

# The resilience and adaptive capacity of social-environmental systems in colonial Mexico

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**Civilization collapse scenarios highlight what for some are worrying parallels between past case studies and societies under threat from apparently unprecedented global environmental and climate change today. Archive-based studies of socio-economic responses to climate variability in colonial Mexico suggest that the complex interactions between environment and society influence the degree to which regional livelihoods may be vulnerable or resilient to disruption and also illustrate that vulnerability to change can lead to improved understanding of risk and increased adaptive capacity. In this paper, I draw on examples to argue that experience of climate variability, extreme weather events, or weather-related events and crises can challenge societal resilience, but can also increase opportunities for learning and innovation, extending the repertoire of adaptive responses. The historical examples selected might help inform the degree to which societies can develop strategies to deal with environmental perturbations at different scales and highlight that social breakdown and collapse are not an inevitable result of transformation.**

There is little doubt that environmental variations in the past have influenced the well being of preindustrial societies (1). Identifying the precise role of environmental parameters therein, however, is fraught with difficulty. Discriminating between environmental and anthropogenic impacts on past civilizations poses a significant challenge because of the paucity of high-resolution evidence, notwithstanding advances in this respect over the past two decades (2). Moreover, societal responses to such external forces are nonlinear in nature, meaning that in the archaeological and historical record, any hypothesized direct linkages between cultural transition and environmental forcing must be treated with caution (3). Major events, particularly those that leave discontinuities in the historical record, are not always linked to major causes (4), so much as a suite of social, economic, political, demographic, and environmental factors that have the potential to coalesce at a particular point in time to cause dislocation. For all these reasons, purely environmental explanations of societal collapse, including climatic explanations, remain less than convincing.

There is also the “possibility that human foresight and innovation can . . . develop paths that sustain natural diversity and create opportunity” (ref. 5, p. 4). Experience of environmental shocks and crises can lead to improved knowledge of risk among affected communities, increasing their awareness of their own vulnerability. Social memory of practices and behaviors is increasingly regarded as “crucial for preparing the system for change, building resilience, and for coping with surprises” (ref. 6, p. 1037). Awareness of droughts and floods as well as disease events in the past, for example, can condition how a society not only conceptualizes the likely risk of events, but also learns from these experiences and anticipates the impacts of future events (7). Furthermore, it has recently been argued that there is “compelling evidence” that communities can capitalize on opportunities presented by episodes of extreme or unusual climate, “to generate sustained socio-ecological improvement” (ref. 8, p. 5203).

Insight into the complex relationship between climate variability and societal response can be gained from investigations of historical interactions between people and the environment in regions where there has been a history of climatic variability and human response in periods for which there are high-resolution temporal and spatial data. Mexico represents one such region

and provides the focus for this paper. By means of a theoretical introduction, however, it is important to first consider the meaning of and approaches to vulnerability, adaptation, and resilience in the context of environmental and climatic change.

## Integrating Vulnerability, Adaptation, and Resilience

As Berkes and Folke illustrate, “there is no single universally accepted way of formulating the linkages between human and natural systems” (ref. 9, p. 9). As increasingly interlinked concepts, however, vulnerability and resilience have gained momentum in recent decades, offering useful insights into the complexity of these relationships. Although there are many different definitions of the term (10), vulnerability can be broadly defined as the potential for loss (11), the “state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt” (ref. 12, p. 268), or “the degree to which human and environmental systems are likely to experience harm due to a perturbation or stress” (ref. 13, p. 255). Frequently referred to in the risk, hazards, and disaster literature (14, 15), vulnerability has become important for understanding people’s susceptibility to harm in the context of uncertain climatic futures. Originally developed by Holling as a means of modeling change in the structure and function of ecological systems, resilience has similarly become a popular concept for exploring the complexities of linked human–nature systems (16). Resilience has been defined as “the degree to which a complex adaptive system is capable of self-organization . . . and . . . can build capacity for learning and adaptation” (ref. 6, p. 1036) and implies a more positive response to environmental problems.

In recent years, there have been efforts to propose synergies between research on vulnerability and research on resilience in linked social–environmental systems (17). As Ibarra et al. suggest, integrated studies of societal vulnerabilities and resilience can provide “guidance in the areas of impacts, adaptation, and societal behaviour” (ref. 18, p. 366), and such studies offer new approaches for analyzing how societies can develop strategies and build capacity to prepare for climate change impacts. Both concepts together might, therefore, help to clarify the complexities of past environment–society relationships and could contribute to our understanding of how societies have coped with and adapted to past climate variability and weather or weather-related events.

It is important, however, to also consider the nature of the climate change, or weather event itself, as well as the mediating context in which it acts, to understand society’s relative resilience and/or vulnerability. The impacts of climate changes and hence the degree to which society is able to respond to them, for example, depend very much upon the time- and place-specific context in which such changes take place. There are often differential impacts and losses, depending on the levels of preparedness of different sectors of the population. Preparedness in turn is dependent upon the social and economic status of a particular group of people and the degree to which they can buffer themselves against the impacts of an event. Low-amplitude, low-frequency

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events have little effect on resilient societies but may affect the most vulnerable societies depending on the temporal, social, political, and demographic context in which they act. High-frequency, low-amplitude events, or sequential climate events, may cause some disruption for resilient societies but acting against a context where society has already been rendered vulnerable by previous events, climatic or otherwise, may lead to greater societal disruption. Low-frequency, high-amplitude events, however, can cause disruption even for resilient societies, although they are often better placed to adapt than the most vulnerable. The rare, extreme event can cause disruption for even the most resilient of societies, but a crisis becomes so only when a significant proportion of the population is at risk or significant life and economic losses are incurred. Moreover, adopting Tainter's (19) definition, societal collapse per se remains a rare phenomenon in the historical and prehistorical record (3). Indeed, although one might argue that the majority of human history is a story of environmental degradation, a case could be made that it is also one of human adaptability and resourcefulness in the face of periods of disruption and crisis.

This adaptive capacity and resourcefulness are manifest at a range of temporal and spatial scales and may involve the establishment and implementation of trading relationships or may be achieved through individual or institutional action and decision making, through legal intervention, through regulation, or through technological change. They might also involve the marshalling and extending of social networks and relationships (20). There is a growing interest in exploring social capital responses as a form of adaptation to climatic change (6). Such capacities are often bound up in an ability to act collectively (ref. 21, p. 388), with community engagement offering a means of reducing vulnerability to the impacts of climate change (22). Adaptive comanagement, which "relies on the collaboration of a diverse set of stakeholders operating at different levels, often in networks, from local users to municipalities..." may also render society more resilient to the threats posed by climate variability (ref. 23, p. 75). To date, most social capital-oriented studies have focused on collective responses to *contemporary* or *future* rather than *historical* climatic changes. However, knowledge of successes and failures in adaptation of a society or a community to past climatic variability may contribute to our understanding of the capacity of that society or community to respond to environmental threats and climate changes on a range of scales (24), and an accumulation of this kind of traditional ecological knowledge (25) might also help societies themselves to manage the challenges of uncertainty.

### Mexico as a Case Study in Vulnerability and Resilience to Climate Change

Mexico has experienced climate change on a range of timescales yet also possesses rich archival material dating back to the colonial period through which to investigate the impacts and responses associated with such changes. Analysis of these sources reveals that seasonal climate variability, extreme events, and related impacts have posed problems, but also opportunities for society across the country. Previous work by the author (26), for example, has drawn these rich archival collections to explore the impacts of and responses to past climate variability and extreme weather events over time in three different regions of Mexico covering a variety of environmental, social, economic, and political contexts and histories and located at key points along a north-south rainfall gradient. These are the Conchos Valley, southern Chihuahua in the arid north (average annual rainfall 350–400 mm/y), the Valley of Oaxaca in the wetter south (1,500 mm/y), and west central Guanajuato located in the central highlands of Mexico, a region of climatic transition (650–1,000 mm/y). Each region developed distinctive settlement and land use characteristics during the colonial period. Guanajuato became the "breadbasket" of the colonial political economy, specializing in the production of cereals, especially wheat and maize, as well as silver mining, and developing a distinctly colonial character. In Oaxaca, in contrast, there was a good deal of indigenous land retention following conquest. Agricultural production continued

to focus on the production of maize, beans, and chile and also the production of cochineal, although wheat and livestock were introduced soon after conquest. In Chihuahua, Spanish colonization was hampered by the coupled problems of drought and indigenous unrest, but by the 17th century, a lucrative livestock and mining industry had emerged across the region.

All these regions have been affected by interannual variations in rainfall, droughts, and flooding, as well as frosts. Some events appear to have affected all three regions and contributed to widespread crisis. As previous work has illustrated, however, the regionally idiosyncratic environmental circumstances, the economic trajectories, demographic transformations, and distinctive land use systems that evolved in each of these three areas were to play a critical role in determining how populations in each region were affected by—and were able to adapt and respond to—climate changes and weather events (26).

However, there is also evidence of contextually contingent societal ingenuity and adaptation in all three regions and it is examples of this that form the focus of the remainder of this paper. Adaptations adopted over a range of temporal and spatial scales to reduce vulnerability to general climate variability in Mexico are first considered. Community responses to specific drought and flood events are then discussed, including schemes that were adopted to take advantage of opportunities presented by such events. It is argued that, although unpredictable climatic variability and the implications of weather-related events might have contributed to social tension and legal wrangling over distribution of natural resources, they did not result in societal disintegration but acted instead as a kind of "trigger" to adaptation, in some cases playing a role in increasing societal resilience at the personal, community, regional, and national level. Particular attention is paid to the way in which periods of disruption and crisis garnered collective action and behaviors.

### Adaptations to Reduce Vulnerability in Pre-Hispanic and Colonial Mexico

**Pre-Hispanic and Colonial Adaptations to Climatic Variability.** A wide variety of adaptive strategies existed in pre-Hispanic Mexico, designed to hedge against the impacts of climate variability (27). Irrigation represents one of the most obvious examples and different groups across the country developed sophisticated systems to manage, store, and transport water for this purpose. Farmers practiced mixed farming and also kept seed and grain harvested from their own crop from one season to the next, a strategy that prevails in parts of the country today (28). The organized storage and trade of grains, food products, and other saleable assets were other important buffers against expected seasonal shortages and such moral economic responses offered a "subsistence ethic" by providing a minimum level of food security during times of want (29).

Changes in demography, administrative organization and settlement, economic exploitation, and agricultural land use and alterations to the distribution and tenure of environmental resources, particularly water and land, in different regions of Mexico following Spanish conquest, modified social and biophysical vulnerability across the country and it has been argued that society was rendered more vulnerable to the impacts of climate variability as a result (30). Many of the adaptive strategies of the pre-Hispanic period, however, continued to operate after conquest. Use of irrigation and permanent and ephemeral watercourses was expanded, rivers and arroyos were all exploited, and groundwater was also tapped in many locations<sup>†</sup> (AGN Historia,

<sup>†</sup>Archival documents are referred to via the following abbreviations: AGN, Archivo General de la Nación, Mexico City; AHMCO, Archivo Historico Municipal de la Ciudad de Oaxaca; AHML, Historico Municipal de Leon, Guanajuato; AHMCH, Historico Municipal de Chihuahua. Archival citations in the remainder of the text are referenced in the following manner: the abbreviation of the archival repository, the document group (*ramo*) consulted, the volume number (Vol.), or Box (*caja*) number, the expediente (Exp.) or legajo (Leg.) number (if applicable), section number (*cuaderno/cuad*) and/or the page (*foja*) number, denoted by fa. (single page) or fs. (multiple pages). (Page numbers may also be accompanied by f (*frente*) facing page or v (*verso*) reverse page.)

Vol. 72, Exp. 9; AGN Civil, Vol. 73, Exp. 3; AGN Tierras, Vol. 514, Exp. 1, Cuad. 2, fa. 47; AGN Tierras, Vol. 618, Exp. 1, Cuad. 3, fa. 61; AGN Tierras, Vol. 1353, Exp. 1, f. 69.). Flood waters were stored for dry season use (AGN Tierras, Vol. 2705, Exp. 3, fa. 1; AGN Mercedes, Vol. 10, fa. 3), and the practice of maintaining a reserve of emergency food supplies to compensate for times of harvest loss and to hedge against price rises during periods of scarcity and the trading of foodstuffs from region to region also remained important strategies for coping with localized harvest failures (31). Government-sponsored grain stores (*Reales alhóndigas*) and granaries (*pósitos*) were established in principal cities across the country. During years of poor or failed harvests, the authorities stocked these city stores and granaries, but actual experience of drought and harvest failure may have in fact stimulated the establishment of a number of these facilities in the three case study areas (AHMCH Caja 2, Exp. 12; AMHCH Caja 3, Exp. 5; AGN Ayuntamientos 196, Exp. 1).

**Importance of Context and Contingency in Vulnerability to Climatic Events.** Irrigation, trading, and storage strategies proved relatively effective in buffering society against the implications of normal or expected climatic variability and single years of hardship. Consecutive periods of anomalous weather, however, or unusual events acting against a context whereby society had already been rendered vulnerable, challenged societal resilience. As has been discussed elsewhere, for example, the majority of recorded agricultural crises and famines in Mexican history and prehistory have been associated with successive droughts or drought combined with other unusual or extreme weather events, often frosts (26, 32), and the most devastating of these periods were those that where weather events compounded other, structural problems, specifically population growth and resource overexploitation, or political instability. Such episodes have been documented in the 1750s, the 1780s, at the turn of the 19th century, and between 1808 and 1810 when prolonged or repeated periods of drought combined with other weather events and, acting in a context of political unrest and population pressure, contributed to widespread food scarcities (26). It was not just drought- and frost-induced subsistence crises, however, that challenged the resourcefulness of Mexican society. The destruction wrought by sudden and violent flooding also represented a problem for riparian communities across the country.

Awareness of vulnerability to fluctuations from normal seasonal rainfall may have been metered out in the many lawsuits over land and water access. Certainly, disputes over land and water resources across and between all sectors of society do seem to have increased during such events. Such tensions may have contributed to the general dissatisfaction that would culminate with the drive for independence in the late 18th and early 19th centuries (33). Equally, however, in the face of widespread crisis, society at large proved to be remarkably resilient. Even where extreme and widespread, periods of crisis do not appear to have resulted in social breakdown. Rather the colonial archives reveal that shared experiences of crisis may have engendered a sense of civic responsibility and collaboration between different sectors of society as well as entrepreneurial and opportunistic responses at the individual, community, regional, or national level. The examples selected below provide insight into a variety of responses and adaptations that developed in the different case study regions and also serve to illustrate that, rather than being considered a driver of societal breakdown, environmental stress may have stimulated responses at a range of scales, some of which were geared toward improving societal resilience.

### **Social Capital Responses to Drought, Agrarian Crisis, and Floods in Colonial Mexico**

**Water Management, Drought, and Social Capital Response.** The control of water was seminal to all cross-sections of society in Mesoamerica (34) and was often the focus of bitter and lengthy lawsuits during the colonial period. The need for an adequate, potable water supply may have been made more acute by

recurrent droughts (35). However, inasmuch as water scarcity contributed to disputes, it also appears to have driven cooperative water management between different sectors of the community. In the Valle de Santiago, southern Guanajuato, there was, for example, substantial water management for irrigated wheat by the start of the seventeenth century (36) and water recycling strategies were adopted to resolve legal differences between competing users. One dispute from 1614 concerns the sharing of water from the Lerma River between the indigenous residents of Acámbaro who required it for irrigation and Francisco de Villadiego Senderos who needed water to run his mill. The case was resolved with an agreement that the water should first be used in the mill and that the “recycled” *remanente* (surplus) water would then be used for irrigation purposes (AGN Tierras Vol. 2680, Exp. 29). By the second half of the 17th century, however, formalized water sharing systems had also been devised and water was divided between landowners according the *tanda* system, which consisted of “turns” in the use of water, usually measured in days of water (AGN Tierras Vol. 2959, Exp. 141, fs. 10v–16v). Water judges were appointed to adjudicate fair distribution, but all landowners in the Valle met to collectively decide and confirm in writing days of water access (36).

Drought in 1780, however, stimulated a collaborative water management project between landowners and the Augustinians in the Valle (AGN Tierras Vol. 2959, Exp. 141, fs. 4, 6v), the latter having invested heavily in irrigated wheat production in the area by this stage. Water shortages experienced during the drought posed a problem in this irrigation-dependent area. The solution lay in using the water of Lake Yuriria. The lake was connected to the River Lerma by a small channel and so its level fluctuated with the river level. A community-based project was devised to use the lake as a reservoir by placing head gates at the entrance to the channel, so enabling the regulation of the flow for when water was needed (36). All of the landowners in the Valle de Santiago were charged with collectively raising the sum of 5,000 pesos to finance the construction, whereas the Augustinians negotiated rights to use the lake from the community of Yuriria (AGN Ayuntamiento, Vol. 97, Exp. 2, fa. 10). Although ultimately the Augustinians dominated the manipulation of the water (36), the project was an example of a collective endeavor designed to reduce community vulnerability to water scarcity.

Seasonal variations in water availability and episodes of drought may have driven public works programs elsewhere. Episodes of prolonged drought in Chihuahua, for example, appear to have galvanized community groups to request government intervention in public health services. Persistent drought years throughout the later 1750s and early 1760s (Archivo Arzobispado de Chihuahua, Gobierno y Administración; Cofradías, 1755, Caja 3, Serie 1.3.3) resulted in “a lack of maize for daily consumption” in San Felipe el Real (Chihuahua City) (AHMCH Gobierno, Caja 30, Exp. 23) and a shortage of grazing land (AHMCH Notarias, Abasto de Carnes, Caja 42, Exp. 2). Epidemics and pestilence were recorded (AHMCH Guerra, Caja 2, Exp. 4), which in turn led to an abandonment of some of the mines and to the migration of hundreds of people. After years of hardship throughout the 1750s, the population was already much weakened and susceptible to disease and it is perhaps not surprising that there were special requests from local communities for financial donations to create a public pharmacy to allow people to access essential medicines (AHMCH Gobierno, Caja 31, Exp. 14). Although 40 years later, in August 1792, there were further pleas for a public pharmacy (AHMCH Hacienda, Caja 49, Exp. 40), perhaps indicating that the community’s initial requests may have gone unanswered, it is clear that this was a group of people spurred on by a shared sense of vulnerability to petition collectively for government intervention to address a recurrent problem.

**Agrarian Crisis and Public Response.** Widespread successive droughts appear to have challenged routine adaptations but equally may have stimulated more strategic regional and national initiatives. A series of droughts in 1780, 1782, 1784, and 1785 and frosts in 1784

and 1785 contributed to the so-called “year of hunger” between 1785 and 1786 (35, 37). This period of crop failure stimulated famine (AGN Alhondígas 15, Exp. 1; AGN Alhondígas 10; Tributos 20, Exp. 15), epidemic disease (AGN Tributos 20, Exp. 15, Exp. 1; AGN Reales Cédulas 134, Exp. 179; *Gazeta de Mexico* TII, nos. 13 and 17), death (AGN Tributos 2, Exp. 5), and economic recession (*Gazeta de Mexico*, TII, no. 13) and affected most of the country. Despite the scale of the crisis that unfolded, and notwithstanding the failure of buffering strategies designed to cope with food scarcity, there were various responses designed to reduce social vulnerability to its impacts. Food and grains were transported across much greater distances to help the neediest areas, particularly in the north of the country (AHMCH Justicia, Caja 126, Exp. 10; Archivo de Casa Morelos, Leg. 841; AGN Ayuntamientos, Vol. 169, fs. 49; AGN Ayuntamientos 173, cuaderno 6), and local benefactors made charitable donations to assist the starving poor (AGN Alhondígas, Vol. 10, Exp. 5, fs. 250–253; AHML Alhondíga, Exp. 8). Regional councils in Guanajuato, which as the grain-growing heartland of Mexico was among the regions hardest hit by the crisis, also provided financial aid (AGN Alhondígas, Vol. 10, Exp. 5, fs. 250–253) and circulated the names of wealthy individuals who could provide food or monetary assistance (AHML Alhondígas, Exp. 8). There is also evidence of community engagement in public works projects focused on irrigation or potable water provision intended to benefit entire communities (AGN Indios, Vol. 91; *Gazeta de Mexico*, Dec 6, 1785, No. 52, fs. 449–450). People from all cross-sections of society were also being encouraged to grow irrigated maize in stretches of territory across central Mexico that were not normally considered suitable for this particular crop, in the spring of 1786 (AGN Alhondígas, Vol. 15).

The 1785–1786 year of hunger represents the pinnacle of one of the most serious famines to affect colonial Mexico yet did not give rise to widespread social breakdown. Instead, there is documentary evidence that communities responded, sometimes spontaneously, or as a result of edicts to act cooperatively, to provide relief or to emplace strategic adaptive strategies designed for collective benefit. Indeed, although there are later periods of anomalous weather that resulted in widespread harvest problems, this period of agrarian crisis remains unmatched in terms of the scale of life loss and the level of disruption to all sectors of the economy. It could be argued that this crisis stimulated coping and adaptive strategies that improved social resilience or contributed to improved knowledge of the kinds of strategic actions that were necessary to avoid a repeat catastrophe.

**Flooding and Collective Response.** Flooding also appears to have driven cooperative strategies and cross-sectoral community interaction. Hundreds of floods are recorded in the colonial archives of Guanajuato, for example, and there was an awareness of the risks posed by the rivers in the region, including the Laja and Lerma (AGN Obras Públicas 17, Exp. 10, fa. 43; Descripción de la Ciudad y Real de Minas de Guanajuato por José Hernandez Chico, 1788, Archivo de la Marina, Museo Naval de Madrid, Ms 563 en *Descripciones Economicas Regionales de la Nueva España 1766–1827*). Flooding was exacerbated by human intervention in the natural hydrology of the region, and specifically the complex myriad of water diversion channels, dams, and reservoirs that had been developed, mainly for irrigation purposes, by the 18th century. Dam breaches were commonplace and, although most instances appear to relate to poor maintenance, floods may have been the result of deliberate sabotage related to feuds between neighboring landowners. Whatever the cause, flooding was recognized as a persistent problem by the mid-17th century, and a series of devastating floods was recorded in the region in 1649, 1692, 1749, 1750, 1753, 1760, 1770, 1771, 1772, 1788, and 1804 (AGN Alcaldes Mayores, Vol. 1, Exp. 309, fs. 439–441; AGN Tierras, Vol. 2071, Exp. 1, fs. 1–110; AGN Rios y Acequias, Vol. 1, Exp. 9, fa. 217), a number of which can be associated with above average summer rainfall. The scale of the losses incurred by the more dramatic of these events stimulated immediate, reactive coping strategies as well as longer-term anticipatory flood

alleviation and remediation schemes and several of these events led to what might be considered social capital and adaptive comanagement responses.

Following the dramatic flood on the Laja at Celaya in 1692, for example, which was associated with unusually heavy summer rains (38, see also 26), a cross-section of representatives of the city undertook a survey of the local river systems “with the objective of . . . developing measures to conduct water to avoid new floods” (ref. 38, p. 149), finally concluding that “the only way to avoid flooding was the construction of a dam above the river . . . to contain the waters that come down from the hills and to release this water, little by little into small storage areas, forming in this way a controlled water flow, so reducing the danger of large floods which have proved so dangerous for the city” (ref. 38, p. 149).

The undertaking was a result of the residents’ shared sense of loss, although the construction of the scheme was implemented and managed according to class distinctions. Whereas Spanish residents were requested to make financial contributions toward the cost of the dam works, the indigenous residents were asked to provide their labor in its construction. Nevertheless, this was intended to be very much a collective effort. Evidence of later damaging floods points to the fact that the project was ultimately only partially successful, although largely because the local council failed to maintain the dam (ref. 36).

Dredging and clearing were among the most common flood prevention techniques. Individual landowners were responsible for ensuring the steady flow of waters that passed through their lands and hence were often charged with the task of clearing their own stretches of the river (AGN Tierras, Vol. 1362, Exp. 1). However, there were also community-based clearance schemes and several documents refer to the need for communities to work together to clear the rivers of debris to reduce flood risk. Flooding in Guanajuato in 1749 led to the development of one such scheme, devised and advanced by local residents living in one street, the Calle de Alonso, who considered themselves “being in great danger” of flooding. They suggested the main cause of the problem lay in the “rubbish and waste of the city and the material from the hills and mine works” that was being dumped or washed into the river (AGN Tierras, Vol. 1197, Exp. 2). They proposed the construction of flood defenses in the areas that had previously been flooded together with an ambitious plan to lessen the gradient of the slopes surrounding the area, so reducing the likelihood of material being washed down into the river. Their proposal also included suggestions for diverting water from the river channel via a series of dikes and reducing its “power” through a number of small waterfalls. In response to this proactive community, the local administration enlisted a group of “experts” for their opinion. They in turn produced a map that showed the areas where debris had built up in the river and suggested “it would be simpler to ask residents to not throw their rubbish and waste into the river” (AGN Tierras 1197, Exp. 2).

That later damaging floods are recorded in the archives indicates that the local administration may have misjudged the scale of the problem and it is perhaps instructive that other later, more ambitious flood mitigation projects do seem to have been implemented. On the night of July 5, 1760 a flood took place in Guanajuato that resulted in both life and economic losses and stimulated a number of coordinated structural responses. Thus, “various bridges were built, they built up many fences, the foundations of the houses and haciendas were re-enforced, and also these and the streets were raised with the same materials as were drawn from the river.” These adaptations appear to have been partially successful as “twelve years later in 1772 there took place another flood . . . although it caused less damage because of the actions and precautions adopted in the previous flood.” Moreover, this event was succeeded on July 27, 1780 by a flood apparently “greater than that of 1772, but less than that of 1760 in its impacts because the river channel was not without some defence. . . .” (AGN Rios y Acequias, Vol. 1, Exp. 9. 214ff). Here then is evidence of the degree to which communities with experience of flood damage

may have attempted to render themselves more resilient to future losses through adaptive response.

**Flooding, Community Cohesion, and Opportunism.** As Eakin and Appendini have demonstrated, communities in Mexico have “historically manipulated flood events in a variety of settings to improve agricultural potential ... and expand cultivable land” (39). The rivers Atoyac, Salado, Xalatlaco, and Tehuanatepec all provided water for irrigation and domestic purposes in colonial Oaxaca and their fertile floodplains were prized for floodwater farming (40). There was also extensive use of swamplands adjacent to such rivers for seasonal grazing. Unusually heavy rains and flooding, especially at the close of the rainy season around September or October, however, regularly disrupted the economic livelihoods of communities and individuals in such locations (AGN Tierras 1861, Exp. 7; AGN Salinas, Vol. 15, Exp. 14). However, there are examples of opportunistic management of flood events. Heavy rains in 1723 resulted in the community of Guadalupe, subject town of ETLA “losing all the harvest of salt” to rising water levels. In response, the entrepreneurial community petitioned for a license to build a dam to allow them to regulate water levels and so prevent economic losses in the future. Their proposal included plans for a reservoir behind the dam that would allow the community to develop fishing resources should a similar situation arise again. The project never came to fruition because the downstream farming community of San Bartolomé opposed the scheme, amid fears that water storage upstream would detrimentally affect their own access to irrigation water (AGN Tierras, Vol. 1861, Exp. 7). Nonetheless, both proposals illustrate how communities and individuals acted in entrepreneurial ways to enhance resilience to the impacts of climatic variability.

Litigious indigenous communities in other parts of the region seem to have capitalized upon particular flood events to seek territorial advantage. One lawsuit, which is accompanied by a sequence of maps showing part of the River Atoyac and environs in Oaxaca, focused on the impacts of a series of flood events between 1775 and 1804 that contributed to a land dispute between the community of Xoxocotlán and the owner of the neighboring hacienda of San Miguel. The two parties used the river as a boundary between their respective lands. Following a flood in 1775, however, “the channel ... was moved by a tempestuous flood”, creating a “... new channel of the river” (see ref. 26, pp. 122–125). The community seized upon this event, together with continued avulsion of the river channel between 1775 and 1785, to make case for a redefinition of the boundaries between their lands and those of the neighboring hacienda. Contention between the two parties persisted into the early 1800s when unusually wet conditions in 1804 led to another period of flooding (maps are held in the Archivo Privado de Don Luis Castañeda Guzman, Oaxaca). It is not clear in whose favor the case was settled, but this example again perhaps illustrates how floods may have been opportunistically used as legal evidence to enhance community resilience.

As this brief consideration of examples demonstrates, periods of unusual weather, agrarian crises, and flood events appear to have stimulated a variety of responses, from the maintenance and enhancement of long-standing strategies designed to reduce vulnerability, to immediate responsive coping tactics and entrepreneurial opportunism. Rather than contributing to social breakdown, it appears that extreme weather events, weather-related events, and periods of crisis may have helped to stimulate proposals for public works geared toward the common good.

The documentary records considered in this paper provide only a partial record of past events in that they were compiled by individuals at a particular time, from a particular perspective, and for a specific audience. The content was thus inevitably influenced by the context in which these documents were created and can, therefore, contain both intentional and accidental bias. It should also be noted that if an event resulted in only limited human impact and economic loss it may well have gone unrecorded. There may, in addition, have been periods when events

or periods of crisis caused sufficient disruption in the administrative systems responsible for record keeping, thus leading to a gap in the record for a period when data are most needed. For all these reasons, archival investigations of the impacts of and responses to events such as droughts and floods are inevitably subject to limitations. It should also be acknowledged that, as with most historical empirical work using historical documentary evidence, there are opportunities for further subjectivity when interpreting these sources from a contemporary perspective, and, as a result, there are myriad opportunities for selective and interpretive bias. Nonetheless, as eye witness accounts or even as expressions of contemporary environmental awareness, these documents offer a unique insight into the way in which Mexican society conceptualized, understood, and responded to climatic variability, weather events, and crises.

### Concluding Discussion

On the basis of suggestions that the archaeological and historical records apparently show many instances of societal collapse associated with a climate cause, it has been argued that the “21st century will likely witness unprecedented social disruptions” in the context of predicted climate changes (ref. 2, p. 610). The possible link between climate and social unrest, it has been argued, has been forwarded as a reason to resurrect environmentally deterministic explanations of social history and prehistory (3). This kind of “catastrophic speculation,” however, in the absence of high-resolution evidence of past collapse, “may induce an unnecessary sense of fatalism and helplessness,” when there is actually scope for positive action (ref. 41, p. 1869). Human societies have demonstrated an inherent adaptability responding to such change via multiple pathways, including adaptation and innovation (42, 43). Periods of rapid change can thus “be a time of crisis but also opportunity framed by previous experience and social memory” (refs. 44 and 45, p. 227), and the unpredictability of climate change can act as a key driver in human innovation (ref. 46, p. 6).

There is still a need for a more comprehensive understanding of the role of institutions and culture in shaping adaptive capacity (47). Historical perspectives might help improve this understanding. The examples considered in this paper carry both intentional and accidental biases. Accordingly, they do need to be interpreted with caution and with an awareness of the context in which, and the audience for which, they were created. Nevertheless, accepting that they provide at best only a partial record of past events and, more importantly from the perspective of the current paper, the responses to them, these examples point to communities who were regularly and frequently affected by the effects of climatic variability, particularly interannual variations in droughts and climate-induced agrarian crises as well as periods of flooding, and yet proved to be remarkably resilient to these events.

In line with contemporary attempts to retrospectively link evidence of climate shocks and crises with evidence of social breakdown and collapse, it might be argued that the series of weather-related crises that affected the country in the second half of the 18th and early 19th century (26, 37), some of which have been discussed in this paper, might have played a key role in the breakdown of social order that was manifest in the independence uprisings around this time. It is no coincidence perhaps that the seeds of insurrection emerged in the agrarian heartland of the colonial political economy, in Guanajuato, where the impacts of prolonged drought induced harvest crisis and also, as has been illustrated, a series of damaging flood events were severely felt. However, it would be naive to make any simplistic connection between environmental event and social response. As Hamnett (33) has illustrated, the roots of unrest lay in a variety of structural problems and social, economic, and political as well as environmental circumstances, and the emergence, in Ponzio’s terms, of a growing and “formidable inequality” within Mexican society (48). The series of climate and environmental crises of the later colonial period may have helped to expose this inequality. However, inasmuch as these events raised awareness of a different social vulnerability, which no

doubt contributed to rising social tensions in the later colonial period, there is evidence to suggest that experiences of crisis sometimes transcended social hierarchies and stimulated co-operative responses. There are also incidences of opportunism at the community level following disruptive events or in response to improved knowledge of their likelihood. The implication is that, even in the face of sometimes widespread and prolonged crisis, societal disintegration was not an inevitability. Indeed, the most challenging periods of environmental stress appear to have led to efforts to strengthen societal resilience.

Adger et al. argue that “social learning, the diversity of adaptations, and the promotion of strong local social cohesion and mechanisms for collective action have all enhanced resilience” (ref. 6, p. 1038) to climatic variability. It seems to be this “social cohesion” and the capacity to self-organize in the face of adversity that emerge as a key explanation for the resilience of colonial

Mexican society. Moreover, the examples of adaptive capacity discussed in this paper imply that interventions might be best focused on fostering capacities “for endogenous institutional change to enhance community resilience to climate shocks” (ref. 8, p. 5203). Other location-specific investigations of societal response to climatic variability in a historical perspective might highlight the importance of adaptive response in improving resilience. Moreover, this kind of approach may become especially important when one considers, as have Clark et al., how little is at present understood about “the long term development of society’s efforts to manage its interactions with the global environment” (ref. 54, p. 4). Furthermore, an appreciation of the experiences of and adaptive responses to environmental and climatic challenges in the past has the potential to provide a powerful counterpoint to contemporary pessimistic environmental anxieties over the likelihood of future societal collapse.

- Büntgen U, et al. (2011) 2500 years of European climate variability and human susceptibility. *Science* 331:578–582.
- Weiss H, Bradley RS (2001) Archaeology. What drives societal collapse? *Science* 291: 609–610.
- Leroy SAG (2006) From natural hazard to environmental catastrophe: Past and present. *Quat Int* 158:4–12.
- Coomes P, Barber K (2005) Environmental determinism in Holocene research: Causality or coincidence? *Area* 37:303–311.
- Holling CS, Gunderson LH, Ludwig D (2002) *In quest of a theory of adaptive change. Panarchy. Understanding Transformations in Human and Natural Systems*, eds Gunderson LH, Holling CS (Island Press, Washington, DC), pp 3–24.
- Adger WN, Hughes TP, Folke C, Carpenter SR, Rockström J (2005) Social-ecological resilience to coastal disasters. *Science* 309:1036–1039.
- Koselleck R (1985) *Futures Past: On the Semantics of Historical Time*, trans Tribe K (MIT Press, Cambridge, MA).
- McSweeney K, Coomes OT (2011) Climate-related disaster opens a window of opportunity for rural poor in northeastern Honduras. *Proc Natl Acad Sci USA* 108: 5203–5208.
- Berkes F, Folke C, eds (1998) *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience* (Cambridge Univ Press, New York).
- Gallopin GC (2006) Linkages between vulnerability, resilience and adaptive capacity. *Glob Environ Change* 16:293–303.
- Cutter SL (1996) Vulnerability to environmental hazards. *Prog Hum Geogr* 20: 529–539.
- Adger WN (2006) Vulnerability. *Glob Environ Change* 16:268–281.
- Luers AL, Lobell DB, Sklar L, Addams CL, Matson PA (2003) A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. *Glob Environ Change* 13:255–267.
- Blaikie P, Cannon T, Davis I, Wisner B (1994) *At Risk. Natural Hazards, People’s Vulnerability and Disaster* (Routledge, London).
- Kasperson JX, Kasperson RE (2001) *Global Environmental Risk* (Earthscan, London).
- Walker BH, Anderies JM, Kinzig AP, Ryan P (2006) Exploring resilience in social-ecological systems through comparative studies and theory development: Introduction to the Special Issue. *Ecol Soc*, Available at [www.ecologyandsociety.org/vol11/iss1/art12/](http://www.ecologyandsociety.org/vol11/iss1/art12/).
- Miller F, et al. (2010) Resilience and vulnerability: Complementary or conflicting concepts? *Ecol Soc*, Available at [www.ecologyandsociety.org/vol15/iss3/art11/](http://www.ecologyandsociety.org/vol15/iss3/art11/).
- Ibararan ME, Malone EI, Brenkert AL (2010) Climate change vulnerability and resilience: Current status and trends for Mexico. *Environ Dev Sustain* 12:365–388.
- Tainter J (1988) *The Collapse of Complex Societies* (Cambridge Univ Press, Cambridge, UK).
- Smit B, Burton I, Klein RJT, Wandel J (2000) An anatomy of adaptation to climate change and variability. *Clim Change* 45:223–251.
- Adger WN (2003) Social capital, collective action and adaptation to climate change. *Econ Geogr* 79:387–404.
- Abramovitz JT, et al. (2001) *Adapting to Climate Change: Natural Resource Management and Vulnerability Reduction* (International Union for Conservation of Nature and Natural Resources, Gland, Switzerland).
- Olsson P, Folke C, Berkes F (2004) Adaptive comanagement for building resilience in social-ecological systems. *Environ Manage* 34:75–90.
- Tompkins EL, Adger WN (2004) Does adaptive management of natural resources enhance resilience to climate change? *Ecol Soc*, Available at [www.ecologyandsociety.org/vol9/iss2/art10/](http://www.ecologyandsociety.org/vol9/iss2/art10/).
- Berkes F (1999) *Sacred Ecology: Traditional Ecological Knowledge and Resource Management* (Taylor & Francis, Philadelphia).
- Endfield GH (2008) *Climate and Society in Colonial Mexico: Studies in Vulnerability*, RGS-IBG Research Monograph Series (Wiley–Blackwell, Oxford and London).
- Wilken GC (1987) *Good Farmers: Traditional Agricultural Resource Management in Mexico and Central America* (Univ of California Press, Berkeley).
- Badstue LB, et al. (2006) Examining the role of collective action in an informal seed system: A case study from the central valleys of Oaxaca, Mexico. *Hum Ecol* 34: 249–273.
- Scott J (1976) *The Moral Economy of the Peasant. Rebellion and Subsistence in Southeast Asia* (Yale Univ Press, Boston).
- Liverman D (1999) Vulnerability and adaptation to drought in Mexico. *Nat Resour J* 39:99–115.
- García-Acosta V, ed (1997) *History and Disasters in Latin America. Network of Social Studies in the Prevention of Disasters in Latin America* (CIESAS, Mexico) (in Spanish).
- Florescano E (1980) A forgotten history: Drought in Mexico. *Nexos* 32:9–13.
- Hamnett BR (2002) *Roots of Insurgency: Mexican Regions, 1750–1824*. Cambridge Latin American Studies (Cambridge Univ Press, Cambridge, UK).
- Berry KA (2000) Water use and cultural conflict in 19th century North-western New Spain and Mexico. *Nat Resour J* 40:759–781.
- Endfield GH (2007) Archival explorations of climatic variability and social vulnerability in colonial Mexico. *Clim Change* 83:9–38.
- Murphy ME (1986) *Irrigation in the Bajío Region of Colonial Mexico*, *Dellplain Latin American Studies*, No. 19 (Westview Press, Boulder, CO).
- Florescano E (1981) *Sources for the History of the Agrarian Crisis of 1785–1786* (Archivo General de la Nación, Mexico City) (in Spanish).
- Zamarroni Arroyo R (1960) *Narratives and Legends of Celaya and the Bajío*, Mexico (Editorial Periodística e Impresora de Mexico, Mexico) Vols 1 and 2 (in Spanish).
- Eakin H, Appendini K (2008) Livelihood change, farming and managing flood risk in the Lerma Valley, Mexico. *Agric Human Values* 25:555–566.
- Kirkby AVT (1973) *The Use of Land and Water Resources in the Past and Present Valley of Oaxaca, Mexico*, *Memoirs, Museum of Anthropology*, No. 5 (Univ of Michigan, Ann Arbor, MI).
- Costello A, Maslin M, Montgomery H (2011) Global health and climate change: Moving from denial and catastrophic fatalism to positive action. *Philos Trans R Soc* 369(1942):1866–1882.
- Hassan F (2000) Environmental perception and human responses in history and pre-history. *The Way The Wind Blows: Climate, History and Human Action*, eds McIntosh RJ, Tainter JA, McIntosh SK (Columbia Univ Press, New York), pp 121–140.
- Fraser EDG, Mabey W, Slaymaker O (2003) Mutual vulnerability, mutual dependence. The reflexive relation between human society and the environment. *Glob Environ Change* 13:137–144.
- McIntosh RJ, Tainter JA, McIntosh SK (2000) Climate history and human action. *The Way The Wind Blows: Climate, History and Human Action*, eds McIntosh RJ, Tainter JA, McIntosh SK (Columbia Univ Press, New York), pp 1–42.
- Folke C (2003) Social-ecological behavioural responses. *Structural Determinants of Environmental Practice*, eds Beil A, Hansson B, Martensson M (Ashgate, Surrey, England), pp 226–242.
- Hulme M (2008) Geographical work at the boundaries of climate change. *Trans Inst Br Geogr* 33:5–11.
- Pelling M, High C (2005) Understanding adaptation: What can social capital offer assessments of adaptive capacity? *Glob Environ Change* 15:308–319.
- Ponzo CA (2005) Globalisation and economic growth in the third world: Some evidence from eighteenth century Mexico. *J Lat Am Stud* 37:437–467.
- Clark WC, Jager J, Eijnhoven vJ (2001) Managing global environmental change: An introduction to the volume. *Learning to Manage Global Environmental Risks: A Comparative History of Social Responses to Climate Change, Ozone Depletion, and Acid Rain*, *The Social Learning Group*, eds Clark WC, Jager J, Eijnhoven vJ, Dickson N (MIT Press, Cambridge, MA), Vol 1.