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Human adaptation to climate change: a review of three historical cases and some general perspectives☆

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Abstract

To study mitigation and adaptation to climate change, social scientists have drawn on different approaches, particularly sociological approaches to the future and comparative history of past societies. These two approaches frame the social and temporal boundaries of decision-making collectivities in different ways. A consideration of the responses to climate variability in three historical cases, the Classic Maya of Mexico and Central America, the Viking settlements in Greenland, and the US Dust Bowl, shows the value of integrating these two approaches.

Keywords: Climate change; Adaptation; Environmental impacts; Policy analysis

1. Introduction

The purpose of this paper is to bridge approaches from two sets of disciplines to the study of mitigation and adaptation to climate change. One approach, linked to policy analysis, may be called ''the sociology of the future''. It consists of research in political sociology, policy sciences, development studies and organizational theory in sociology that describes, analyzes and evaluates possible responses to climate change, principally on the part of national governments and international organizations. This research is often centered on models and on general discussions of social systems. Much of this work has grown in recent years through the activities of individuals and groups linked to the Intergovernmental Panel on Climate Change. The other approach may be called ''the comparative history of the past''. It consists of research in archaeology, anthropology and history that examines the responses of earlier societies to climate variability and to other environmental factors (Le Roy Laudurie, 1967; Jones et al., 2001; Davis, 2001). This research is often very concrete and empirical. Some of it consists of chronological correlations of climate variability and extreme social change. This work represents a longer-established approach, associated in part with the journal *Annales d'histoire économique et sociale* and with environmental perspectives in archaeology.

This paper takes some initial steps at linking these two approaches. Each can offer the other a great deal. The comparative historical studies can provide data to test models and can also offer some insights on methodological issues. The sociological studies can provide the historical studies with analytical frameworks that may serve to permit generalization.

This paper centers on the analysis of three cases of societal response to climate variability. Before discussing the cases, it is important to address two questions of definition raised by this question. Firstly, following the usage of the Framework Convention on Climate Change, the term ''climate variability'' will be used to refer to climate fluctuations that are non-anthropogenic and ''climate change'' to refer to the current shifts, in which a major part of the change can be explained as the result of anthropogenic causes. It may be noted that this distinction can be difficult to maintain in some specific cases, since it masks the fact that some earlier societies created strong negative environmental impacts. As we will soon see, there

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are earlier cases in which the economic activities of societies have led to environmental change that have increased their vulnerability to climate fluctuations. They have also altered vegetation in ways that probably influenced precipitation on a regional, though not on a global, scale. So though it is correct to say that human influence on global climate is recent, human influence on regional climate is much older.

Secondly, the word ''adaptation'' has a number of different meanings. This term comes easily to biologists and to psychologists, who have sharply defined and fully operationalized measures of well-being at the individual level. This term seems as if it could easily be extended to human collectivities, since there are some ready measures of human well-being—increases in life expectancy, nutrition and health, and perhaps in general flexibility and responsiveness; the reduction in vulnerability to external fluctuations might also seem a sign of adaptation. However, it bears noting that human history is filled with examples of groups that have proposed models of societal progress that turn out only to benefit a fraction of the population, so it is important to be cautious in using the word ''adaptation''. Within the IPCC framework, adaptation has been defined as ''adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities'' (FCCC, 2001: Annex B). Within this broad range of adaptations, several axes can be recognized, between anticipatory and reactive adaptation, between private and public adaptation, and between autonomous and planned adaptation. Defined in this fashion, adaptations stand in contrast to mitigation, defined in the same source as ''an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases''. Mitigation thus seeks to reduce a principal cause of the problem, rather than seeking an accommodation with the problem. This difference is reflected not only in the definitions themselves, but also in the fact that the former is associated with Working Group II and the latter with Working Group III. However, many of the activities associated with adaptations can influence the sources and sinks of greenhouse gases.

Related to the concept of adaptation is the notion of maladaptation, generally absent from the IPCC reports that seek to offer an optimistic view of humanity's capacity to respond to problems, but strongly articulated in Jared Diamond's recent book, *Collapse*: *how societies choose to fail or succeed* (Diamond, 2005). Drawing on the comparative history of the past, especially in its careful examination of Pacific island societies, it focuses on the sharply divergent trajectories of societies faced with environmental challenges. Some respond positively, adapting to new circumstances, while others collapse: they face large-scale, long-lasting and dramatic declines in population or in socio-economic or political complexity. Easter Island represents the most dramatic case of collapse. The Polynesians who settled the island created a society of agricultural chiefdoms that built, transported and erected the enormous stone heads for which the island is famous; they also deforested the island, making it impossible for them to build canoes that allowed them to catch porpoises and offshore fish, and creating erosion that reduced agricultural yields. Populations declined sharply and the construction of monuments ceased, offering a dramatic example of the collapse that can attend a failure to adapt to environmental problems, such as deforestation. Before presenting the specific cases that are discussed in this paper, it bears noting that the adaptation (at least in some senses of the word) to climate variability is a long-standing part of our species' history on this planet. Indeed, in some views, it is a central part. The evolution of the hominid family within the primate order can be linked to the gradual drying of the African forests and to the development of the savannah landscapes that favored bipedalism, the development of the human hand and perhaps the social and cognitive elements that favored more collective food production. The evolution of human culture and language has also been linked, perhaps less conclusively, to the extensive climate fluctuations of the Pleistocene that required more complex patterns of social learning and transmission. The human patterns of tool-use and collective behavior that allowed early humans to cope with the rapid shifts in temperature and precipitation were passed on through these more elaborate systems of culture and language. And finally, the development of agriculture and urban civilization (to use yet another term whose definition is also difficult) can be linked to the more stable climate of the recent millennia of the Holocene.

These times may seem remote to us, so it is worth mentioning these earlier periods to keep in mind that humans have a longer history than is often recognized. This paper, however, focuses on cases from more recent times, only from the last two millennia. They are relatively well-studied ones: the Maya civilization of Mexico and Central America from about 250 to 900 A.D., one set of the numerous Viking settlements throughout the North Atlantic and Baltic regions from about 985 to 1430 A.D., and the Dust Bowl of the US in the early and middle decades of the 20th century.

A comparative effort of this sort can offer a preliminary assessment of straightforward hypotheses. Two examples of such hypotheses link the scale and novelty of climate fluctuations to societal capacity for response. Societies might respond more effectively to smaller climate fluctuations than to larger fluctuations and to climate fluctuations that they have experienced on a smaller scale than to entirely novel climate fluctuations. Though these cases do support these views, they also indicate some challenges to testing these hypotheses that result from the complexity of societies themselves and of their interactions with environmental factors, both climatic and non-climatic. Firstly, the impact of climate fluctuations, and therefore the challenges to which societies must respond, does not depend only on the scale and novelty of the fluctuations. Societies change their environments, and thus alter their own vulnerability to climate fluctuations. Secondly, societies respond to many

forces, not only climate fluctuations, so it can be difficult to sort out the components of change that are direct responses to climate fluctuations and those that are linked to other factors and that might have occurred even in the absence of climate locations.

The rich documentation for these three cases allows some exploration of the impacts of climate fluctuations on society, of the societal responses to these fluctuations and impacts, and of the societal processes that affect societal response. There is sufficient material to discuss the adaptations that these societies made to climate fluctuations and to evaluate their success. Recent developments in the geosciences and in ecology offer detailed accounts of the climate fluctuations themselves. As will be discussed more fully in later sections, it is possible to demonstrate a significant capacity for adaptation in these societies, but also to note limitations to this capacity, particularly in the face of large-scale and unfamiliar climate fluctuations.

2. Case 1: Classic Maya collapse

The Maya are one of the major civilizations of the world. They represent one of most important cases of the autonomous development of civilization, since they arose in the New World, with no contact with the early civilizations in Africa, Asia and Europe. The Maya cultural region lies in Mesoamerica, including what is now south-eastern Mexico, Guatemala, Belize and western portions of El Salvador and Honduras.

The natural environment is a strong influence on human society in this region as elsewhere. As a tropical zone, the temperatures are usually high. A marked separation of the rainy and dry seasons means that the bulk of the precipitation falls in the second half of the year. Part of the Central American isthmus, much of the Maya region is fairly close to the sea. The largest section consists of flat lowlands, with thin soils resting on a limestone base. The soils are relatively poor. The porous limestone absorbs much of the water that falls during the rainy season, so there are many areas with few rivers and lakes. There is a small highland section associated with a belt of volcanoes. This region has richer soils and more moisture, but it is smaller in area. There is also a narrow band of lowlands along the Pacific; soils there are richer, but the climate is drier.

The critical constraints on economic activity in the Maya region, therefore, are the poor soils and the seasonal droughts. Agriculture in this area has relied heavily on rainfed agriculture of maize and beans. Since the thin soils were not very productive, long fallow periods were required, limiting population density. This agriculture can be supplemented by marine fish and some tree crops. In the view of many, the Maya case is an exception to the rule that civilizations develop in areas of intensive agriculture; it is also unusual for the relative scarcity of domesticated animals, since dogs and turkeys were the only domesticates. Some archaeologists have noted examples of intensification, such as the terracing of some hillsides and the cultivation of seasonal wetlands known as *bajos*, possibly with the construction of raised fields similar to those found elsewhere in Mexico and in South America (Dunning et al., 2002).

Archaeologists conventionally divide Maya history into three periods. The Preclassic can be traced back to 1500 B.C. and earlier. The basic set of crops and tools for production and processing of crops had developed by this period, and the spatial framework of the agricultural village developed.

Some of the later Preclassic societies began to dig canals, enlarge water holes and build subterranean water storage facilities to address the critical issue of water availability in this region with a long dry season and little surface water (Adams, 1991). The last century or two of the Preclassic, from about 100 to 250 A.D., was a time of increase of population levels and settlement sizes. Large buildings were constructed in some villages, including temple pyramids. This was the period of the development of sacred kingship. Rulers lived in compounds at the center of settlements and conducted complex sets of rituals. Associated with this political and religious life was the development of art, particularly stone carving, pottery, working of jade and other precious stones.

These elements expanded in the Classic Period from 250 to 900 A.D. Extensive ceremonial centers were built, with large pyramids and temples arrayed around central plazas. Many of these contained elaborate carvings and frescoes. They were the site of massive rituals led by members of noble clans; their descent from semi-sacred ancestors allowed them to communicate with the gods who assured the continuance of life. The ritual knowledge expanded into many areas. Systems of writing, mathematics and astronomy developed, allowing the Maya to recognize constellations, track the movement of the moon and planets and to establish a calendar (Freidel and Schele, 1988). Archaeologists have been able to decipher and understand Maya hieroglyphic writing and to correlate the dates that are inscribed on many sites with the Western calendar. Though some archaeologists refer to these centers as city-states, they could better be understood as ceremonial centers. The largest states, such as Tikal, ruled areas of over 3500 km^2 with populations of over 300,000. The populations at the ceremonial centers often ranged from 25,000 to 50,000. They were supported by large populations of peasant households and by craft specialists. These centers linked in trade networks that transported precious stones, tropical plants and craft items throughout the entire Maya region and to more distant areas, especially in central Mexico, as well. They competed with one another and fought wars that had strongly intertwined religious and political aspects. The victors gained in a material sense, since they had a larger population that would provide tribute in the forms of crops, and in a religious sense as well, since their ritual power was increased. Pollen remains indicate significant deforestation for the expansion of agriculture in this period, and there is also some evidence for the

intensification of agriculture and the development of irrigation in some areas (Dunning et al., 1997). The common people lived in many ways as they had in earlier times, in simple thatched huts. The rituals that took place in the ceremonial centers were mirrored on a smaller scale at the household. Some precious and trade goods, especially from stone, were found in peasant households as well. These points suggest the involvement of the peasants in the ritual world of the nobility.

By the 8th century, many of the largest ceremonial centers were abandoned. Construction of monuments came to an end. Archaeologists have been able to record the last major date inscribed on a stone stela to this period (Houston, 2000). Archaeologists describe the period from 900 to the Spanish Conquest as the Post-Classic. The collapse of Maya civilization has offered dramatic images. To many, the Maya landscape was a haunting one, in which ancient pyramids, covered with vines, were surrounded by the huts of simple farmers who were the descendants of the former civilization, still speaking the same language and following rituals that bore some resemblance to earlier ones. Archaeologists have noted that different centers were abandoned in the relatively short period of 750–950 A.D., with the western settlements declining earlier and the eastern ones later. In a few sections, major centers did continue to be inhabited. In the northern portions of the Yucatan Peninsula, Chichen Itzá and Uxmal survived into later centuries, though this region has a higher watertable and might be better able to weather droughts. Other settlements on the Pacific Coast expanded, in connection with cacao production and trade. These Post-Classic sites were smaller than the major Classic sites.

Archaeologists have long debated the causes of this collapse. Climate has long been considered as a factor. The need of the Maya for water resources is evident in their longstanding concern for surface water and their elaborate construction of water storage facilities. A recent article offers data that looks particularly persuasive (Haug et al., 2003). A proxy for climate variability with fine temporal resolution has recently been developed. The Cariaco Basin in the Caribbean Sea, off the coast of Venezuela, receives a heavy load of sediment from nearby rivers. These are deposited stably, because of the weakness of currents, and are well-preserved because the waters contain no dissolved oxygen. Annual laminations occur once a year, so the sediments can be read like layers in ice cores or like tree rings. In years of heavy rainfall, the sediments contain higher titanium concentrations because of greater erosion and runoff in the drainages of rivers that run into the basin. These sediments show multiyear droughts that began around 760, 810, 860 and 910 A.D., which contrast with the generally moister climate in earlier centuries (Haug et al., 2003).

To be sure, other environmental explanations have also been offered. Pollen records from lakes show a general depletion of forests during the Classic Maya period, and suggest that soils may have been impoverished (Dunning et al., 1997). Classic societies were supported by the incorporation of previously uncultivated areas, a tactic that could not be sustained indefinitely. Lake records also show some increase of erosion during this period (Dunning et al., 1997).

Other social explanations have been offered. Unlike many ancient civilizations that rested on state-controlled irrigation, the Maya ceremonial centers did not provide the masses of agricultural peasants with any key inputs, so they were able to withdraw more readily from supporting the nobility. It is possible that the burdens of such support did increase. The growing number of fortified sites in Late Classic and Post-Classic period suggests an increasing militarization of late Classic Maya society, which in turn might imply greater dissatisfaction on the part of the bulk of the population (Demarest, 1997). The question of the involvement of the mass of Maya peasant cultivators with the elite rituals is an important matter, and a difficult one to infer from the archaeological record. The spatial isolation of some elite ritual sites suggests a more exclusive ritual in which the masses did not participate, though the alternative view, of the religious legitimacy of the elite, is supported by the presence of some prestige artifacts in commoner households and in some similarities between commoners and elites in sacrifice and burial practices.

Another line of explanation is that Maya region was influenced by social pressures that originated elsewhere. In particular, the decline of Maya ceremonial centers occurred soon after the decline of the state of Teotihuacan in central Mexico; in turn, this could have disrupted trade routes that supplied the prestige goods that were vital to the religion-centered system of rule in the Maya region. This argument gains support from the earlier collapse of Maya ceremonial centers in the areas closest to Teotihuacan.

These explanations are, of course, complementary. It could be argued that Classic Maya civilization had systems of political rule that were weakened by the competition of different centers and by the lack of direct state involvement in production. Moreover, drought might have had an effect on Teotihuacan.

Another critical question in the case of the Maya is whether the abandonment of the major ceremonial centers can genuinely be equated with a total collapse of society. Though some studies argue for a sharp decline in population, other researchers offer at least a partial challenge to this view. It can be difficult to estimate populations in prehistory. Such estimates rest on a tally of the number and density of houses, which can be difficult to trace in prehistory. There is some evidence that many households moved further from the population centers, redistributing themselves across the landscape. Some studies of lake sediments have claimed that pollen records in sediments demonstrate an increase in forest area, but this may have occurred centuries after the Maya collapse rather than in the following decades. Other studies have used skeletal remains to suggest that the health of the Maya population was declining at the end of the Classic period, especially since stature declined. These studies have

suggested that there were outbreaks of epidemic disease, perhaps associated with malnutrition (Wright and White, 1996). They have examined the ratios of isotopes in bone, teeth and collagen to assess the amount of protein in the diet and the reliance – or over-reliance – on maize (White et al., 2001). These isotope studies offer little evidence of widespread malnutrition.

3. Case 2: the abandonment of Viking settlements in Greenland

The Vikings were the first Europeans to settle in Greenland. They came from Iceland, which had itself been settled in 874 through 930, around 985, as part of the general Viking expansion throughout the north Atlantic and the Baltic (Amorosi et al., 1997). Often seen as bands of marauders and pirates, the Viking settling expeditions were in fact highly organized with chiefs and followers, and with a strong cultural patterning of their behavior; their taking of territory involved ritual acts of possession. Though Greenland and Iceland are relatively near each other, with a distance of only about 175 km at their closest, this settlement required significant effort. The largest ice-free areas in Greenland are in the southwest and west of the island, about 850 km from Iceland.

There were two principal Viking settlements in Greenland. They are generally known by their Viking names as the eastern settlement, near the present Julianehab, and the western settlement, near Gothalb, or Nuuk. The western settlement lies principally to the north of the eastern settlement; their latitudes at 64°N and 61°N, respectively (Buckland et al., 1996). The populations may have peaked at around 3000 in a total of about 280 farms, suggesting a large mean household size. The farms were dispersed, at distances of about 5–10 km between them. The smaller western settlement had about 800–1000 people, with about 500 cattle and 1600 sheep and goats.

Though the initial settlers practiced their traditional polytheistic religion, the settlements joined the general move of Vikings to Christianity. The Icelandic Parliament voted to accept Christianity in the year 1000. Greenland was Christianized in the following decades by delegations from Norway. A bishop was sent to the eastern settlement in the 12th century (Amorosi et al., 1997).

The disappearance of these settlements around 1350–1400 has long fascinated outsiders, especially the Scandinavians. The Danes sent expeditions in the 17th century to locate what they presumed were the Viking descendants who had reverted to paganism. They were surprised to see that the settlements were empty. Various theories have been proposed to account for their end, including pirate raids and the deleterious effects of inbreeding.

There are a number of lines of evidence that provide details of the Viking settlements. The documents have all been collected and subject to extensive scholarly scrutiny. These include the Icelandic annals and early geographical descriptions of the landscape. These records provide information on the history of changing amounts of sea ice off the coast of Iceland. Archaeology has been conducted in the area since the 1930s and 1940s, with increasingly rigorous and scientific techniques in recent decades. Great advances have also been made in paleoecology. It is possible to determine the temperature of rooms at the time of human habitation from the remains of insects, since insect species live and breed at characteristic temperatures (Buckland et al., 1996). It is also possible to determine the season when game animals were killed by the formation of annual rings on their teeth. Finally, extensive analogies can be drawn with the similar, more densely populated and much better documented Viking society on Iceland.

The nature of the farm economy of the settlements on Greenland is well established. Since cultivation of crops was impossible, the settlers relied on livestock, cattle, sheep and goats. The animals could graze out in the open for only 3 months of the year, July, August and September. Dairying was an important activity from June through September. Hay production was carried out in August to provide fodder for the 9 months of the year when the animals could not graze. The hay barns occupied a large portion of the farm homesteads, especially in the western settlement. In some areas, irrigation channels were dug to favor the earlier development of grass in the summer. There was little use of seaweed to feed cattle, though this has been practiced in other areas. This was one of the most extreme cases of the pattern of summer haying and winter indoor feeding that is characteristic of much of temperate Europe.

Hunting also provided important sources of food. The settlers took seals, especially migratory seals in spring at the outer fjords, some 70–80 km from the western settlement and perhaps 40–50 km from the eastern settlement. They often attacked seals on beaches when they were bearing their pups. In some cases they set up sealing stations, stringing nets across harbors and between islands. Individuals or families may have owned these sealing stations (Barlow et al., 1997). They also hunted caribou, largely in the autumn. In some cases at least there were organized caribou drives, again organized and led by certain leading households. They slaughtered the caribou at some distance from the homesteads and brought the larger limbs to the settlement, where they were served in feasts. They did not hunt non-migratory seals very much, and did not set out to hunt seals from seagoing boats. They hunted some seabirds, especially murres and guillemots, throughout the year (Gotfredsen, 1997). The game that was available in winter – hares and ptarmigan – did not provide very much meat.

Interestingly, they fished relatively little. They did gather wild berries seasonally. The late winter was the hardest season for them, when hay was scarce for the livestock, stores of meat and cheese were limited, and it was too early to hunt seals. The Vikings cracked bones into fragments in order to extract marrow. They carried out this practice far

more extensively than the native populations at the same time, suggesting that food was scarcer for them.

Despite the remoteness of the settlements, they were actively involved in trade with Europe. They provided some local pastoral products, such as butter, cheese and wool, but more important were the Arctic products, walrus ivory, polar bear skins, and Arctic falcons, which were traded throughout Europe and beyond. These products came from regions further north, around 68–70°N. Some of these were provided as tribute, but they received other products in exchange, such as iron, salt, timber, honey and dyes. This trade was a Norwegian monopoly after 1261. The Norwegians promised to send a ship each year, though they did not always comply with this requirement. The settlers relied on outside ships; they had boats that could travel along the coast, but apparently did not venture out to Europe on their own.

The social organization in the small settlements rested on extended farm households. The wealthy and powerful had larger farms, with larger halls for meetings and feasts, and larger craft shops, such as smithies. There were stone churches in both settlements, and the eastern settlement had monasteries and a cathedral with stained glass windows and bronze bells (Buckland et al., 1996).

An interesting aspect of the history of these settlements is their interactions with native peoples. At the time of their arrival, this portion of the Greenland coast was not settled, though there had been earlier groups known as the Paleo-Eskimo or Saqaaq. The Dorset culture groups had withdrawn from the area around 600 A.D. However, a new group, known as the Thule culture, had moved eastward across continental North America and had begun to edge downward the west coast of Greenland around 1000 A.D. They had met the Viking settlers on their expeditions for Arctic goods at least by 1200 A.D., if not earlier. The Vikings called them ''skraelings'' or wretches (Barlow et al., 1997). These native people (the Inuit were a later group) obtained iron and small objects from the Vikings, but the absence of native goods in Viking settlements suggests that they did not receive, or seek, goods from them.

The ice cores and the historical records of sea ice document runs of cold years in 1308–1318, 1324–1329, 1343–1362 and 1380–84 (Grove, 2001). Though one would imagine that cold winters would be particularly difficult for the Vikings, it is possible that low summer temperatures would have been more difficult, if they reduced the production of hay. However, cold winters might have been a problem too, if ice blocked the fjords and access to the sealing grounds that provided food at a particularly critical time of year. It seems likely that the colder weather did end their settlements. Some accounts have suggested that the Vikings fled these settlements. They draw as evidence the absence of human remains and the relative scarcity of artifacts in the settlements, claiming that these would have been found if the settlers had died in Greenland. However, a removal of the settlers would have been likely to be mentioned in the chronicles. Archaeologists have found some possible native adzes in the western settlement in positions that suggest that Thule people came to scavenge Viking metal after the settlements were abandoned. Moreover, archaeozoological evidence provides strong evidence of crisis in late winter or early spring. The highest layers of twigs and dung show that temperatures had fallen, so that animals would have been brought from their barns into human quarters. The bones of hunting dogs, bearing clear signs of butchering, demonstrate that the settlers were desperate enough to eat these animals (Buckland et al., 1996).

It has also been argued that an interruption in the trade with Europe had a strong negative effect on the settlements. Indeed, there were reports of more extensive sea-ice in that portion of the Atlantic. Moreover, Europeans developed other sources of the scarce goods that came from Greenland. In particular, African sources of ivory substituted for walrus tusk. However, the trade with Europe brought only a small proportion of foodstuffs. Perhaps the metal for tools was more critical.

Though there are few good sources of radiocarbon dates, since wood, brought from outside in any case, was much reused. But the available evidence does match with the documentary records, suggests a date in the mid-14th century for the end of the western settlement and a date early in the 15th century for the eastern settlement (Buckland et al., 1996).

Though the Vikings suffered in these years, they were not difficult for the natives. There is the question of why the Vikings did not learn from the natives, whose kayaks and harpoons must have been familiar to them. A few accounts suggest that there were tense relations between the two groups, particularly a much-quoted though brief document from the mid-14th century in which residents of the eastern settlement propose sending an expedition to defend the inhabitants of the western settlement from fights with the natives. However, evidence of violence is generally scanty. It is possible that the Vikings were unwilling to give up their entire way of life, to abandon trade with Europe and shift to a greater reliance on hunting wild animals. This might reflect some general principles about the flexibility of cultures, or the strength of the Viking's belief in the superiority of civilization and Christianity (Barlow et al., 1997).

A very detailed study of animal bones in one large western settlement site with long records (McGovern et al., 1996) permits the tracing of a shift in subsistence. There was an increase in consumption of caribou in mid-12th century, and a general increase of wild animals, both caribou and seals, in the early 14th century in relation to cattle, sheep and goats. The archaeologists note that the Vikings cracked bones to obtain marrow far more extensively than the native populations, a possible sign of the scarcity of foodstuffs. Interestingly, goats increase relative to sheep in this period, contrary to what might be expected. In the early decades of the settlement, goats might have foraged on the low birch and willow, and sheep might have fared better as the

vegetation shifted to become more predominantly grasses and sedges. The specific characteristics of the Viking breeds were probably a factor.

Though the climate shifts seem critical to the end of these settlements, other factors have been proposed for their decline. Environmental decline is one. Pollen taken from cores suggests a shift in vegetation and an overgrazing of meadows, and there are some hints of erosion as well; these problems are well documented for Iceland, where deforestation and loss of soil fertility are more extensive. Others have suggested that the lords and the church exacted so much tribute that the settlers become impoverished. Native hostility has also been proposed. These factors may have interacted. It remains a dramatic image, the end of these small settlements that had lasted for twenty generations at the end of the earth.

4. Case 3: the US dust bowl

The third case is the response to periodic drought in the southern portion of the Great Plains of the US. This area corresponds to the states of Oklahoma, and portions of Kansas, Texas, Colorado and New Mexico. This region generally has rich soils, like other temperate grasslands where climate promotes formation of deep layer of humus, though some portions of the area have relatively alkaline soils. Its topography is fairly flat, though rivers are often incised in broad valleys. The rainfall corresponds generally to a longitudinal gradient, with greater moisture in the east and less in the west. The vegetation follows this gradient, with tall-grass prairie east of longitude 100°W, and short-grass prairie further west.

This area was settled millennia ago by Native Americans who relied on agriculture and hunting. The hunting economy, centered on buffalo, grew after the local groups acquired horses around 1700 from the Comanches; the Comanches, in turn, had received them from the Apaches who had obtained them from Spaniards in the early 17th century. Some Spanish and Mexican settlement had begun in lower portions of this region in the late 18th and early 19th centuries. The Native Americans were displaced from this region throughout the 19th century. There was an expansion of cattle ranching in this region in the last third of the 19th century.

The livestock economy in these areas grew up after the close of the US Civil War in 1865. There were major cattle drives in the 1860s and 1870s to the railheads, from which cattle were shipped to markets in the eastern US. Important technological changes that facilitated this growth were the introduction of barbed wire in 1873, favoring fencing and more sustained investment, and the use of refrigerated rail cars in the 1880s (though these were opposed by the organizations that represented butchers in large cities, who wished to see live cattle continue to be shipped to slaughterhouses). An unusually cold winter of 1885–1886 led to the death of many cattle.

The agricultural frontier that had moved westward from the Atlantic Coast since the 17th century, at a varying pace, reached this region around the 1870s. This expansion was encouraged by the federal Homestead Act of 1862, a law that promoted the establishment of farms with 160 acres, about 65 ha. This law followed the general tendency of the more industrial and capitalist North to promote commercially oriented family farms. The farmers in this area were known as ‘‘sod-busters’’ because they broke the dense layer of prairie grassland vegetation. Their first houses in this treeless region were often built of sod blocks. The frontier reached Kansas in the 1880s and continued into the flat expanses of eastern Colorado, towards the foothills of the Rocky Mountains. It was driven by demand for grain in the US and abroad, and facilitated by the expansion of railroads. The decline of cattle-raising after the winter of 1885–1886, especially in northern portions of the region, also favored the rise of agriculture.

The first settlers had unrealistic expectations about the moistness of the climate of this region. They drew on their experience with wetter regions further east, on the general optimism of the period and of frontier settlers generally, and also on beliefs that ‘‘rain follows the plow’’—that cultivation would render the regions wetter (Opie, 1998). Though they had a relatively short historical experience in the region, and were unlikely to respect the accounts of Native Americans of cycles of rainfall and drought, they did neglect the earlier accounts, especially those of the expeditions that crossed this region in the 1840s, a drier period, and reported it to be a desert.

A drought hit the region in the late 1880s. It ran from 1889 through 1892 and led to certain shifts in agricultural production and agronomic techniques. Farmers shifted to deeper plowing to utilize moisture deeper in the soil, though this practice led to a weakening of soil structure. They left some regions in fallow. There was a shift from maize to wheat, particularly more drought-tolerant sorts of wheat. This set of techniques was known as ‘‘dry farming’’ and was believe highly suited to the region. With these techniques, farmers produced good yields through the first years of the 20th century. However, a drought in 1910–1913 affected the southern plains. It created the first massive dust storms of the period. Farmers began to be aware of wind erosion as a problem, and discussed methods to control it.

This drought was soon forgotten with the rains that came in 1914, especially since World War I led to an increase in the price of wheat. The acreage of wheat increased through the prosperous years of the 1920s, which was generally a moist period, with a run of somewhat drier years in 1917–1921 and lower prices in early 1920s. The farms became more mechanized, as farmers replaced horse-drawn equipment with automobiles, tractors, and the combine thresher-harvester. The disk plow dug the soil more deeply, a practice that was valued in this era of ‘‘dry farming’’. Farmers incurred high debts, encouraged by the availability of loans and the presence of farm equipment stores.

The dust bowl itself occurred during the 1930s, the years of scanty rain and of the Great Depression. The drought was most severe in southern Kansas, western Oklahoma and adjacent portions of Colorado, Texas and New Mexico. Stripped of vegetation, without rain to bring crops, the soils, deeply dug, were eroded by wind. There were a few dust storms in 1932, and more in the following years. The worst storms generally occurred in 1935, the year of many ''black blizzards'' when the dust made it difficult to see even at noon. Heavy dust fell on cities hundreds of miles away on the East Coast. The storms continued through 1937. These images are powerful in the minds of Americans, who are familiar with the photographs of the Farm Service Administration and the novels about the period, such as John Steinbeck's *The Grapes of Wrath*. Farmers migrated from these states to cities and to more prosperous regions, especially on the West Coast (Opie, 1998).

These conditions brought farm foreclosures, as farmers were unable to pay their mortgages and loans. Roughly 5% of the farms were taken over by creditors, and many more were sold at low prices. Farms were in crisis elsewhere in the US as well. In 1933 the New Deal government of Franklin Roosevelt set up the Farm Credit Administration for the federal government to assume and administer mortgages. This year also brought the Agricultural Adjustment Act, in which the US government provided payments to farmers who agreed to limit production. This program, declared unconstitutional, was replaced by another program in 1936 that has continued. This marked the beginning of price subsidies and of allotments, in which farmers are given a certain maximum production that can be sold at guaranteed prices.

The government also sought to improve farming techniques to reduce erosion. It encouraged terracing, contour tilling and furrowing, and strip-cropping that left untilled zones. It also encouraged management of grasslands to avoid overgrazing. The US government set up programs to encourage Soil Conservation Districts, though these were created by state, rather than federal, law. They began in 1937 and were supported by federal funding to encourage techniques to protect soils. The Forest Service hired unemployed farmers and other workers to plant trees for windbreaks. The Farm Security Administration bought some land with poor soil which they hoped to restore to use for grazing, though this presence of the federal government as a landowner proved unpopular with many, who saw it as a kind of socialism. This period, interestingly, led to the expansion of the scientific field of ecology. Frederic Clemens, from this region, studied at the University of Nebraska and developed the concept of ecological succession.

The rains returned in 1940, and World War II brought increased demand for crops, especially beans, wheat and cotton. Farmers and commercial interests sought to undo soil conservation legislation that limited production. Marginal lands were brought into cultivation. There were droughts in the 1950s that brought dust storms. The area of wind erosion, in the states of Colorado, Oklahoma, Texas, Kansas and New Mexico, was more extensive than in the 1930s. The economic crisis, however, was not as severe, because of lower population densities and more extensive government support programs.

A new federal program, the Great Plains Conservation Program, run by the Agricultural Conservation Program Service, began in 1956. It offered 10-year contracts with assured sales and subsidized credit to farmers who agreed to adopt conservation measures and to shift from agriculture to grazing. This program supported the expansion of irrigation, particularly of alfalfa to support livestock. New technologies and inexpensive energy made it possible to irrigate large areas with groundwater, chiefly from a groundwater basin known as the Ogallala Aquifer. This basin contains what is essentially fossil groundwater, accumulated in earlier, moister geological eras and drained much faster than it can accumulate (Woodhouse and Overpeck, 1998). It continues to be overexploited, though the rate of withdrawal has slowed down somewhat since the 1980s with rising energy prices and some more efficient irrigation technologies. Nonetheless, this irrigation is clearly unsustainable, and little is being done about it. Groundwater is only loosely regulated in the US, and is chiefly the responsibility of the states rather than the federal government.

Recent paleoclimate research has shown that this region has been characterized by periodic drought for millennia (Laird et al., 1996). Natural vegetation has shifted correspondingly, and portions of the Great Plains were sand dunes in earlier periods. The current agriculture, supported by cheap energy and finite groundwater, cannot remain indefinitely. Other environmental problems affect the areas, such as pollution from the enormous cattle feedlots and the loss of biodiversity with continued draining of water, leveling of land, and removal of native vegetation. The livestock are a significant source of greenhouse gas emissions. Some have proposed creating a vast prairie national park and restoring native vegetation and buffalo, though this project is unpopular with many local farmers and with the anti-federal states-rights views of the region.

5. Discussion

These three societies discussed here, the Classical Maya, the Viking colonists in Greenland, and the frontier farmers of the Great Plains, are all quite different from one another, but they all faced climatic fluctuations that threatened the food production systems on which they rested. To examine their responses to these fluctuations, we can draw on the approaches mentioned earlier, the sociology of the future and the comparative history of the past. The former offers broad concepts, particularly adaptation and mitigation, which can contribute to the urgent debates of the present. The latter permits us to trace the complex interactions of different elements within each society. These two approaches complement each other in useful ways.

Emphasizing the sociology of the future, it is possible to observe in these cases the applicability of the concept of adaptation, because of the transformations of agriculture and other production systems that permitted effective use of climate-constrained environments, and because of the development of new economic and social forms as well that also favored survival and expansion in these environments. However, there are limits to these adaptations as well. The societies did not learn from experience that some forms of agriculture and production that are faced with repeated problems, or they forgot these lessons after a decade or two.

Emphasizing the comparative history of the past, it is also possible to observe a second set of lessons: the difficulty of applying the concept of adaptation. As is demonstrated by Le Roy Laudurie's comparative climate history (1967) and subsequent work in this tradition, the elements of benefit and harm, central to the concept of adaptation, cannot be easily operationalized, since they include disparate components and cover varying temporal and social scales. These problems remind us of the difficulties of finding simple metrics by which complex historical processes can be summarized. It is therefore important to acknowledge the importance of combining the urgency with which sociologists of the future face new processes climate change and the caution with which comparative historians examine the long record of climate fluctuations.

Turning first to the applicability of the notion of adaptation, all three societies expanded on established traditions in new ways in response to opportunities and challenges. Some of these opportunities and challenges were environmental and, more specifically, climatic, though others were economic and political. In this sense, it is reasonable to argue that these cases demonstrate the societal capacity for adaptation. The Maya societies grew in scale and complexity. During the Pre-Classical and Classical periods, they used land more intensively, with some practices of intensive agriculture and water storage, and reduced the forest cover significantly to increase the availability of agricultural land. The Viking societies also expanded and settled new places. In Greenland, they chose a particularly remote and cold place, though one with valuable scarce resources, and extended their earlier practices of livestock-keeping and hunting. Faced with a shorter growing season than in their homeland, they found new ways to build farmsteads and to store fodder. They develop techniques to hunt new game and to market the products of this game. In the US, frontier agriculture, with its particular mix of independent households, linkages to market, and reliance on national government, expanded into drier areas. Farmers experimented with new crops, new forms of soil management and new markets. The development of dry farming limited water loss, and improved cultivation techniques after the 1930s may have reduced vulnerability of soils to wind erosion as well. Some of these adaptations took place during periods of intermediate climate fluctuations. The Maya had lived through earlier dry periods, the Vikings in Greenland had experienced previous runs of cold years and of extensive sea-ice, and the Great Plains had had droughts in the decades before the Dust Bowl. These responses seem to fit well with the IPCC definition of adaptation, "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities."

However, these societies did not develop responses that allowed them to cope with more extreme climate variability. The Maya were not able to intensify food production beyond certain limits or to develop adequate water supplies. The Vikings may have learned to hunt seals and caribou and to extend the forms of hay production in Greenland, but they could not shift to entirely new systems of subsistence. The Dust Bowl offers strong examples of farmers who return time and again to plow vulnerable soils in years of greater rainfall and higher crop prices, despite the devastation that had occurred earlier within their lifetimes. These increases in mortality and this abandonment of settlements and lifeways are sobering messages about the limitations of societal capacity to adapt to climate variability.

These limits to adaptation stem in part from the way that societies exacerbate rather than ameliorate vulnerability to climate fluctuations. In all three cases, societal responses created environmental problems that made it more difficult for them to cope with climate variability. It is noteworthy that deforestation and vegetation change occurred in all three cases, despite the differences among them. Extensive rain forests were cleared in the Maya region, birch and willow cover was depleted in Greenland, and grassland biomass and complexity were reduced in the Great Plains. These changes led to soil erosion and, in the case of the Great Plains, were accompanied by overuse of water resources as well. These changes made it more difficult for societies to maintain their levels of production when faced with climate fluctuations. Moreover, these societies all faced other social, economic and political challenges: increased political competition and military conflict between ceremonial centers for the Maya, shifts in patterns of trade for the Vikings, and the political movements of the 1930s for the Dust Bowl.

These limits also stem from the divisions within society. The Maya rulers, faced with drier climates and reduced agricultural production, sought to bolster the position of particular ceremonial centers rather than to alleviate the conditions of the population at large. The Norwegian kings who nominally administered Greenland in the 13th and 14th centuries were more concerned about trade in valuable products and in keeping open trade routes than in the well-being of the farmers. The competing political groups in the US often used the plight of the Dust Bowl farmers to advance political programs in general, at times to the detriment of addressing the needs of the farmers and the sustainability of their livelihoods.

It is important to note that these complexities, particularly the societal modifications of environments and the social divisions, make it difficult to correlate scales of climate

variability and adaptation as some sociologists of the future might wish. It is possible to point to the earlier droughts in the Maya region and in the Dust Bowl, or to the earlier cold periods in Greenland, and to say that they were lesser than the ones that brought about such dramatic change and decline. Such correlations have indeed been offered. It appears, though, that they are easier to make in hindsight than prospectively.

However, these cases also support a view that the notion of adaptation is not directly applicable. The attention of comparative history to social complexity raises three concrete difficulties. Firstly, the Framework Convention on Climate Change defines adaptations as ''adjustments that moderate harm or exploits beneficial opportunities''. This definition requires consequences to be directly comparable, so that one can measure the reduction in harm and the increase in the exploitation of opportunities. However, human life involves many disparate domains of action that cannot be easily compared. For the Maya farmers who moved from the agricultural zones surrounding the ceremonial centers into forested areas, there was a change in economic activity and a change in religious activity: it is difficult to say whether the balance was positive for them. In contrast, the Vikings in Greenland, only a few centuries after their Christianization, refused to abandon the customs that defined them as European and civilized in order to adopt the locally successful practices of the indigenous populations whom they scorned; in this case, the efforts, broadly speaking, were to retain economic activity and religious activity, and it is equally difficult to say whether this balance was positive or not.

Secondly, the definition suggests that there is a collectivity that carries out the adaptation, a set of people for whom the benefits and costs can be totalled. These cases show the difficulties of demarcating such collectivities, a point underscored with particular effectiveness in another case of comparative history of the past, a study of El Niño-related famines in colonial settings (Davis, 2001). Societies are marked on the one hand by internal divisions between groups that may experience very different outcomes; in addition, the costs and benefits can flow across the boundaries that might mark off one society from another. In all three cases we can observe differences in the relative fates of dominant groups (Mayan elites, Norwegian nobles and traders, financial corporations) and the larger populations of farmers and herders Both the Classical Maya and the Viking colonies in Greenland were engaged in trade with other societies; it is difficult to determine the relative values of the precious items (feathers, ivory and the like) and subsistence goods (salt, cheese) that travelled between these societies and their trading partners. In the Dust Bowl, many resources flowed across the boundaries of the region, capital, energy that subsidized the extraction of groundwater, and votes, among others. These matters further complicate the question of distinguishing cases of adaptation from other cases.

Thirdly, the definition of adaptation leaves open the question of the time scale on which harmful and beneficial consequences of action are compared. These consequences vary on different time scales. In the Maya case, short-term decline may have led to long-term restoration. The growth of the forests that accompanied the decline of the major Maya centers probably restored local precipitation somewhat, by increasing local evapotranspiration, and may have permitted groundwater to build up as well. The reverse may be true in the Great Plains. The ongoing use of fossil fuel to extract groundwater from deep aquifers may allow short-term maintenance of agriculture, but can lead to long-term unsustainability. It is unclear which set of actions could be categorized as adaptations.

These cases point as well to difficulties, not only with the general concept of adaptation, but also with the categorization of types of adaptation developed by the IPCC. It is not always possible to distinguish public and private adaptations in stratified monarchies in which the public sector is closely linked to the private interests of certain clans and classes, and indeed it is difficult to separate public and private adaptation on the part of the farmers of the high plains of the US, since the settlement of the region and the development of agriculture were at all times tightly connected with government programs. It is similarly difficult to decide how to separate autonomous from planned adaptation, as the case of the Dust Bowl shows with particular clarity; the course of agriculture in the Great Plains is shaped both by the specific government agencies often held responsible for planning and by the farm households whose actions might be called autonomous. Even the contrast between anticipatory and reactive adaptation is difficult to maintain, granted the multiple time frames within which individual and collective action is situated.

These difficulties that challenge the concept of adaptation also raise problems for the related concept of collapse, perhaps the most dramatic form of maladaptation. Drawing on the comparative history of the past, Diamond suggests that researchers can detect the phenomenon of collapse (a rapid, extended, long-lasting decline in population or complexity) in societies that are otherwise very different. He confidently lists the Maya as a case of drought-induced collapse, exacerbated by the overuse of land and short-sightedness of governing elites; nonetheless, the evidence for the changes in the material well-being of the Maya population on different time scales is far from unambiguous. Even the evidence of starvation at the end of the Viking settlements that Diamond cites, describing the famished settlers who killed and butchered their hunting dogs, strikes many readers as dramatic because of the extreme isolation of the settlements: harsh winters were a time of increased mortality for the indigenous Greenlanders and for most Europeans as well, and many Alpine villages were abandoned in the downslope expansion of glaciers during the Little Ice Age.

It is interesting to note that Diamond's writing on collapse, or maladaptation, differs from the IPCC reports in his handling of the topic of migration. His attention to the balance of population and resources leads him to address migration as a possible outlet for societies faced with

livelihood systems that are becoming unviable. It is striking that migration was an important response in all three cases. The migrations from the Dust Bowl to other areas in the US are well documented. At the end of the Classic Period among the Maya, many agricultural households moved from sites closer to the major ceremonial centers to more dispersed areas further away. What was a crisis for the elites of the ceremonial centers may have been a set of adjustments in settlement for the farmers; as was indicated before, there is not clear evidence of declines in population and nutritional status. It seems as well that at least some of the Viking settlers left Greenland for other areas, perhaps in Iceland or in continental Europe, moving on a smaller scale. Had the Greenland colonies not been so spatially isolated, their abandonment might be more easily compared to other shifts in European settlement patterns over the centuries. What could be taken as an extreme crisis at the scale of particular settlements would not look so severe at a regional scale.

In recent years, there has been some discussion of the possibility that sea-level rise will make it impossible for human populations to remain in Tuvalu, a nation consisting of low-lying atolls in the western Pacific; New Zealand has been discussed as a possible site of relocation. The possibility of migration as a response to climate change is still rarely broached in the literature on adaptation to climate change, perhaps because it would seem so unpopular, or because it lies entirely outside the acceptable range of proposals: it is certainly the case that there would be enormous economic, cultural and human costs if large populations were to abandon their long-established home territories and move to new places, but the relative absence of the recognition of this possibility is also a striking form of silence. In the present international order, each country is granted considerable autonomy in controlling its borders and in setting policies on immigration; it would be a violation of presuppositions about the obligations of states to their citizens to propose pro-emigration policies.

In his discussion of the collapse of the chiefdoms on Easter Island that erected the famous stone heads, Diamond notes that emigration was not a possible solution to resource depletion, because of the extreme isolation of that island. He pointedly suggests that Easter Island serves as a useful model for the contemporary world, threatened by climate change as well as resource depletion, since humans cannot very well migrate to other planets. He states, ''The parallels between Easter Island and the whole modern world are chillingly obvious'' (op. cit.: 119). When he suggests that Easter Island may not be a perfect metaphor for the contemporary world, he raises the possibility that societies will engage in long-term planning and will consider altering core values that lead to wasteful resource use, as a few societies (Japan and some Polynesian and Melanesian island societies) have done. The possibility of migration might indeed serve as an example of such planning and reconsideration of core values, since it would require human institutions to rethink broadly the notion of citizenship that separates nationals and aliens.

In a more immediate fashion, this instance of migration offers a point of synthesis between the sociology of the future and the comparative history of the past. It shows that the latter can offer examples of responses that receive little attention on the part of the former, because they are so extreme and because they contradict the political frameworks under which the contemporary debate over global warming takes place. From the comparative history of the past, it can be seen how fragile human societies can be and how resistant they can be to changing established patterns of action; it can also be seen that most people somehow survive in both a biological and a cultural sense. From the sociology of the future, the urgency for addressing the growing threats of climate change becomes clear, even as the gap remains between mitigation and adaptation, between addressing causes of problems and finding ways to cope with them. The issue of migration shows that contemporary societies, like the Vikings whom many deride for their failures to adapt, have their own limits of alternatives that they deem acceptable; it shows as well that extreme threats can lead to the consideration of new responses. The comparative history of the past shows the costs of failing to address those threats.

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