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Vulnerability and Adaptation to Drought in Mexico**

ABSTRACT

The country of Mexico has a long and varied experience with drought, whether described by early historical chronicles or contemporary climatic data and disaster declarations. Much of Mexico is semi-arid and interannual rainfall is highly variable. The experience of drought has resulted in a wide range of adaptations to climate variability, yet today many Mexicans are still extremely vulnerable to lower than average rainfall. This article provides an overview of the nature, causes and consequences of drought in Mexico, focusing on how vulnerability and adaptations vary over time and space. Some preliminary results of a case study of the recent drought in northern Mexico illustrate the state of vulnerability and the limits of adaptation in contemporary Mexico.

THE CLIMATIC ORIGINS OF DROUGHT IN MEXICO

Mexican climate spans from the hot, dry conditions of the northwestern Sonoran desert where annual average rainfall is less than 100 mm,¹ to the wet, tropical climates that characterize the forest regions of southern Mexico, especially Chiapas and the Gulf coasts, where average annual rainfall can reach 2000 mm.² (Figure 1). These climates originate in latitudinal belts of atmospheric circulation which shift seasonally and range from the westerlies, which bring precipitation to northern Mexico in winter, through the sub-tropical highs associated with stable, dry conditions, to the intertropical convergence zone (ITCZ) and trade winds which deliver summer rainfall to the central and southern regions of the country. Other key influences on precipitation are fall hurricanes on both Caribbean and Pacific coasts, the summer monsoons in the north, and summer high pressure which disrupts the flow of moist air and creates a period of dry conditions known as the *canicula* or midsummer drought. The mountainous and varied topography of Mexico dominates many other climatic influences,

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** This article is also to be published in *Drought, in HAZARDS AND DISASTERS: A SERIES OF DEFINITIVE MAJOR WORKS* (Donald Wilhite, ed., Routledge Press, London) (forthcoming).

1. 3.9 inches.
2. 78.7 inches.



Figure 1

producing cooler temperatures and higher rainfall in the highlands and central plateau, and rain shadows behind coastal mountains.³

Meteorological data is available for some parts of Mexico since the nineteenth century,⁴ and centuries of Mexican climatic history have been reconstructed using tree rings, pollen and lake levels. Marine and pollen records suggest much dryer periods prior to 9000 BP, and around 2000 BP.⁵ Analysis of tree rings from northern Mexico (where narrower annual growth rings are associated with dryer conditions) indicates some intense periods of drought during the last 500 years.⁶ For example, Figure 2 shows a tree ring chronology from northern Mexico that indicates severe drought

3. See S. E. Metcalfe, *Historical Data and Climate Change In Mexico: A Review*, 153 *GEOGRAPHICAL J.* 211, 211-13 (1987). Pedro A. Mosino Aleman & Enriqueta Garcia, *The Climate of Mexico*, in *WORLD SURVEY OF CLIMATOLOGY* 345 (Reid A. Bryson & F. Kenneth Hare eds., 1974).

4. See SERVICIO METEOROLOGICO NACIONAL, *NORMALES CLIMATOLOGICAS, PERIODO 1940-71* (1976) (Mexico City, Mex.) (available through Cornell University, MANN QC986.M6 N84 1976a).

5. See R. Ben Brown, *A Summary of Late-Quaternary Pollen Records from Mexico West of the Isthmus of Tehuantepec*, in *POLLEN RECORDS OF LATE QUATERNARY NORTH AMERICAN SEDIMENTS* 71, 71 (V. Bryan & R. Holloway, eds., 1985) (American Association of Stratigraphic Palynologists, Dallas, Tex.).

6. See STUART D. SCOTT, *DENDROCHRONOLOGY IN MEXICO* (1966); Metcalfe, *supra* note 3, at 219 (July 1987).

in the latter part of the sixteenth century (1545–1600), 1752–1768, 1801–1813, 1859–1868, and, most recently, the 1950s.⁷

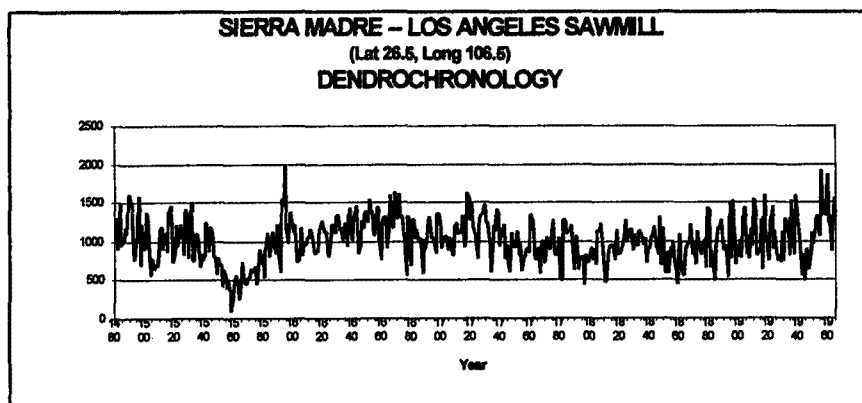


Figure 2

For the period of reliable instrumental records, Douglas⁸ has calculated the Palmer Drought Severity Index (PDSI) for 18 climatological divisions in Mexico. PDSI plots for selected regions are shown in Figure 3. Severe drought is usually identified with PDSI values of -2 and below. In region 3, roughly contiguous with the northwestern state of Sonora, several extended periods of severe drought are apparent, particularly the intense droughts of 1942, 1943–44, 1946–50, the 1950s, 1973–74, 1980–81, 1983 and 1987–88. The mid-1980s were relatively wet. In region 11, which includes parts of the important agricultural states of Guanajuato, Jalisco and Michoacan in west-central Mexico, severe droughts occur in the early 1950s, 1957, 1969–71, and in the summers of 1976, 1979, 1983 and 1988. In region 16, which includes the state of Oaxaca in southern Mexico, there were intense droughts in 1934–35, 1940–41, 1945–50, 1954, 1957–58, 1977, 1983–84 and 1987. Several of these droughts coincide with the variations in Pacific sea-surface temperatures associated with El Niño. El Niño conditions (warmer Pacific) correlate with the 1957–58, 1977, 1982–83, and 1987 droughts in Oaxaca. La Niña conditions (colder Pacific) seem to correspond

7. See NOAA, *International Tree-Ring Data Bank*, <ftp.ncdc.noaa.gov> (login is anonymous, the password is your e-mail address, and the directory is /pub/data/mexican).

8. See DR. ARTHUR DOUGLAS, NATIONAL CLIMATE DATA CENTER, MEXICAN TEMPERATURE, PRECIPITATION AND DROUGHT DATABASE (1996) (Asheville, N.C.) (available on the internet at <ftp.ncdc.noaa.gov/pub/data/mexican>).

to droughts in the 1950s, 1974 and 1988 in northern Mexico. Significant correlation between El Niño years and drought has also been observed in Oaxaca, associated with a southward displacement of the InterTropical

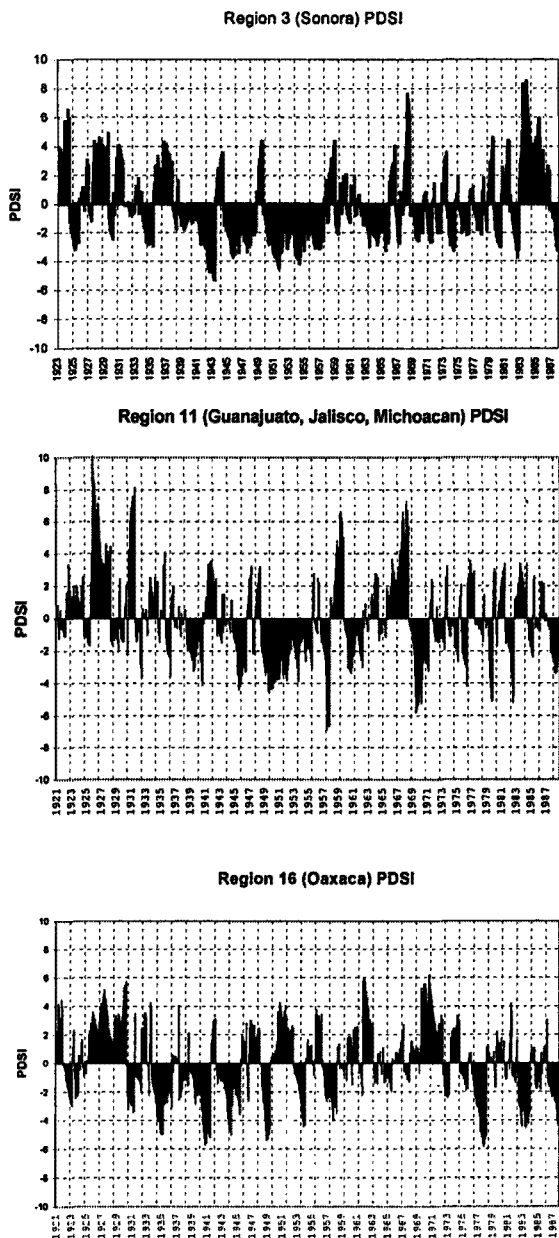


Figure 3

Convergence Zone (ITCZ) and diminished hurricane frequency in the Gulf of Mexico during El Niño years.⁹ Cold (El Niña) events have been linked to lower than average winter rainfall in northern Mexico, and higher than average summer rainfall in central Mexico because of northward shifts in the ITCZ and weaker trade winds.¹⁰

THE HUMAN AND ECOLOGICAL IMPACTS OF DROUGHT IN MEXICO

Drought has played a significant role in the human history of Mexico. Archaeologists have investigated the impacts of drought on pre-Columbian populations, and have debated the possibility that drought may have played a role in the collapse of Mayan and other Meso-American civilizations.¹¹ The evidence is inconclusive and it is likely that, although drought-induced harvest failures and water shortages may have stressed regions such as the Yucatan and central Mexico, the reasons for political and demographic decline were more complex. Nevertheless, it is clear that drought was a concern in pre-Columbian Mexico. Several important deities—such as the Aztec god of rain, Tláloc—were worshipped to insure that rainfall would be timely and abundant, astronomical observatories were built to help predict the weather, and extensive irrigation works and reservoirs were constructed to store and transport water. The Codex Ramirez documents a terrible drought from 1450–1454 causing famine and out-migration from the valley of Mexico. Although the Aztec Empire distributed maize from central granaries in times of hunger, the drought of 1454 was so severe that people sold themselves or their children into slavery and human sacrifices were made to the gods of rain.¹²

The arrival of the Spanish in 1519 altered climatic risks in important ways. There was a tremendous expansion of irrigation which increased the range and reliability of crop production, whilst increasing competition for limited water supplies in some regions. However, the Spanish often

9. See Maxx Dilley, *Synoptic Controls on Precipitation in the Valley of Oaxaca, Mexico*, 16 INT'L J. CLIMATOLOGY 1019 (1996).

10. See Tereza Cavazos & Stefan Hastenrath, *Convection and Rainfall Over Mexico and Their Modulation by the Southern Oscillation*, 10 INT'L J. CLIMATOLOGY 377 (1990).

11. See T.P. CULBERT, *THE CLASSIC MAYA COLLAPSE* 11, 276, 297, 334, 486 (1973); Edward S. Deevey, Jr., *Pollen Analysis and Mexican Archaeology: An Attempt to Apply the Method*, 10 AM. ANTIQUITY 135, 141–46 (1944); Bruce H. Dahlin, *Climate and Prehistory on the Yucatan Peninsula*, 5 CLIMATIC CHANGE 245 (1983); David A. Hodell et al., *Possible Role of Climate in the Collapse of Classic Maya Civilization*, 375 NATURE 391–94 (1995).

12. See ALAIN MUSSET, *DE L'EAU VIVE À L'EAU MORTE: ENJEUX TECHNIQUES ET CULTURELS DANS LA VALLÉE DE MEXICO (XVII^e - XIX^e SIÈCLES)* (1991) (Paris: Éditions Recherche sur les Civilisations); Jaime Sancho y Cervera & David Pérez-Gavilán Arias, *A Perspective Study on Droughts in Mexico*, 51 J. HYDROLOGY, MAY 1981, at 41, 43.

controlled the best land and water, and their cattle and wheat replaced the more moisture-conserving agriculture of the indigenous people. Historians have blamed drought for famine and social unrest during the colonial period. Between 1521 and 1821, 88 droughts were recorded with the worst in 1695, 1749, 1771, 1785 and 1809. Production declines were accompanied by price increases in corn and meat, death of livestock, and reduction in subsequent planting because of lack of draft animals. There is also evidence of large-scale migration, epidemics, unemployment, deaths of indigenous and farming peoples, and social unrest.¹³ In 1785, drought triggered the starvation of more than 300,000 people—mostly members of the indigenous Indian population.¹⁴

Florescano has linked variations in the price of maize in the sixteenth and seventeenth centuries to droughts and other climatic events.¹⁵ He claims that the majority of price rises were preceded by a severe drought, but he also notes the role of speculation and economic arrangements in triggering price rises and associated famines. He suggests that the economic and land tenure relations imposed by the Spanish crown and church created a tremendous vulnerability to drought among the poorer and indigenous *campesino* populations. The colonial political economy allowed the larger landholders and merchants to manipulate the price of staples in drought years to the disadvantage of poor consumers and small producers.

The impacts of drought in twentieth century Mexico can be seen in declines in production and exports of crops and livestock and corresponding increases in imports, reductions in yields and area in production, declines in livestock production, and increases in forest fire and losses. For example, the impacts of drought, interacting with other factors such as economic conditions and prices, can be seen in the variations in overall maize production and imports for Mexico since 1960 (Figure 4).¹⁶ Production decreased in 1973–76, 1979, 1982, and 1986–89, partly due to droughts in those years, but exacerbated by economic crises. Imports have grown steadily in response to increasing population demand, but increase sharply following the drought and production decline in the early 1970s, 1982, and late 1980s. Government responses have included grain imports, extension

13. See *id.* at 44–46.

14. See Enrique Florescano, *Una Historia Olvidada: La Sequía en México*, 32 NEXOS 9 (1980).

15. See ENRIQUE FLORESCANO, PRECIOS DEL MAÍZ Y CRISIS AGRÍCOLA EN MÉXICO: 1708–1810 (1969) (Mexico City, Ediciones Era).

16. See INSTITUTO NACIONAL DE ESTADÍSTICA, GEOGRAFÍA E INFORMÁTICA, ESTADÍSTICAS HISTÓRICAS DE MÉXICO 337–44, 394–96 (1985).

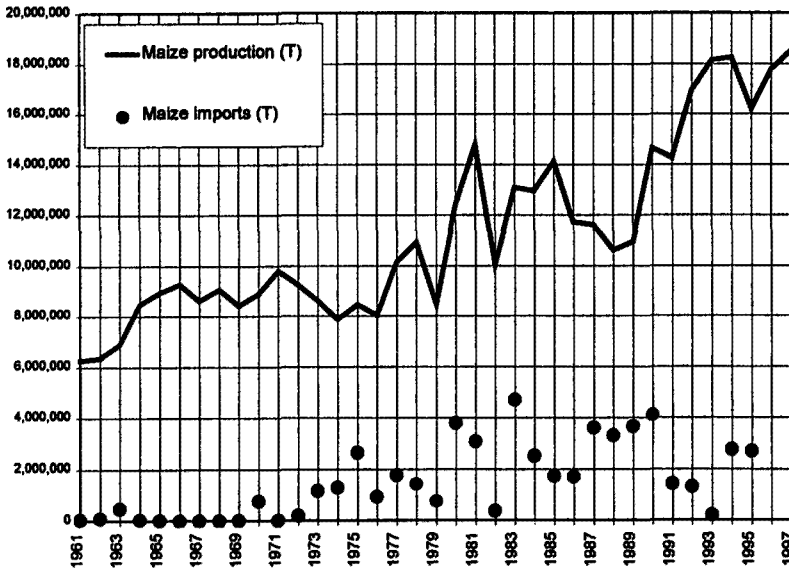


Figure 4

of credit payments, dam construction, and, in 1969, a Drought Combat Plan to provide jobs in disaster zones.

The geography of drought impacts is also revealed in the reports of crop losses in Mexican agricultural censuses and statistics.¹⁷ In 1930 the agricultural census reported a total of 1.2 million hectares lost to natural disasters, a total of 17 percent of the area planted, with the most serious losses in northern and north-central states such as Nuevo León (40 percent loss) and San Luis Potosí (50 percent). A similar area was lost in 1940, with northern states losing 20–40 percent of their planted area. The 1950 census was the first to report loss from specific hazards, and of the 1.43 million hectares lost, 1.1 million suffered from drought in regions such as the Bajío and Quintana Roo. The 1960 census reports a drought loss of 0.8 million hectares, lower than previous census reports, with states averaging only about 10 percent losses. However, the 1970 census, which separates winter and summer growing seasons, includes some very high drought losses, with 22 percent of the growing area lost to drought in summer (2 million hectares). The drought impacts were most severe in Aguascalientes (70

17. See Diana M. Liverman, *Natural Hazards in Mexico*, Presented at the Annual Meeting of the Association of American Geographers, Fort Worth, Texas (Apr. 1989) (unpublished paper on file with author).

percent loss), Zacatecas (65 percent), and Chihuahua (53 percent) (Figure 5).¹⁸ General patterns emerging from this historical analysis suggest that drought impacts are frequent and often severe in Mexico, with 10–20 percent of the total planted area lost especially in northern Mexico. The states of Aguascalientes, Nuevo León and San Luis Potosí seem particularly vulnerable.

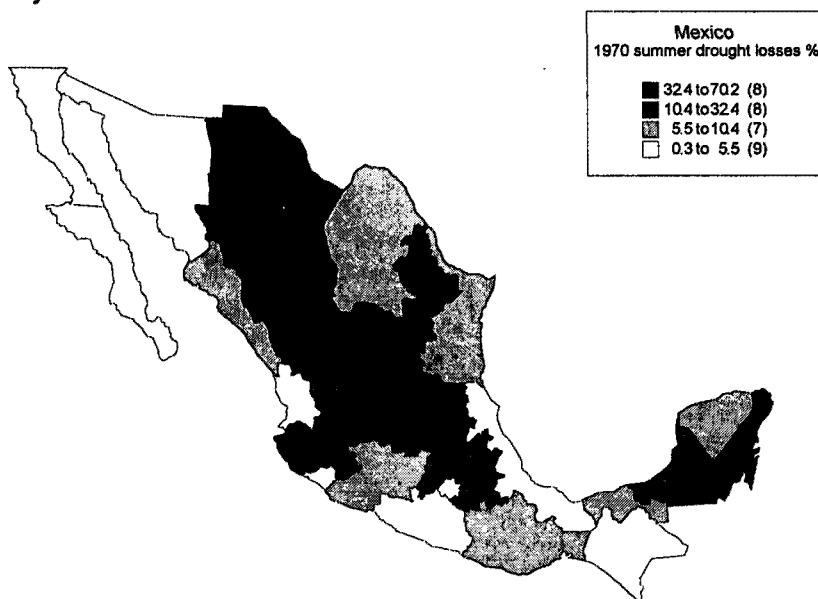


Figure 5

VULNERABILITY

Vulnerability to drought in Mexico is determined by both biophysical and social conditions.¹⁹ Biophysical vulnerability is greatest in the northern and north-central regions of the country where rainfall is most variable, and in the highlands where frost limits the growing season and the timing of rainfall and the extent of the mid-summer drought are critical. Biophysical vulnerability to drought may also be increasing as a result of deforestation and overgrazing which result in increased temperatures and

18. See *id.*

19. See Diana M. Liverman, *Vulnerability to Global Environmental Change*, in *ENVIRONMENTAL RISKS AND HAZARDS* 326, 339 (S. Cutter ed., 1994).

reduced soil moisture.²⁰ And, of course, anthropogenic greenhouse gas emissions to the atmosphere are likely to result in global warming that would bring warmer, drier conditions to much of Mexico.²¹

Social vulnerability to drought varies greatly by region and social group, and has altered over time as a result of technological, economic and demographic changes. Mexico's rapid economic and population growth has increased demand for both food and water, especially as consumption increased in urban areas and irrigated agriculture expanded. For example, the states bordering the United States saw an expansion of their irrigated acreage from about 700,000 hectares in 1930 to 2.4 million hectares in 1980 (Figure 6).²² Mexico's overall population grew from 16 to over 80 million people during the same 50-year period.²³ One estimate projected a doubling of water use between 1970 and 2000.²⁴

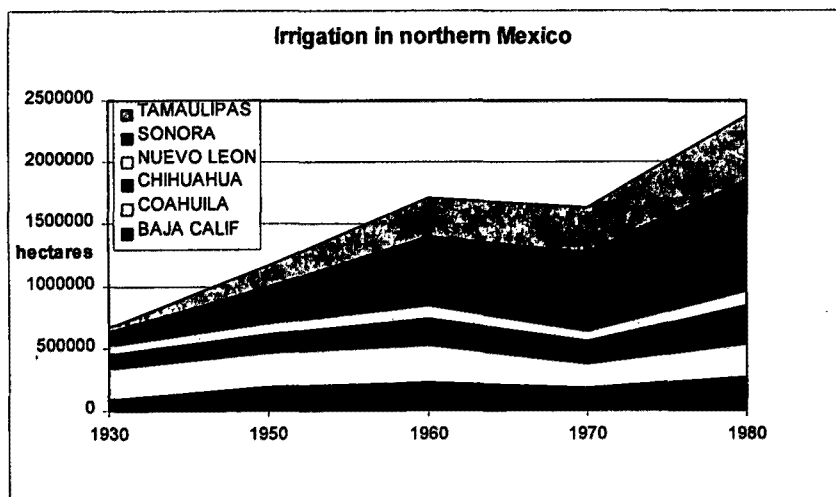


Figure 6

20. See Conrad J. Bahre & David E. Bradbury, *Vegetation Change Along the Arizona-Sonora Boundary*, 68 ANNALS AM. ASS'N GEOGRAPHERS 145 (1978); R.C. Balling, *The Climatic Impact of a Sonoran Vegetation Discontinuity*, 13 CLIMATIC CHANGE 99 (1988); N. A. Bryant et al., *Measuring the Effect of Overgrazing in the Sonoran Desert*, 17 CLIMATIC CHANGE 243 (1990); F. MEDELLIN-LEAL & M. ANAYA-GARDUNO, INSTITUTO DE INVESTIGACION DE ZONAS DESERTICAS, UNIVERSIDAD AUTONOMA DE SAN LUIS POTOSI, LA DESERTIFICACION EN MEXICO (1978).

21. See Diana M. Liverman & Karen L. O'Brien, *Global Warming and Climate Change in Mexico*, 1 GLOBAL ENVTL. CHANGE 351, 351 (Butterworth-Heinemann LTD ed. 1991).

22. See DAVID E. LOREY, UNIV. OF CAL. AT L.A. LATIN AMERICAN CENTER, UNITED STATES-MEXICO BORDER STATISTICS SINCE 1900, at 93 (1990).

23. See *id.* at 21-23.

24. See *id.*

The restructuring of agriculture has resulted in increased water use as producers shift from basic grains, such as maize, to forage and vegetable production. In the irrigation districts of northern Mexico, acreage has shifted from maize and wheat to crops such as alfalfa and tomatoes that consume more water.²⁵ In the valley of Oaxaca, some farmers have purchased mechanical pumps to irrigate alfalfa for dairy cows and cheese production and this has resulted in a drop in the groundwater levels. Poorer farmers have found it increasingly difficult to reach water using traditional manual techniques to irrigate their subsistence crops. Groundwater supplies have also declined as a result of the deforestation of hill slopes surrounding the valley and urban pumping for the expanding city of Oaxaca.²⁶

Some groups and sectors are much more vulnerable to drought than others. More than 50 percent of Mexican cropland is operated by *ejidos*, a form of cooperative land tenure established to allocate land in the aftermath of the Mexican Revolution. A comparison of drought losses on *ejidos* and private farms at national and state levels using data from the agricultural census for 1950, 1960, and 1970 suggests that *ejidos* tend to experience much higher crop losses to drought than private landowners of more than five hectares (Figure 7).²⁷ At the state level the differences are even larger. In Nuevo León in 1950 drought losses were 11 percent on private land and 29 percent on *ejidos*; in 1960 the loss was 20 percent on private land and 28 percent on *ejidos*.²⁸ In winter 1970, private land in Nuevo León lost 14 percent of the crop area to drought and *ejidos* 39 percent; and in summer 1970 the loss on private land was 26 percent and on *ejidos*, 50 percent.²⁹

Several factors explain the relative vulnerability of *ejido* land. Land reforms tended to give less productive and drier land to the new cooperative sector, except in regions where those claiming land were particularly aggressive in their demands. In many regions, the *ejidos* do not have as

25. See Diana M. Liverman, *Economic and Environmental Change in Mexico*, Presented in First Open Conference on the Human Dimensions of Global Environmental Change, Duke University (June 1995) (unpublished manuscript on file with author).

26. See *id.* at 26; S. Lees, *Oaxaca's Spiralling Race for Water*, 6 *ECOLOGIST* 20-22 (1976); F. Brian Dilley, *Climate Change and Agricultural Transformation in the Oaxaca Valley, Mexico* 220-23 (Aug. 1993) (unpublished Ph.D. dissertation, Penn. State Univ. Dep't of Geography) (on file with author).

27. See Liverman, *supra* note 17.

28. See *id.*

29. See *id.*

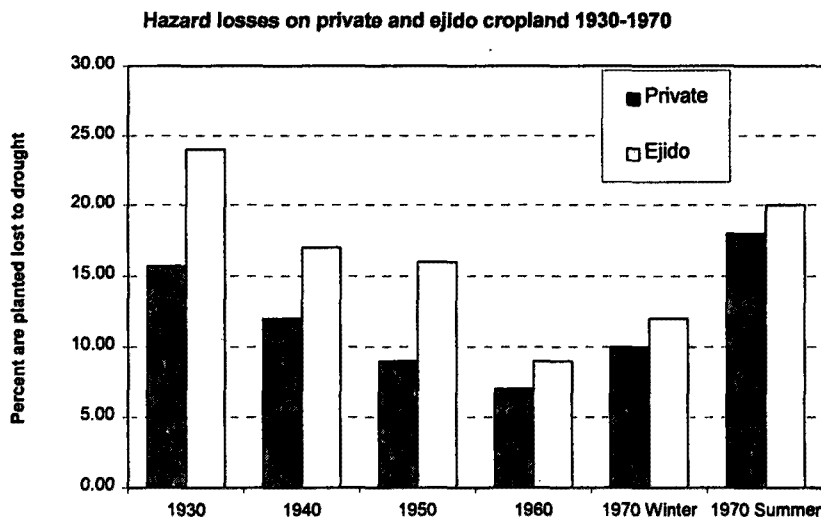


Figure 7

much irrigated land and also have problems in getting access to credit, improved seeds or other resources.³⁰

ADAPTATION AND RESPONSE TO DROUGHT

Local communities in Mexico developed many traditional technologies for coping with drought. As in many semi-arid regions, sophisticated irrigation systems have developed over centuries to store and transport water to settlements and agriculture. Archaeologists and others have described prehispanic water control systems such as the *chinampas*—the highly productive raised fields in the wetlands around Mexico City—and the *galeria* tunnels which bring water from the hillside aquifers to the valley of Tehuacan, Puebla.³¹

The heterogeneity of the Mexican landscape and the high interannual climate variability also promoted a diversity of crop varieties,

30. See Diana M. Liverman, *Vulnerability to Drought in Mexico: The Cases of Sonora and Puebla in 1970*, 80 *ANNALS ASS'N AM. GEOGRAPHERS* 49 (1990); D.T. Nguyen & M.L. Martinez, *The Effects of Land Reform on Agricultural Production, Employment and Income Distribution: A Statistical Study of Mexican States 1959-1969*, 89 *ECON. J.* 624 (1979).

31. See GENE C. WILKEN, *GOOD FARMERS: TRADITIONAL AGRICULTURAL RESOURCE MANAGEMENT IN MEXICO AND CENTRAL AMERICA* 176-77, 198-201 (1987).

especially of maize, and many farmers still plant several different varieties to minimize risk from drought, frost and diseases.³² Traditional farmers in Oaxaca adjust to drought by selecting a maize variety appropriate to expected rainfall conditions, altering the ratio of beans and maize planted, and adjusting the planting density of crops.³³

Indigenous social institutions and traditions also served as drought adaptations and risk management strategies. Rituals following the agricultural calendar invoke rain and other key influences on harvests. Traditional weather prediction techniques monitor the first days of January or phases of the moon as ways to predict growing season weather.³⁴ The harvest can be redistributed through social events such as the *guelagueza* of Oaxaca where local leaders are responsible for sharing food with other members of the community.³⁵ In drought years some communities rely on traditional sources of famine food and liquid such as cactus, agave and mesquite fruit.³⁶

Many of these traditional drought adaptations survived the ecological and social transformations associated with the arrival of the Spanish, although, as noted earlier, some scholars believe that drought vulnerability increased as a result of Spanish changes in land use and economy.

In the twentieth century, new forms of adaptation have accompanied the expansion and intensification of Mexican agriculture. Irrigation reduced short-term vulnerability to drought, whilst increasing water use and vulnerability to multiyear droughts such as occurred in the 1950s and 1990s in northern Mexico and brought reservoirs to very low levels. For example, three years of drought resulted in reservoirs at only 10 percent of capacity across most of northern Mexico at the beginning of the 1995

32. See Miguel A. Altieri & Javier Trujillo, *The Agroecology of Corn Production in Mexico*, 15 HUM. ECOLOGY 189 (1987); Mauricio R. Bellon, *The Ethnoecology of Maize Variety Management: A Case Study from Mexico*, 19 HUM. ECOLOGY 389 (1991); Stephen B. Brush et al., *Agricultural Development and Maize Diversity in Mexico*, 16 HUM. ECOLOGY 307 (1988); PAUL C. MANGELSDORF, CORN (1974).

33. See Anne V. T. Kirkby, *The Use of Land and Water Resources in the Past and Present Valley of Oaxaca, Mexico*, in 1 MEMOIRS OF THE MUSEUM OF ANTHROPOLOGY UNIVERSITY OF MICHIGAN, PREHISTORY AND HUMAN ECOLOGY OF THE VALLEY OF OAXACA (Kent V. Flannery ed. 1973).

34. See Hallie Catherine Eakin, *Adapting to Climatic Variability in Tlaxcala, Mexico: Constraints and Opportunities for Small-Scale Maize Producers* 156-64 (1997) (unpublished masters thesis, Univ. of Ariz. Dep't of Geography and Regional Dev.) (on file with author).

35. See Kirkby, *supra* note 33, at 148-A; ARTHUR D. MURPHY, *SOCIAL INEQUALITY IN OAXACA: A HISTORY OF RESISTANCE AND CHANGE* (1991).

36. See P. E. Minnis, *Famine Foods of the Northern American Desert Borderlands in Historical Context*, 11 J. ETHNOBIOLOGY 231 (1991).

growing season (Figure 8).³⁷ In those districts that rely on groundwater, increased demand and sustained drought have contributed to declines in

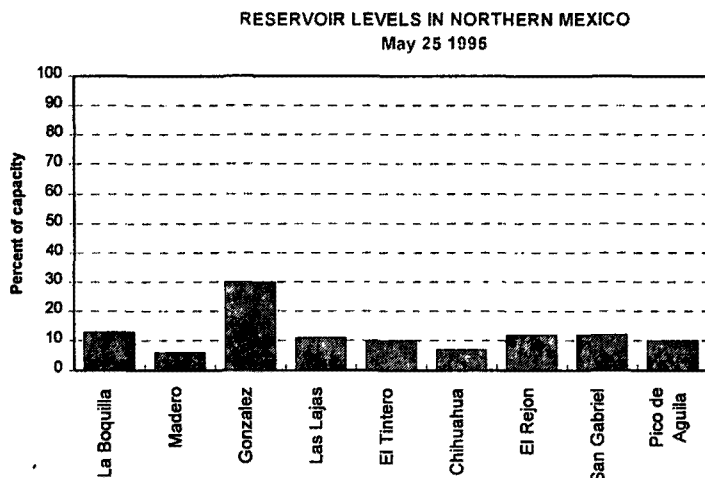


Figure 8

the water table and saline intrusion.³⁸ Over the longer term, improvements in irrigation efficiency have reduced drought vulnerability in some irrigation districts, and new proposals for decentralized management and water pricing may allow more flexible adjustment to water supply variations.³⁹

In the 1950s the "Green Revolution" brought improved seeds, fertilizer and mechanization to Mexican agriculture. Plant breeders developed new, higher yielding varieties of maize and wheat that increased production, especially for those farmers with irrigation and access to credit and fertilizer. Although some new varieties were drought resistant, there are some indications that the Green Revolution increased the sensitivity of

37. See Perez U. Matilde, *Agotamiento de Pozos Agrícolas en Municipios de Chihuahua*, LA JORNADA, May 29, 1995, at 5 (Mex.) (available on the internet at <<http://serpiente.dgsc.unam.mx/jornada/1995/may95/950529/seco528.html>>).

38. See generally Everardo Aceves-Navarro, *Salinity Problems in Food Production of the Mexican Irrigation Districts*, in PROC.: WATER AND WATER POLICY IN WORLD FOOD SUPPLIES (Wayne R. Jordan ed., May 26-30, 1985); RONALD G. CUMMINGS, *WATER RESOURCE MANAGEMENT IN NORTHERN MEXICO* (1972); RONALD G. CUMMINGS ET AL., *WATERWORKS: IMPROVING IRRIGATION MANAGEMENT IN MEXICAN AGRICULTURE* (1989).

39. See Carlos Casasus, *Privatizing the Mexican Water Industry*, 86 J. AM. WATER WORKS ASS'N, Mar. 1994, at 69.

agricultural production to climatic variations and drought.⁴⁰ In Puebla, where development projects focused on increasing yields of rain-fed maize, drought and economic crisis interacted to bring the yields of those using the new technologies below those of traditional farmers in some years.⁴¹ Because the new commercial technologies sometimes require farmers to go into debt to purchase them, drought induced harvest failure can be more serious for these farmers than those using traditional techniques without purchased inputs.⁴²

Urban areas have responded to drought and increased demand by constructing storage reservoirs and rationing water. Mexico City now pumps water at great expense from an area 100 miles distant and a thousand feet lower.⁴³ Many northern cities compete for water with agriculture and had severe water rationing during the recent drought. Many rural communities required water to be trucked in at considerable expense. In Chihuahua 42 deaths were attributed to the lack of drinking water because of drought and poverty.⁴⁴

Institutional response to drought in contemporary Mexican agriculture includes a complex set of agricultural subsidies and emergency relief measures. Mexican agricultural policy has varied quite dramatically in terms of guaranteed support price and year to year crop area is very sensitive to relative prices for different crops. In 1981, for example, prices for growing basic grains were increased to promote national food self-sufficiency, and production increased.⁴⁵ In the last decade, however, financial restructuring and the liberalization of trade have resulted in a decline in the guaranteed prices for producers, and this has increased the economic uncertainty and associated environmental risks.⁴⁶ In the early 1980s, subsidies for agricultural inputs were reduced from 27.5 percent of

40. See Patrick J. Michaels, *The Response of the 'Green Revolution' to Climatic Variability*, 4 CLIMATIC CHANGE 255 (1982).

41. See H. Diaz-Cisneros, *The Impact of Support Prices for Corn on Small Farmers in the Puebla Valley 1967-1989*, in *ECONOMIC RESTRUCTURING AND RURAL SUBSISTENCE IN MEXICO: CORN AND THE CRISIS OF THE 1980S* (Cynthia Hewitt de Alcantara ed., 1994).

42. See K. Appendini & Diana M. Liverman, *Agricultural Policy, Climate Change, and Food Security in Mexico*, 19 FOOD POLICY 149, 149-64 (1994).

43. See MANUEL AGUILERA GOMEZ ET AL., *LAS CIUDADES MEXICANAS EN LA ULTIMA DECADA DEL SIGLO XX* (1989); R.B. ZENTENO & J. BENIGNO MORELOS, *GRANDES PROBLEMAS DE LA CIUDAD DE MEXICO* (1988) (Mex.).

44. See *Por el Calor, 42 Muertos en 15 Dias en Chihuahua*, LA JORNADA, May 26, 1996, at 1 (Mex.) (available on the internet at <<http://serpiente.dgsca.unam.mx/jornada/1996/may96/960526/SECAS00-2505.html>>).

45. See K. APPENDINI, *DE LA MILPA LOS TORTIBONOS : LA RESTRUCTURACION DE LA POLITICA ALIMENTARIA EN MEXICO* (1992).

46. See Appendini & Liverman, *supra* note 42.

the cost of grain production in 1985 to only 6.5 percent in 1990.⁴⁷ The government's fertilizer corporation, FERTIMEX, was privatized in the early 1990s and fertilizer prices are now near those of the international markets.

Less than 10 percent of Mexican producers have crop insurance, although some coverage is increasingly required as government credit declines and producers turn to banks to provide loans. But the recent collapse of the peso and associated surge in interest rates has made access to both credit and insurance difficult for the majority of farmers.

1996 DROUGHT IN NORTHERN MEXICO

Four years of below normal rainfall produced severe drought conditions in northern Mexico by 1996.⁴⁸ By June, reservoirs were at 50-year lows, below five percent of capacity in some cases, more than 4.6 million hectares of cropland was damaged and six million hectares remained unplanted because of the drought. Ranching, important to the economy and culture of states like Sonora, was suffering great losses as herds died off or were sold at prices 40 percent lower than in 1996. An estimated 300,000 cattle died and 700,000 were sold at very low prices. By the end of the year, Mexico's livestock herd had declined one-third from 1990 levels. The Federal Agricultural Department estimated farm losses at more than one billion dollars (U.S.) and planned to import an extra four million metric tons of basic grains for a total grain import of about 11.25 million metric tons in 1996 compared to six million metric tons in 1991. Farmers groups estimated the loss to producers at nearer 2.5 billion dollars (U.S.).⁴⁹ The drought provoked interstate political conflict, with Sonora and Sinaloa competing for the water from the Huities Dam, Nuevo León and Tamaulipas competing for the remaining water in the El Cuchillo dam, and even Mexico, as a nation, requesting Río Grande water from Texas, and being refused.⁵⁰

47. See ALAIN DE JANVRY ET AL., *REFORMAS DEL SECTOR AGRICOLA Y EL CAMPESINO EN MEXICO* 67 (1995).

48. See Agricultural Trade Office, American Embassy, Mexico City, Mex., *Economic Consequences of the Mexican Drought* (1996) (visited Feb. 13, 1999) <http://www.fas.usda.gov/scripts/gain_display_report.exe?Rep_ID=10007307.0>.

49. See *Agriculture Secretariat Estimates Direct Losses from Drought at 8 Billion Pesos This Year*, 7 SOURCEMEX, June 12, 1996; Agricultural Trade Office, *supra* note 48.

50. See Jim Patterson, American Embassy, Mexico City, Mex., AGR No. MX6053, *Agricultural Situation: Drought Alert Report: Nuevo Leon* (1996) (visited Apr. 4, 1999) <http://www.fas.usda.gov/scripts/gain_display_report.exe?Rep_ID=10007170.0>; Marcelo Morichi & Jan Gilbreath, U.S.-Mexican Policy Studies Program, *Drought Brings Severe Crop Reductions and Cattle Losses in Northern Mexico* (Jul. 21, 1995) (visited May 31, 1998) <<http://www.utexas.edu/lbj/usmex/xdrought.html>>.

The government responded to the drought with 1.147 billion pesos (\$155 million U.S.) in drought aid for feed purchases, drinking water supplies, and jobs in infrastructural improvements as well as with ongoing price support programs such as *Procampo*, which made direct cash payments to farmers for area planted. State government and local producers' organizations also provided drought relief. For example, in Sonora the state government joined with irrigators to invest \$500,000 (U.S.) in cloud seeding, and also provided feed to ranchers.⁵¹

Individual responses to the drought varied widely with some farmers planting and then praying for rain or government relief, and others deciding to abandon their land and migrating to find work in other regions of Mexico or in the United States.⁵² Many ranchers and rain-fed crop producers found the combined impact of the drought and economic crisis overwhelming, with the low rainfall, high input prices, low producer prices, and high interest rates placing them at great risk. Smaller landholders were disproportionately affected, especially those who were in debt, or who farmed or ranched more biophysically marginal land.⁵³

CONCLUSION

The 1996 drought in northern Mexico drew attention to the overall and differential vulnerability of Mexican agriculture and society to climate variability. Although agriculture contributes less than 10 percent to Mexico's Gross National Product, it is important to rural stability and national political strategy. Drought exacerbated the effect of economic crises in the agricultural sector and stressed the water supplies of rapidly growing cities and communities. Partly as a result of the drought, the Mexican government is now undertaking major review of water resources management, including decentralization of management, improvements in infrastructure, and potential for seasonal climate forecasting. Agricultural production in many irrigation districts increased in 1997, and, overall,

51. See *Preven Inducir Lluvias*, NACIONAL, May 15, 1996 (newspaper circulated in Hermosillo, Sonora, Miercoles); ESTADO DE SONORA, PROGRAMA EMERGENTE PARA SEQUIAS, APOYA A LA COMPRA DE ALIMENTO PARA GANADO (1996).

52. See Elizabeth Velasco, *Se Tendran Que Importar 8 Millones de Ton. de Granos*, 4 EXCELSIOR: PRIMERA PLANA, May 26, 1996 (Mexico City) <<http://www/excelsior.com.mx/exe04.html>>.

53. See Diana M. Liverman & J. Rosenberg, Latin American Area Center, Preliminary Assessment of the 1996 Drought in Sonora, (1996) (unpublished report by the Center in Tucson, Ariz.).

the Mexican economy was recovering.⁵⁴ But the future of the most vulnerable farmers and ranchers on rain-fed and marginal land is less clear in the face of the decline in support prices, the continuing difficulties in access to input and credits, and the unequal participation in economic recovery.⁵⁵

54. See American Embassy, Mexico City, Mex., *Mexican Agricultural Situation and Outlook* (1997) (visited Feb. 13, 1999) <http://www.fas.usda.gov/scriptsg/gain_display_report.exe?Rep_ID=25130129.0>.

55. See Victor M. Quintana S., *La Séquia de Todos Tan Temida*, in INFOSEL (1996) (Mex.) (visited May 26, 1996) <<http://query.infosel.com...=102194&p=1&b=&bd+sequia>>.