term slide toward near-total depopulation of the region; potential vulnerabilities were realized, people suffered, and institutions collapsed. We discuss this collapse more fully under “Contribution 3.”

The Zuni area (see figures 8.1, 8.2), which spans the Arizona–New Mexico border along the southern margin of the Colorado Plateau, is one of only three areas in the Southwest continuously and densely occupied from the early centuries CE, through the Spanish Conquest, and up to the present (Ferguson and Hart 1985). From 850 to 1200 CE, settlements were relatively small and short-lived and the population was widely distributed (Peoples and Schachner 2007). By the end of the 1200s people had aggregated in large towns that, until the late 1300s, were concentrated in the eastern portion of the Zuni area (Kintigh 1985, 1996; Kintigh, Glowack, and Huntley 2004). As the long-term hydraulic conditions changed in the mid-1200s (see figure 8.4), an early reliance on small floodplain and sand-dune agricultural fields watered by groundwater and

floodwater gave way to an agricultural strategy heavily reliant on small-scale runoff farming that, after 1300 CE, was augmented by ditch irrigation from large springs. By 1400 the entire population had moved to long-lived towns with canal-irrigated fields set on broad floodplains adjacent to the Zuni River (Kintigh 1985).

The Zuni case illustrates how social and physical changes together kept potential vulnerabilities from being realized. The water delivery infrastructure in the Zuni region was much smaller-scale and more dynamic. Farming strategies were altered with shifts in climate, hydrology, population density, and social institutions. Despite considerable investments in physical infrastructure (villages and fields), Zuni villagers did not become place-focused until the end of the prehistoric sequence when they had developed social institutions that could sustain the aggregated populations. The area's population seems to have leveled off by the late 1200s, and people in the proto-historic settlements evidently lived within their productive means. In this context, potential vulnerabilities to extended droughts seem not to have been realized.

For arid-land farmers, physical infrastructure that captures or directs water for agriculture ameliorates short-term temporal and spatial variability in precipitation and improves productivity. It makes town and village life possible in many places where it would not otherwise have been. Comparisons across these cases allow us to understand the interactions of social, technological, and environmental factors that promote the vulnerabilities that accompany irrigation agriculture and influence resilience in specific contexts. These comparisons help us understand, in social terms, why people experienced changes in climate in different ways. Looking across these cases, it is clear that any relatively short-term view (e.g., fifty years) would not allow us to understand the complex dynamics or predict their outcomes; a long-term view is essential.

CONTRIBUTION 3: RIGIDITY TRAPS IN SOCIAL-ECOLOGICAL SYSTEMS

Intellectual traditions from Marxism to Buddhism understand a basic truth that is also central to resilience thinking: change is inevitable. Change is also the basic subject of historical inquiry, including archaeology; however, in studying many historical trajectories in the US Southwest, we are struck by the varied nature of changes. In some cases archaeologists and anthropologists document considerable continuity in traditions over long time spans in the context of other changes. In other cases, such as those discussed in this section, cultural traditions come to an end, sometimes with great loss of life. In this research we asked why some changes are so much more traumatic than others, why people do not address the disturbances that confront them. More specifically, we examined the hypothesis that resistance to change, described by a concept known as a *rigidity trap* in resilience thinking, contributes to sever-

ity of change when it (inevitably) comes. Rigidity traps prevent people from effectively responding to deteriorated conditions.

A rigidity trap is described by C. S. Holling and colleagues (2002: 96) as a situation in which there is a high degree of integration and the system can persist “even beyond the point where it is adaptive and creative . . . [with] efficient methods of social control whereby any novelty is either smothered or sees its inventor ejected.” Did rigidity traps make change more difficult or traumatic among farming societies in the ancient Southwest? To answer this question, we undertook a comparative study of three cases of transformation—Mimbres, Mesa Verde, and Hohokam (see figures 8.1, 8.2). For each case we assessed:

1. The nature and severity of the transformations: How many people were affected and how were they affected? Did they leave their homeland? Is there any evidence of physical suffering?
2. The degree of rigidity: How integrated was the society? How hierarchical? Is there conformity, indicative of some kind of social control?

The original presentation of this research (Hegmon et al. 2008) details how these concepts were assessed in terms of a series of archaeologically measurable variables and describes the extensive data sources. Here we simply summarize each transformation and evidence for rigidity in each case.

The Mimbres region in southwest New Mexico is known for its beautiful pottery (figure 8.6), made mostly during the Mimbres Classic period (1000–1130 CE). The end of this period saw the end of this pottery tradition and the movement of many people out of their farming villages. Because archaeologists had defined the period as marked by village life with a certain type of pottery, its end had been interpreted as a collapse. But our research (see also Nelson et al. 2006) showed that the transformation itself was fairly mild. A few thousand people did leave their villages, moving both north and south of the Mimbres region, but some of them simply resettled a short distance from their former villages in what had been their temporary field houses, where they started importing and possibly making other kinds of pottery. It was a flexible strategy that exhibited no evidence of hierarchy, mild integration, and little rigidity overall.

The Mesa Verde region of southwest Colorado was occupied by tens of thousands of people in the early 1200s CE, and by 1300 CE it was virtually empty (Varien et al. 2007). After decades marked by competition and hostilities, including a village massacre (Kuckelman, Lightfoot, and Martin 2002), many of the people moved to northern New Mexico (Ortman 2009). This large-scale and traumatic transformation was associated with considerable rigidity, created in this context by increasingly aggregated settlements with large public architecture and some indications of hierarchy.



8.6. *A Classic Mimbres black-on-white painted bowl from 1000–1130 CE. Courtesy, Eastern Mimbres Archaeological Project, Arizona State University, Tempe.*

As discussed in the previous section, the Hohokam region in central and southern Arizona is known for the largest prehispanic canal irrigation system in North America (see figure 8.5). That system, which was enormously successful for centuries, went out of use sometime in the late fourteenth to the fifteenth century. Tens of thousands of people depended on it, but few were still in the area at the time of Spanish contact; the population seems to have died out, moved away, or both. This was an enormous and traumatic transformation, and it was preceded by a long period of rigidity, described in the book *Centuries of Decline* (Abbott 2003). There is evidence of social institutions that in this context were not responsive to changing conditions: hierarchy, public architecture that excluded many, and strongly aggregated settlements. In some settlements serious health problems were caused by poor diet, yet, unlike in the Mesa Verde region, people stayed and apparently suffered, possibly for generations. In the Hohokam case the irrigation that had worked so well to manage change and variability in precipitation and stream flow and to boost the productivity of this desert environment was part of a rigidity trap. People

committed to this way of life were left with no options; their rigidity trap kept them in deteriorating conditions until the inevitable collapse that included tremendous population loss, in some cases through mortality resulting from poor health.

This research on rigidity in social systems demonstrates that humans unintentionally construct traps that both create vulnerabilities and prevent people from acting in their own interest to address changed conditions. These unintended consequences of development and commitment to stability have implications for the human experience of “hazards.” The concept of a “hazard” is as much a product of human construction as of the conditions of the environment (e.g., Burton, Kates, and White 1993). One lesson from analysis of these cases is that the rigidity of social configurations, however they are constructed by people, can create conditions that exacerbate the influence of “hazards” of all sorts.

FUTURE RESEARCH, LESSONS FOR THE PRESENT

This research has several important implications for resilience thinking with regard to vulnerability in social-ecological systems. It shows that resilience concepts can be assessed systematically in the archaeological record and thus pave the way for more research on long-term processes relevant to contemporary decisions about vulnerability and resilience. It shows how an understanding of relatively small-scale societies in the ancient past can provide insights relevant to our world today. Nuanced thinking about the costs and benefits of diversity, the tradeoffs in vulnerability resulting from investments in infrastructure, and the role of humans in constructing rigidity traps is important in managing toward reductions in the impacts of various disturbances or hazards. We offer a few specific thoughts for future consideration; they apply well beyond our thinking about the human experience of hazards.

1. Diversity has costs as well as benefits. In the subsistence realm it may be examined more productively in terms of the responsiveness of plants to varied climate conditions than as a simple function of the number of kinds of plants. What kind of diversity we promote in today's world may be more important than the simple value of diversity.
2. Addressing vulnerabilities in one domain or at one scale can create new vulnerabilities in other domains or at other scales. Absolute resilience is not a reasonable goal. Rather, the best we can do is seek to find a balance among vulnerabilities that reduces the cost of experiencing disturbances or disasters; in resilience terms, we must develop adaptive capacity to manage inevitable yet often unpredictable disturbances (including those that may be known hazards for which timing and intensity are unpredictable).

3. Isolation can contribute to rigidity and eventually to the severity of collapse and transformation. That is a lesson worth keeping in mind in today's world as we grapple with global connections.

Archaeologists have much to offer to modern policy making through explorations, over long timescales, of the key concepts employed in efforts to build resilience in modern social-ecological systems.

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