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# 21

# The effect of climate fluctuations on human populations: two hypotheses

MARTYN J. BOWDEN, ROBERT W. KATES, PAUL A. KAY, WILLIAM E. RIEBSAME, RICHARD A. WARRICK, DOUGLAS L. JOHNSON, HARVEY A. GOULD, AND DANIEL WEINER

## Abstract

The relationships between climatic fluctuations, population dynamics and social vulnerability are examined in the Tigris–Euphrates Valley 6000 BP to the present; the Sahel AD 1910–74; and the US Great Plains AD 1880–1979. Two major hypotheses are tested. The *lessening* hypothesis states that societies are able to lessen the impact of *minor* climatic stress (events with a return period of the order of less than 100 years) upon the resident population and indirectly on the entire society. The *catastrophe* hypothesis states that the increasingly elaborated technology and social organisation that insulate a livelihood system from recurrent minor climatic stress do little to reduce and may *increase* the system's vulnerability to *major* climatic stress (defined as events with a return period of the order of more than 100 years).

Comparison of the effects of the two similar droughts of 1910–15 and 1968–74 in the Sahel revealed that the Sahelian peoples, except for the nomadic minority, experienced a *lessening* in the toll of human mortality in the recent drought. Lessening resulted from the region's increased dependence upon external aid and consequent changes in internal structure. Exaggeration of these trends in a future drought could bring the region to the verge of a system collapse.

The long-term population declines that mark the two major population cycles in the Tigris–Euphrates Valley (6000–2500 BP and 2500–750 BP) seemingly result from a sequence or combination of environmental stress, political–social instability, and an absence of technological innovation.

In the first 60 years of Great Plains history, *lessening* is strongly evident in the impact of agricultural drought on population change and society at local and regional levels. The trend is less clear during the last 40 years, and drought–wheat-yield relationships demonstrate no strong evidence to support the lessening trend in the last half-century. The 1930s drought, a major climatic stress, provides a test of the catastrophe hypothesis. Adjustments to minor climatic stress in the Plains were insufficient to insulate the region from the major climatic stress of the 1930s drought. Recent and full integration into the national social

system (made possible by recent changes in American attitudes to government involvement in the economy and in disaster relief) averted a system collapse in the Plains. 'Catastrophe' took the form of a devolution of impact into the nation. Thereafter, the effects of *all* subsequent droughts were diffused to the national system.

Calculations of the range of impact of Plains droughts at the global level suggest that a recurrence of the 1930s drought could cause declines of 7–19 per cent of total wheat export in 1985. Whether a future Plains catastrophe would be absorbed by the nation or ripple into other economies less able to adjust to sudden loss of staples is a question of global concern.

## Introduction

Evidence for the effect of climate stress on human populations is meagre and consists primarily of a few detailed studies, many historical anecdotes, and much speculation. The dynamics of the relationship of climatic fluctuation to human well-being and social change are still elusive.

Our research tests the relationships between climatic stresses, population dynamics, and social vulnerability. Three contrasting cases were selected: the Sahel, the Tigris–Euphrates Lowland of Iraq, and the US Great Plains. In the Tigris–Euphrates River Valley, six millennia of historical and archaeological data may make it possible to capture the range of fluctuations and interactions existing in an irrigation-based society. The century-long history of settlement of the Great Plains is rich in detailed documentary material. This makes possible careful analysis of the changing vulnerability of the system over time. The Sahel is the setting for an examination of climate and society in the context of different theories of development in the Third World.

Two major hypotheses are examined. The first, the *lessening* hypothesis, states that all societies are able, through their technology and/or social organisation, to *lessen* the impact of *minor climatic stresses*, defined as events with a return period of the order of less than 100 years. By being adaptive they will experience over time diminished effects from such minor climatic stress.

The second hypothesis states, however, that success in insulating a livelihood system from minor climatic stress does little to reduce, and may increase, vulnerability to *major climatic stress*, defined as an event with a return period of more than 100 years. In a partially closed livelihood system, poorly integrated with the world economy, such extreme climatic stress may cause a collapse of the system, evidenced by major population decline (a loss of more than 10 per cent of pre-stress population). In more open and enlarging systems, the effects of extreme events will be devolved or shared ever more widely, rippling into previously non-dependent areas or societies that may experience ill-effects far from the locus of climatic impact. This is the 'catastrophe' hypothesis.

## The Sahel

The Sahel–Sudan climate and vegetation zone is the home of 30 million people. Between 1968 and 1974 the area experienced low rainfall years that led to drought, famine, and worldwide interest. A major debate developed as to the drought's causes and effects. Most scholars concluded that the affected population had become more vulnerable to the impact of drought than it had been in the past (referred to below as the 'worsening' argument). The people were the victims of a colonial and neocolonial international economic and technical order that had increased their dependency and reduced their self-sufficiency by decreasing the area devoted to food crops, by draining off the agriculturally important labour supply by migration, by creating technical conditions that prompted rapid increase in population and livestock numbers, and by adopting policies that favoured the small urban élites.

A minority of scholars contend that the people, with all their difficulties, saw less vulnerability to drought than in the past because the Sahelian nations called upon the conscience of the world for assistance (the 'lessening' argument). Extended families were not entirely dependent on vulnerable crops or herds. Medical care restrained the childhood disease epidemics that previously accompanied famine, and a rudimentary infrastructure and national organisation were available with international aid to assist great numbers of people. Only where governments failed to act (Ethiopia) and in extremely remote areas was there great loss of life.

### *Meteorological drought*

To test the assumptions of the contending scholars an analysis was made of the rainfall of the last great drought in 1910–15 and of the recent one (Fig. 21.1). The rainfall in the more extreme year of the pair 1912/13 or the pair 1972/73 is shown as a percentage of the average rainfall for the period 1931–60, to yield a rough comparison of the magnitude and areal extent of rainfall deficiencies. In both droughts deficiencies persisted over six years. In both there were at times average or even good rainfalls, marked variations from place to place and great seasonal variability within any given year. There is some suggestion of a greater total short-fall of precipitation in the more recent drought, but the indications are that the single most serious drought year this century (1913) occurred in the earlier drought (Sircoulon, 1976). We conclude that the two droughts were reasonably comparable except for their spatial pattern. Drought affected sedentary farmers in the southern Sahel and Sudan zones (east and south) more seriously in the earlier drought, whereas the recent drought more seriously affected the nomadic pastoralists of the sub-desert and northern Sahel (north and west).

### *Crops and animal losses*

Except for Senegal and Nigeria, the Sahelian countries are among the poorest in the world, and their statistical reporting services for crop production are limited and improvised, other than for certain export crops. Similarly, the actual size and composition of the national herds is never really known. In the recent drought, there was some urgency in developing estimates of crop and animal losses, and many were made (Table 21.1). Analysis of these estimates suggests that in the worst years estimated losses of one-third to one-half of the food crops and herds are reasonable and conservative.

Against this we must compare occasional reports from 1910 to 1915. For example, in Senegal in 1912–13 it was reported that 'grains are beginning to become scarce in certain *cercles*'; 'bovine epidemic disease, mortality from 33–42%' (Pourafzal, 1978)[1]; in Nigeria, 1914, 'the Wodaabe pastoralist Fulani of Western Bornu Province were estimated

Fig. 21.1. Drought in the Sahel: rainfall deficiencies for 1912–13 and 1972–73.

| | WEST | | | CENTRAL | | | EAST | | |
|---|---|---|---|---|---|---|---|---|---|
| | Stations | 1912-13 | 1972-73 | Stations | 1912-13 | 1972-73 | Stations | 1912-13 | 1972-73 |
| SUBDESERT 100-300mm | | | | 10 Tombouctou-Kabara 220mm | 58 | 47 | | | |
| SAHEL 300-650mm | 1 Podor 336mm | 39 | 33 | 11 Niamey 576mm | 58 | 64 | 16 Bol 341mm | 13 | [illegible] |
| | 2 St. Louis 347mm | 43 | 43 | | | | 17 Zinder 508mm | 42 | 58 |
| | 3 Kaedi 410mm | 66 | 32 | | | | 18 N'Djamena 639mm | 48 | 49 |
| | 4 Dakar 578mm | 53 | 20 | | | | 19 Maiduguri 650mm | 54 | 66 |
| | 5 Tivaouane 615mm | 39 | 24 | | | | | | |
| | 6 Rufisque 620mm | 54 | 20 | | | | | | |
| SUDAN 650-900mm | 7 Thies 694mm | 34 | 32 | 12 Segou 730mm | 76 | 69 | 20 Sokoto 719mm | 57 | 54 |
| | 8 Kayes 743mm | 89 | 66 | 13 Ouagadougou 872mm | 46 | 81 | 21 Kano 843mm | 57 | 49 |
| WOODLAND >900mm | 9 Sedhiou 1379mm | 66 | 61 | 14 Bobo-Dioulasso 1170mm | 69 | 75 | | | |
| | | | | 15 Gaoua 1190mm | 64 | 73 | | | |

Percentage of Mean Annual Rainfall (1931-1960) in Worst Year Either of 1912 or 1913 and 1972 or 1973

Larger deficiency shown in grey

Table 21.1. *Estimated single year crop and cattle losses in the Sahel 1968–74*

| | Crop losses[a] (%) (worst years: 1968–74/1967–68) Millet/ Sorghum | Cotton[b] | Peanuts | Cattle losses (%) EDF[c] 1972–73 | Other[d] |
|---|---|---|---|---|---|
| Mauritania | 77 | — | — | 45 | 25, 30, 42, 60–80 |
| Niger | 42 | 86 | 76 | 36 | 33, 45, 50, 60–65 |
| Mali | 42 | +2[e] | 19 | 34 | 16, 32, 40, 50 |
| Chad | 38 | 36 | 15 | 34 | 34, 40 |
| Senegal | 51 | +20 | 43 | 25 | 10, 15, 20 |
| Upper Volta | 11 | 25 | 14 | 15 | 2, 7–8, 13, 30 |

[a] Data taken from Berg (1975).
[b] (1968–69 base year).
[c] European Development Fund Study cited in Berg (1975).
[d] Various sources.
[e] Plus denotes a gain.

at 10 000 with 88 000 cattle in 1913 and 5500 with 36 000 cattle in 1914' (Watts, 1978)[1]; and in Niger, 1913, 'millet production [was] insufficient for subsistence needs ... some areas had only half of the average and others none at all' and 'animal mortality: cattle, 1/3; sheep and goats, 1/2; and camels, negligible' (Pourafzal, 1978)[1]. These qualitative assessments could well be interchanged with similar reports during the recent drought. In both of the drought periods the Sahel–Sudan inhabitants faced losses of their food supply on the order of one-third to one-half. What were the consequences of these comparable losses?

### *Human impacts*

A review of seven studies (Center for Disease Control Village Surveys (CDC), 1973, 1975; Kloth, 1974; Caldwell, 1975; Garcia & Escudero, in draft; Imperato, 1976; and Faulkingham, 1977) leads us to two conclusions. First, in the recent drought the death rate rose in the drought-affected regions of the Sahel–Sudan zone in selected years by 25–100 per cent over the relatively high pre-drought death rates of 25–40 per thousand, and, second, the widely quoted figure of 100 000 deaths (Imperato, 1976; Ware, n.d.; Swift, 1977) is probably conservative. Premature deaths, particularly of young children, extended over a population at risk of 10–15 million for several years could easily number two or more times the widely cited estimate.

A review of malnutrition surveys (CDC, 1973, 1975; Seamon, Rivers, Holt & Murlis, 1973; Garcia & Escudero, in draft; and de Goyet & de Ville, 1976) suggests that the high rates of acute malnutrition endemic among children (5–10 per cent) doubled in the severe drought areas and throughout the Sahel during the worst years of the drought.

The difficulties in estimating drought-related mortality are grossly magnified in the period 1910–15. A handful of references appear in the colonial reports. In Niger in 1914 estimates of mortality note '1/4 of the population', '20 000 people', 'approximately 80 000'; and there are reports of intestinal disease from eating wild foods. Infant mortality was reported 'very high' in Segou, Mali, 1914, whereas in Senegal in the same year there were reports of plague, but of no famine deaths (Pourafzal, 1978)[1] Recent histories extend these figures. The Comité Information Sahel (1974) notes for Mali, 1913, that it was estimated that '10% of the population died, a number that is surely an underestimate', and Bonte (in draft) comments on Niger, 1914, that 'the 1914 famine (called *Kakalaba* by the Nigerian Hausa) was among the most murderous and is engraved in the collective memory down to this day', and taken to be severer than the 1973 famine. Writing of Nigeria, 1913–14,

> Hastings, in a flight of fancy, suggested that in Kana province alone the death toll was on the order of 50 000. Polly Hill states that 'many thousands of people died in Kano ... and at least 4000 in northern Katsina.' For the rest we have to be content with vague colonial references to 'very high death rates in Daura and Zongo', 'considerable mortality in Kozaure' and a 'rather heavy figure for Gunel' (Watts, 1978).

Many of these observations on mortality are 'unreliable, spatially inconsistent, and almost wholly non-quantitative' (Watts, 1978). Yet where more reliable quantitative data are available they show totals which are absolutely higher for a comparable area than similar totals for 1968–74. Given that the population in 1968 was almost three times the 7.5 million recorded in the area of French colonial administration in 1910, relative losses must have been far higher in the earlier drought than in 1968–74.

### *The case for lessening*

The case for lessening in the recent drought rests on the lower mortality rate in the face of a similar meteorological drought, and on similar crop losses (perhaps higher animal losses). Watts' (1978) report, which carefully integrates what is known about the Sudan zone of Northern Nigeria, concludes that:

> Superficial parallels should not serve, however, to cloud other more important structural differences. Firstly, there are some simple but important differences in magnitudes; in 1913 human mortality was enormous but in 1973 minimal; price inflation of grains occurred in both famines but was proportionally much greater in 1913 ...
>
> Informants who had experienced both famines invariably stressed that the crucial distinction between 1913 and 1973 was food availability – and by extension the mechanics of its genesis. In Katsina and Daura elders emphasized that in 1913, for quite extended periods, grain was simply not available in the market-place irrespective of whether purchasing power was available. In 1973 conversely, only in a few isolated areas did grain disappear entirely; grain was available, said most informants, but purchasing power congruent with prevailing prices was not.

### *The case for worsening*

The arguments for absolute worsening focus on the pastoral peoples and particularly on the nomads of the Sahel. It is the view of most observers, supported by the nutrition surveys and the census of the refugee camps, that nomads proportionately suffered the greatest burden in the recent drought. The data suggest greater climatic stress in 1968–74 than in 1910–15, a worsening of the livelihood systems of 2½ million nomads, and an increase in the impact of drought. The sparseness of references to nomads made by colonial administrators 1910–15 is consistent with this conclusion, although this inference must be qualified by the knowledge of the administrators' hostility to the nomads over whom they had yet to extend power.

If absolute worsening of the nomads' situation did occur, it was probably the result of the severe decline in the nomads' access to land and resources and in their political power. The process of semi-sedentarisation and the lower population growth rate of the nomads compared to that of the sedentary peoples resulted in a cutting in half of the proportion of the nomads relative to the total population and in a cutting back of nomadic territories into the driest areas. The problem was compounded by the entrenchment in the current governments of most Sahelian countries of leaders from the sedentary agricultural regions, a permanent shift in the former balance of political power that resulted from the defeat of nomadic military power by the French. The problem was made worse by the tripling of the region's population between 1918 and 1968.

The case for relative worsening – a permanent and increasing dependence on outside aid – rests on the increasing inability of subsistence systems to provide a livelihood for those dependent on them, and on the gradual monetarisation of all exchanges. The development of trade in food crops, the increased sales of land, the emergence of agricultural wage earning, and even a rise in the sale of prepared food are symptoms of incipient failure of the systems (Raynaut, 1977).

None of the scholars who argue for worsening asserts that the people of the Sahel were better off when more died from drought in an earlier era. One must infer that it is the relative worsening, the gap between what is and what might be, that causes their concern. They envisage a society that could provide greater social and subsistence security in contrast to one that at best is dependent upon the slim reed of international aid received at a great cost to the social fabric.

### *Weighing the evidence*

For the majority of the Sahelian peoples, particularly the 13–15 million whose equivalent numbers did not exist in 1910, the recent great drought comparable to that of 1910–15 saw a lessening in the grim toll of human mortality. This is less clear for the $2\frac{1}{2}$ million nomadic peoples whose political, social and subsistence positions worsened in the 60-year interim, and whose suffering probably reflected this worsening. But there should really be naught for our comfort in this relative improvement. For even with overall lessening, the toll of mortality was large and the morbidity great, stunting and wasting the youth of the region.

The processes which have, in the past, led to a lessening of the overall susceptibility to drought, could, in the future have opposite effects. Lessening where and when it occurred in the recent Sahelian drought resulted from the region's increased dependence upon external aid and consequent changes in internal structure. This provided for increases in the availability of imported food, external opportunities for work, ease of movement, and advances in preventing infectious disease. But these same factors are implicated in the loss of villages, food self-sufficiency, the growth of human and animal population, and the breakdown of traditional controls on land degradation. Exaggeration of these trends in a future drought could bring the region to the verge of a fundamental, irreversible change in the ability of either the region's fragile resource system to provide for its inhabitants' sustenance or of the social system to provide alternative livelihood.

A simulation of the agricultural carrying capacity of the Sahel–Sudan region, based on a considerably improved and ecologically sound agriculture, found the region capable of supporting only 33 million people (Matlock & Cockrum, 1974). In that model of improved agriculture, improvement came with the loss of jobs for 60 per cent of the work force. Moreover, while sustenance increased considerably in the model's projection, it would be insufficient to meet the needs of a population projected by the end of the century to be 42 million (Caldwell, 1975).

### Tigris–Euphrates Lowland

The Tigris–Euphrates Lowland provides a research opportunity different from that of the Sahel and Great Plains where the case for short-term lessening can be tested and demonstrated, but where catastrophe, depending on its definition, can only be speculated upon. In the Tigris–Euphrates Lowland, the sketchy data base, extending back over 6000 years, does not permit consideration of climatic events with recurrence intervals of 20–50 years as in the Sahel and the Great Plains. Thus, we can say little about possible lessening of the impact of minor climatic stress.

#### *Theories of social change*

The Tigris–Euphrates Lowland does, however, provide an extended record of population growth made possible by Adams' (1965, 1981) 6000-year record of population change derived from archaeological data (mainly the surface concentration and areal extent of potsherds). This record (Fig. 21.2) clearly indicates 2½ cycles of growth and decline and allows us to consider how these changes correlate with major changes in the natural environment, society, governmental structure, and technology. By allowing this long-term examination, the Tigris–Euphrates Lowland fills a particular hiatus in environment–society studies related to possible differences in the frequency and phasing of environmental, as opposed to social and demographic events. The last several centuries have seen unprecedented demographic, social and technological change. In contrast, there have been relatively few (and certainly geographically restricted) major environmental changes. Thus to consider the interaction of environment and society more complet v, we sought a region of

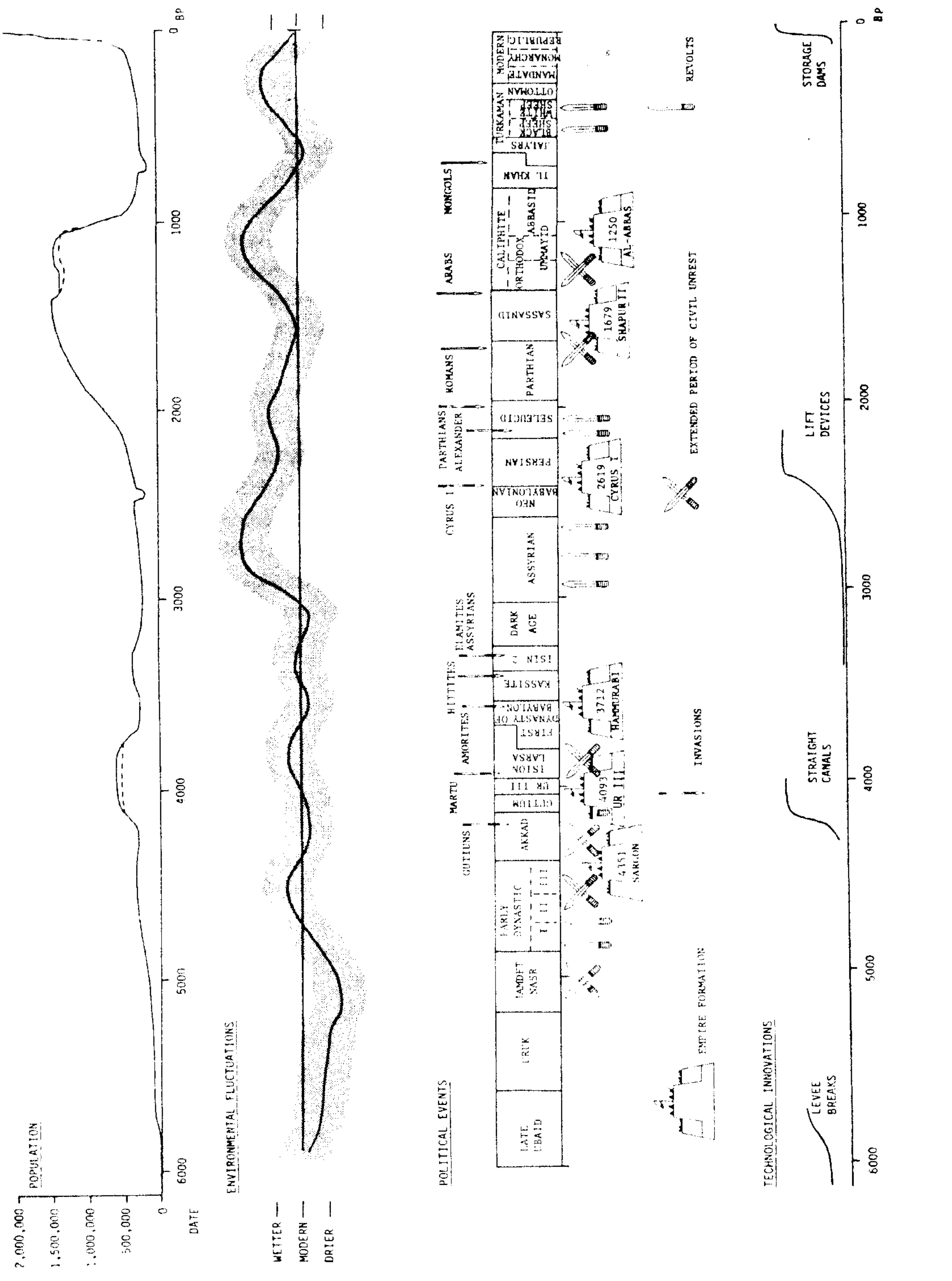



Fig. 21.2. Fluctuations in population, society, and environment in the Tigris–Euphrates Lowlands.

the world where an extended human record could be found, one long enough hopefully to include the occurrence of rare climatic events. We found it in the Tigris–Euphrates Lowland, one of the best known areas of the ancient world, where at least in terms of the human record, the coincidence of system, clay tablets and dry weather, serve to extend our knowledge of society well beyond the temporal limits of most regions of the world.

There are difficulties in using these data. The attempt to infer streamflow fluctuation from a variety of geophysical and biological proxy data suffers well-known difficulties, and the contradictory evidence offered by such techniques captures secular fluctuations at intervals of a century at best. Not only is the environmental evidence imprecise on a human time scale, but also human response (especially if successful) is generally rapid and may pass unnoticed in the archaeological record. Moreover, political reconstructions are biased towards kingship rather than agricultural engineering, and the role of technology is inferred from the episodic appearance of key technologies rather than from a detailed record of gradual and comprehensive development.

The data we employ are those that exist in the literature and they are subject to varied interpretation. When we are puzzled, we hope to employ modelling and simulation to explore plausible alternatives, and this work is still in progress. Nonetheless, one significant conclusion can be demonstrated here: the two catastrophic population declines that took place between 3800 and 3000 BP and again between 1100 and 800 BP, do not correlate with any single recurrent factor of drought, war, political unrest, or technological change. Rather, they are the product of a complex of interacting variables, the exact importance of which remains to be established.

This initial conclusion runs counter to many standard explanations for social and demographic change in this region. These generally emphasise single factors rather than a complex of interacting variables, and in the Mesopotamian case, are generally better developed as explanations of growth rather than decline.

Theories of societal collapse are of three types. The first (type 1) stresses the role of natural events, particularly those external to the local agricultural system. Most commonly these theses utilise either long-term climate change or the adverse impact of natural catastrophes as the driving variable. Neumann & Sigrist (1978), for example, demonstrate that Mesopotamian barley harvest dates were 20–30 days earlier in the period 1800–1650 BC than for the period 600–400 BC. They suggest that the warmer, drier conditions in the first period encouraged over-irrigation and this resulted in soil salinisation that degraded the productive capacity of much of southern Mesopotamia. The more abrupt and catastrophic impact of violent climatic events, such as the floods produced by heavy precipitation in the mountainous headwaters of the Tigris and Euphrates, have been reviewed by Mallowan (1971) for the Early Dynastic period and by Sousa (1965) for the Islamic period.

Human causation external to the local system also plays a prominent role in some theories. Such hypotheses (type 2) often stress the adverse impact of invading nomadic hordes, or the depredations of neighbouring states, such as the Gutian invasions that ended in the final collapse of the Sargonid empire in 2159 BC (Bottero *et. al.*, 1967), or the *coup de grâce* administered to the Abbasid Caliphate and the population of Baghdad by Hulagu Khan in AD 1258 (Le Strange, 1900). Another related suggested explanation for population decline is as the result of disease often transmitted in the wake of military conflict (McNeill, 1976).

The best-developed theories of decline (type 3) examine the impact of factors internal to the Mesopotamian irrigation system. Most of these explanations emphasise the breakdown of managerial procedures. Thus, Redman (1978:235) points out the negative impact of excessive élite consumption practices and inept leadership among other factors. Development of these tendencies can lead to progressive deterioration of the irrigation system due to shorter fallow cycles (Gibson, 1974). This would compound the effects of siltation and salinisation (Jacobsen & Adams, 1958).

Except for the climate change/desiccation hypothesis articulated by Childe (1952) and Wright (1976), few growth theories give paramount place to environmental factors as promoters of social change. Rather, most theories identify societal developments as fundamental. Among them are Adams' emphasis on increasingly elaborate social organisation (1966), Wittfogel's (1957) insistence that the requirements of large-scale irrigation promoted the growth of centralising water-managing bureaucracies, Flannery's (1965) focus on trade and exchange mechanisms, Smith & Young's development of the population growth hypothesis (1972), and Redman's (1978) sophisticated attempt to construct an integrative systems–ecological hypothesis.

Of the factors involved in population growth and decline, four, natural environment, social and political events, and technology, are considered briefly.

### *Factors affecting population dynamics*

For the agricultural societies of arid Mesopotamia, streamflow is a critical environmental variable. The temporal rhythm of the annual hydrograph is out-of-phase with the agricultural cycle. Peak flows occur in April–May, at the harvest season; minimum flows occur in August–October, when the second crop is growing. Unlike the Nile, there is no long historical record of environment in the Tigris–Euphrates Valley. Neumann & Sigrist (1978) derive growing season thermal conditions from barley harvest dates, but the data are few. If a history of streamflow is to be had, it must be inferred from the palaeoclimate of the basin as reconstructed from geological and biological proxy data. The Tigris and Euphrates rise in the mountains of eastern Anatolia and northwestern Iran. The melting of winter snowfall is the main source of water (al-Khashab, 1958). Information related to winter conditions in the head-waters must, therefore, be considered along with more direct proxy streamflow data.

Palaeoenvironmental data for the Middle East is of highly variable quality with respect to absolute dating, temporal resolution, and climatic interpretation. Fig. 21.3 exhibits some of the chronologies consulted in this study. The varve sequences (Kempe & Degens, 1978; Schoell, 1978; Lamb, 1977) offer temporal resolution on the scale of one year to one decade. The chronologies, however, are imperfectly fixed in time, and the climatic relationship is not well established. The pollen records (van Zeist & Woldring, 1978; van Zeist & Bottema, 1977; Niklewski & van Zeist, 1970; Beug, 1967; van Zeist *et al.*, 1975) are also poorly dated, and are not particularly sensitive environmental records. At best, temporal resolution is possible only to the scale of several centuries. Geological proxy evidence, such as marine sediments (Diester-Haass, 1973) and glacial deposits (Erinc, 1978) bear only inferred dates, and have temporal resolutions only of millennial scale. Fig. 21.3 shows a lack of synchrony in the timing of climatic episodes and in the direction of climate change (although a consideration of synoptic patterns indicates that these differences are not necessarily contradictory). With the data at hand, we can only derive the tentative and very generalised streamflow curve presented on the bottom of Fig. 21.3 and on Fig. 21.2.

Fig. 21.2 shows that there is no consistent relationship between the streamflow and population curves. Our hypotheses relate to the impact of extreme climatic events and so to climatic *variability* rather than to long-term means. A test of the hypotheses, using Mesopotamian popu-

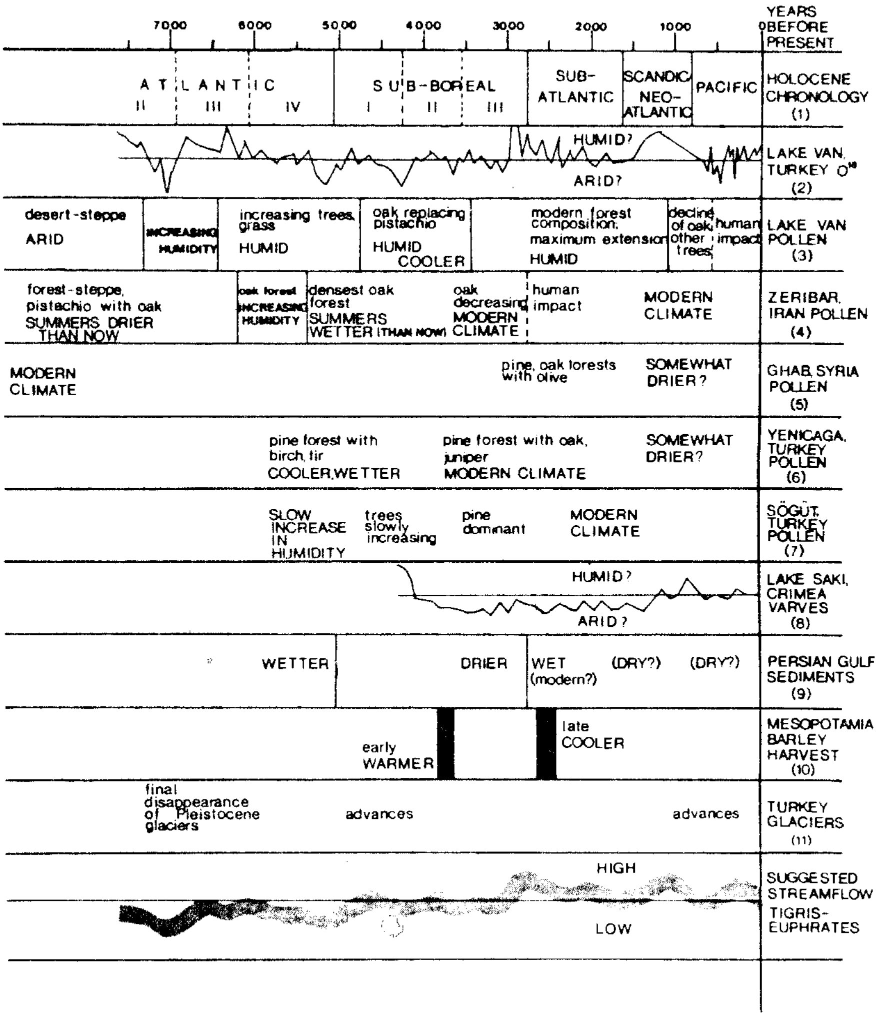



Fig. 21.3. Geological, biological and historical evidence for temperature and moisture conditions in the Tigris–Euphrates Basin, and adjacent regions, 7500 BP to the present. (Sources: (1) Wendland & Bryson, 1974; (2) Schoell, 1978; (3) van Zeist & Woldring, 1978; (4) van Zeist & Bottema, 1977; (5) Niklewski & van Zeist, 1970; (6) Beug, 1967; (7) van Zeist, Woldring & Stapert, 1975; (8) Lamb, 1977; (9) Diester-Haass, 1973; (10) Neumann & Sigrist, 1978; (11) Erinc, 1978.

lation and streamflow, is therefore not now possible: a record of the frequency of extreme wet and dry episodes would be required in order to determine whether past conditions were more or less variable than those of a present in which the full range of possible variation has not yet been experienced (Clawson, Landsberg & Alexander 1971).

The relationship between political and social organisation is equally complex. Although the data are not complete, the existing reconstruction of major political events does permit identification of the broad outline of societal development. This evidence is summarised in Fig. 21.2. No consistent pattern of internal empire building or external invasion accounts for the growth and decline of Mesopotamian population. It is clear, both that considerable private entrepreneurial activity was associated with the central irrigation bureau (Walters, 1970), and that population growth, irrigation construction, and bureaucratic activity took place simultaneously, interactively, and incrementally. This conclusion stands in contrast to those theories that stress the crucial role of a centralised bureaucracy in organising the labour required to construct the irrigation system. None-the-less, the role played by an efficient central government in maintaining stability and increasing access to resources on an increasing areal scale was an important aspect of population growth. Conversely, the absence of effective government for any substantial period is linked to reduced stability in the irrigation system and heightened vulnerability to adverse external events.

Similarly, technological change took place episodically, and in phase with population growth cycles. The four most important technological innovations were (*a*) small, artificial breaks in natural levees; (*b*) the substitution of human-designed, straight canals for the sinuosities of natural streams; (*c*) the development of waterlifting devices (*shaduf*, *na'ura*, later the *saqia* or Archimedean screw); and (*d*) storage dams. These innovations are not necessary preconditions for population growth. On occasion they serve to reinforce and stabilise other societal trends. However, they share two common characteristics. The first is their ability to bring into production new resources on a wider scale than those previously available. The second is the buffer they can provide for society against inopportune streamflows, particularly low flows.

### *Tigris–Euphrates conclusions*

Given the reconstruction of the fluctuations in population, streamflow, society and technology at the scale of centuries rather than years, what might be said of lessening and catastrophe?

The environmental record does not allow us to test the hypothesis that societies develop in a way that allows the impact of minor climatic fluctuations to be lessened. In this region, population declines occur for reasons that as yet exhibit no consistent pattern. However, some sequential or concurrent combination of environmental stress, political and social instability, and absence of technological innovation seems required before a population's equilibrium is disturbed. Ultimately a new stability is achieved at a new, generally substantially lower population level.

Finally, we should note that, on this long time scale, catastrophe occurred (if at all) not with a bang but a whimper. Even the precipitous decline from the Abbasid period population of 1.5 million to the post-Mongol invasion low of one-tenth that number probably took three centuries. Measured on the human scale of generations, it was surely a time of troubles, possibly in Post's (1977) terms even a cascade of crises; but, by modern standards, it was a very long and drawn out collapse.

## US Great Plains

The climate history of the North American Great Plains is punctuated by recurrent drought. Within the period of instrumental record major droughts have occurred in the region approximately every 20 years. Recent tree-ring analysis suggests a 22-year rhythm of widespread drought in the western US back to about 1600 (Mitchell, Stockton & Meko, 1978), although considerable controversy surrounds the notion of drought cycles. Within the period of agricultural settlement, droughts occurred during 1887–96, 1933–36 and 1952–56, and less important droughts occurred in the 1910s and 1970s. Dendroclimatological data indicate that the drought experienced in the Plains during the 1930s was the worst event in the entire 360-year record, a major climatic stress. The rarity of the 1930s drought is substantiated by simulation analysis of northern Great Plains moisture data (Eddy & Cooter, 1978) which assigns a 250–300-year return period to the 1930s drought in Kansas. Other droughts, minor climatic stresses, had a return interval of less than 100 years.

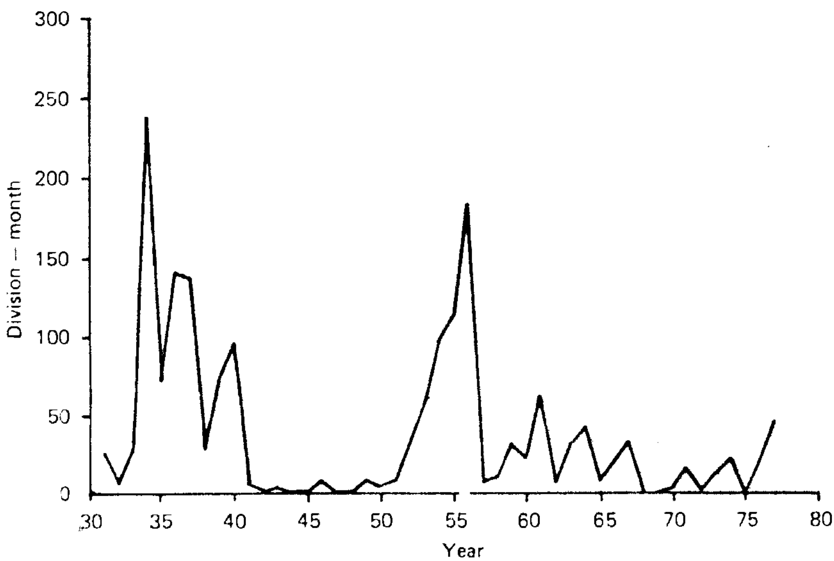
Ideally, the drought history of the Plains should be assessed in a consistent manner if the agricultural and social impacts are to be compared over time. In this vein, Fig. 21.4 presents a drought history for the US Great Plains as a whole. The plotted values represent growing-season accumulations of the number of climatic divisions exhibiting specified levels of the Palmer Index.[2] Thus, without specifying exact location within the area, these 'division-month' data represent one means of indicating relative drought severity by incorporating drought magnitude, areal extent, and duration. Peaks and troughs on the curve indicate maxima and minima in the overall extent of the drought: note in particular the extensive drought of the 1930s and 1950s.

### *Examining the lessening hypothesis*

How did the Great Plains fare during each of the five major droughts? Our operating framework is to relate drought measures to agricultural production and these to societal impacts. We focus on annual yields of wheat, a crop which is sensitive to drought, important in world trade, and central to Great Plains agriculture.

*Drought and wheat yields* Average wheat yields per harvested acre for eight Great Plains states[3] were plotted over time, from 1890 to 1977 (Fig. 21.5). The number of abandoned acres was also plotted from 1929, when consistent data became available. A polynomial curve was fitted to observed yields in order to depict the trend over time. The departures from this trend provide a measure of the relative decline in yield during poor years.

Fig. 21.4. Great Plains drought area 1931–77; number of divisions exhibiting severe or extreme drought ($\leq -3.00$) conditions, based on Palmer Index values summed over 5 months, April through August. (Data source: NOAA)



With each major drought occurrence since the 1890s, wheat yields were significantly reduced, reflecting the sensitivity of wheat to moisture conditions. There were other drops, such as that around 1950 due to rust. Since the 1930s, the relative impact of drought on yields, when defined according to the two worst years, has lessened over time (Table 21.2). However, after roughly normalising for severity by dividing the yield depressions by division months of drought for the years concerned, the relative impact of drought on yields appears approximately constant over time. On this basis there appears to have been no strong lessening of impact.

An extensive literature deals with climate–yield relationships based on regression-modelling using historical grain yield and concurrent weather data. The issues addressed relate to trends in expected yields: has there been a change, and, if so, which is responsible, technology or weather?

Newman (1978) concludes that relative variability in annual yields has been reduced, apparently due to technology. The United States Department of Agriculture (USDA) (1974) strongly concurs. McQuigg and others, writing for the National Oceanic and Atmospheric Administration (NOAA, 1973) argue forcefully that the apparent increases and reliability of yields in recent years have been due primarily to an unusual streak of very favourable weather, a point of view with which Schneider & Temkin (1978) and Haigh (1977) agree. The Institute of Ecology (1976) and Gasser (1976) claim that both technology and unusual weather account for recent increases in yields and production. In short, the voluminous literature is inconclusive and controversial regarding lessening. Both arguments have weaknesses. Newman does not

Fig. 21.5. Wheat yields in the Great Plains 1890–1972. (Date sources: USDA statistics)

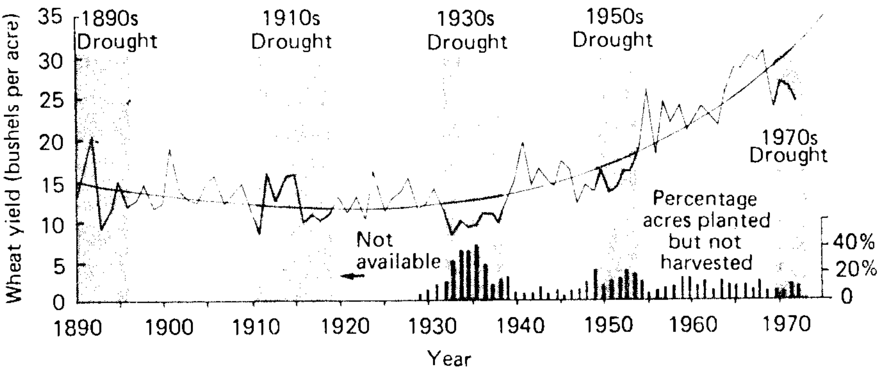


Table 21.2. *Relative wheat yield declines for historical droughts in the Great Plains*

| | Drought decades | | | | |
|---|---|---|---|---|---|
| | 1890s | 1910s | 1930s | 1950s | 1970s |
| Percentage decline, from trend[a] | 25 | 24 | 29 | 19 | 17 |
| Percentage decline per division-month of drought (× 100)[b] | — | — | 8 | 6 | 7 |

[a] Average of the two worst years.
[b] $\leq -1.00$ Palmer Index summed over all climatic divisions during the March July growing season.

account for persistent droughts. NOAA (1973) does not preclude the possibility that buffering technology also improved during the unusually favourable recent years, and both sides deal with a broad-scale analysis.

We dealt with these problems by employing smaller units of observation (state or crop reporting districts) and by including more recent drought events. Kansas was chosen for intensive study because it is the centre of winter wheat production in the Plains and because a number of droughts have occurred there since the 1950s. A continuous record of Kansas wheat yields from 1890 was assembled, and a third-degree polynomial curve was fitted to describe the trend. On the basis of the trend curve, years of 'good' yields and 'poor' yields were selected, being defined in terms of positive and negative residuals (i.e., the difference between observed yields and the fitted trend curve). Separate trend curves were then fitted to the good and poor years, on the assumption that if 'lessening' were occurring one would detect a relative convergence of the two curves (Fig. 21.6).

The trend curves actually diverge (see the table accompanying Fig. 21.6) because of overall increase in yields over time; in absolute terms, a worsening. But our notion of drought impact is concerned more with losses in relation to some expected 'good' yield, i.e., relative declines. Therefore, the more appropriate measure of yield-impact is the relative difference between the curves, expressed as a percentage (as indicated in Fig. 21.6). Assuming that drought is a major contributor to poor yields, the small differences in these values suggest that the relative impact of drought on yields has remained stable over time, i.e., neither lessening nor worsening.

Additional analysis employed a University of Wisconsin weather–wheat yield regression model (Michaels, 1978) constructed on the basis of climate and yield data obtained from 31 crop-reporting districts from 1932 to 1975. It incorporates a 'technology' trend, a habitat variable (a weighting to adjust baseline yields to differences in distinct growing environments) and an empirically derived weather component. The model explains 95 per cent of the variance in the wheat yields over 31 × 44 observations; the weather variables explain about 40 per cent of the variance remaining after the 'technology' and 'habitat' effects are factored out. As a way of testing for differences in sensitivity of yields to weather, a number of runs were made of the model, such that fewer recent years were included in successive runs (Table 21.3). If lessening had occurred then one might have expected the variance explained by climate to have decreased progressively from the 'older' years (1932–57). Clearly, lessening is not evident.

If, indeed, 'lessening' is not occurring, as our example indicates, the implications are far reaching. Generally, it is assumed that the arsenal of agricultural technologies, in particular the soil and water conservation practices so strongly encouraged since the 1930s, in addition to increas-

Fig. 21.6. Kansas wheat yield trends. (Data source: USDA)

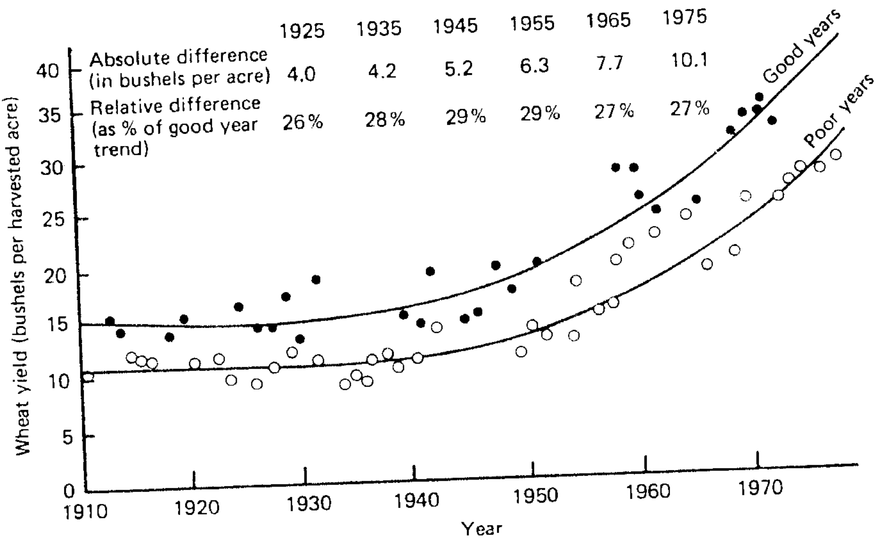


Table 21.3. *Wheat yield variance explained by climate by periods of increasing length*

| Run years | Percentage variance reduced by climate |
|---|---|
| 1932–57 | 46.1 |
| 1932–60 | 52.1 |
| 1932–63 | 48.5 |
| 1932–66 | 47.3 |
| 1932–69 | 45.7 |
| 1932–72 | 44.9 |
| 1932–75 | 45.2 |

ing yields and reducing production costs, have also been effective in buffering agricultural production from drought stress. Our data suggest that caution should be exercised in accepting such an assumption. This kind of knowledge of climate impact becomes critical as society faces the issue of which sets of management strategies to devise for future droughts on the Great Plains.

*Impact of societal well-being* Of the numerous indicators of societal well-being related to drought history in the Plains we first considered population migration. The alternation of wet and dry decades in the Great Plains presents a rare opportunity to estimate the relationship between climate and outmigration (displacement of population).

The severity of droughts within the dry decades was measured by summing growing-season division months with values of −3.0 and lower on the Palmer Index. The worst of the droughts was the 1930s, a major climatic stress. The other droughts were minor climatic stresses, in order of severity: the 1950s, the 1890s, the 1910s and the 1970s. Decennial census figures, the only population measures available Plainswide, reveal that the dry decades (1890s, 1910s, 1930s) experienced population losses and that the wet decades (1880s, 1900s, 1920s) saw population increases. However, the extent of population loss directly related to drought is consistently underestimated. This is because drought occurred in the middle of dry decades. Unaware that these were dry decades people flowed unabated into the Plains in the first three years before the onset of drought, and quickly resumed the inflow in the last three years of the decade after the drought was over. Thus, the population recorded by the census at the beginning of the decade *underestimated* the population level at the drought's onset, while census population figures recorded at the end of the decade *overestimated* the population level at the end of the drought. This is substantiated in those instances in which states (e.g., Kansas and Nebraska) collected or estimated intercensal population numbers. To achieve a more accurate estimate of population change during the drought we therefore used decennial census statistics to project the population trend of the preceding decade to the third year, and that of the succeeding decade back to the seventh year, and compared the difference, i.e.,

$$\Delta X(\%) = 100(X_B - X_A)/X_A$$

where

$$X_A = X_n + 0.3(X_n - X_{n-1})$$
$$X_B = X_{n+1} - 0.3(X_{n+2} - X_{n+1})$$

and where $X_n$ means population at decadal year $n$ (e.g., if $n = 1930$ then $n-1 = 1920$, $n+1 = 1940$, $n+2 = 1950$).

The declines in population between the third and seventh years are shaded for all climatic divisions in the decades of the 1890–1960 period (Fig. 21.7). Increases are unshaded.

The contrast between outmigration in the dry decade of the 1890s and the wet decade of the 1900s is remarkable. In the latter, only 3 of the 63 climatic divisions experienced any loss in population. Increase in population was general. Comparison of the minor drought decade of the 1910s and the wetter decade of the 1920s reveals a similar contrast, the more telling if it is noted that the population loss in the northwest Plains (Montana) in the 1920s is a delayed response to the late 1910s drought (1919–21) in that area. By the time of the 1950s drought, however, the pattern of population change is similar to that of the wet decades of the 1940s and 1960s.

Certainly the levels of loss in the 1950s are much lower than those common in the lesser droughts of the 1890s and 1910s. In the 1890s, the loss is intense in dry-farming margins of the Plains region, where many climatic divisions lost between one-half and three-quarters of their population and 6 of the 63 divisions experienced near total depopulation. The Plains were poorly integrated into the world economy and the people unprepared for drought. The pattern suggests complete failure of farming practice and a collapse of the system in the western Plains in the face of a minor climatic stress. There was also a major decline in population in the drought of the 1910s. This hit selectively in the western Dakotas Montana and in the Dust Bowl sections of Texas, Oklahoma, Colorado, and Kansas, and produced system collapse and prompted population losses between 25 and 50 per cent over extensive areas. These were lands newly settled by inexperienced, under-capitalised farmers and losses were proportionately high (Bowden, 1977).

The impact of drought appears to be most immediate and, as measured by net migration, most severe in the wheat and cotton regions of the drier western margins. The stock-raising regions of the Flint Hills, Sandhills, and Black Hills respond to drought, but usually in a delayed fashion. Quite different are the diversified farming regions growing corn, wheat and other cereals, and fattening livestock in the Eastern Plains Transition Areas. Since the 1890s these wetter margins of the Plains have shown little response, in population numbers, to the presence or absence of drought.

*The 1930s – major climatic stress* The effects of lessening are well illustrated in a comparison of the impacts on population of the droughts of the 1890s and the 1930s. Although on meteorological grounds the drought of the 1890s was a minor climatic stress and that of the 1930s was a major climatic stress, the impact in the 1890s as measured by, for example, the area with above 25 per cent outmigration, was much greater. Nevertheless, it is as the one rare climatic event of the last century of Plains history that the major climatic stress of the 1930s interests us. Was the 1930s drought, with a return period variously estimated between 250 and 400 years, a 'catastrophe'?

Clearly, the Plains economy did not collapse in the 1930s even though a sizeable minority of writers in influential popular magazines and a majority of government spokesmen in 1934–36 seriously thought Plains agriculture to be permanently damaged and on the verge of collapse. In the Dust Bowl section of the southern Plains localised collapse did occur, as indicated by a major population decline – over 10 per cent and in some places over 25 per cent. This is supported in our analysis of Haskell County, Kansas, and Jackson County, Oklahoma, in which the scale of foreclosure of mortgages and of sales of tax-delinquent property for 1934–36 brought farming practically to a standstill that would have extended for four years or more, had not the state and federal governments enacted emergency legislation to extend credit to farmers and the length of the period of forgiveness for tax delinquency.

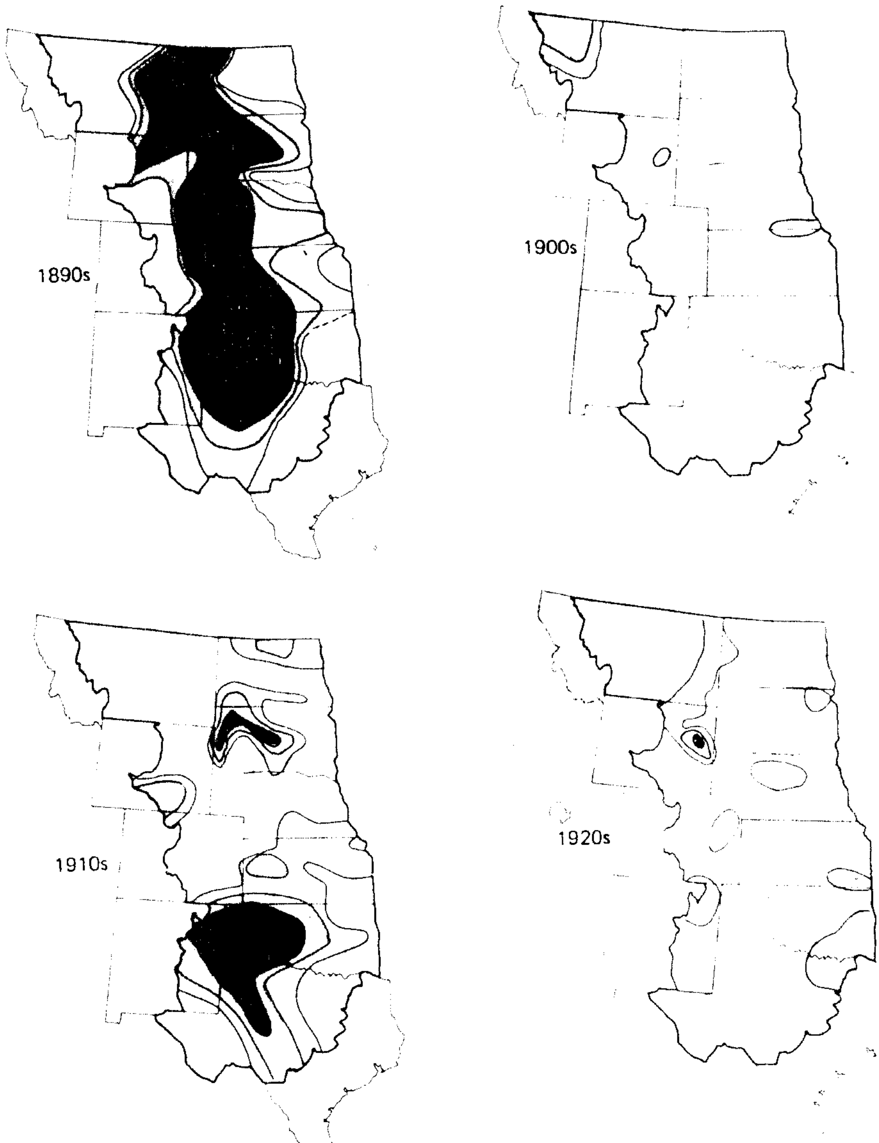



Fig. 21.7. Great Plains population declines.

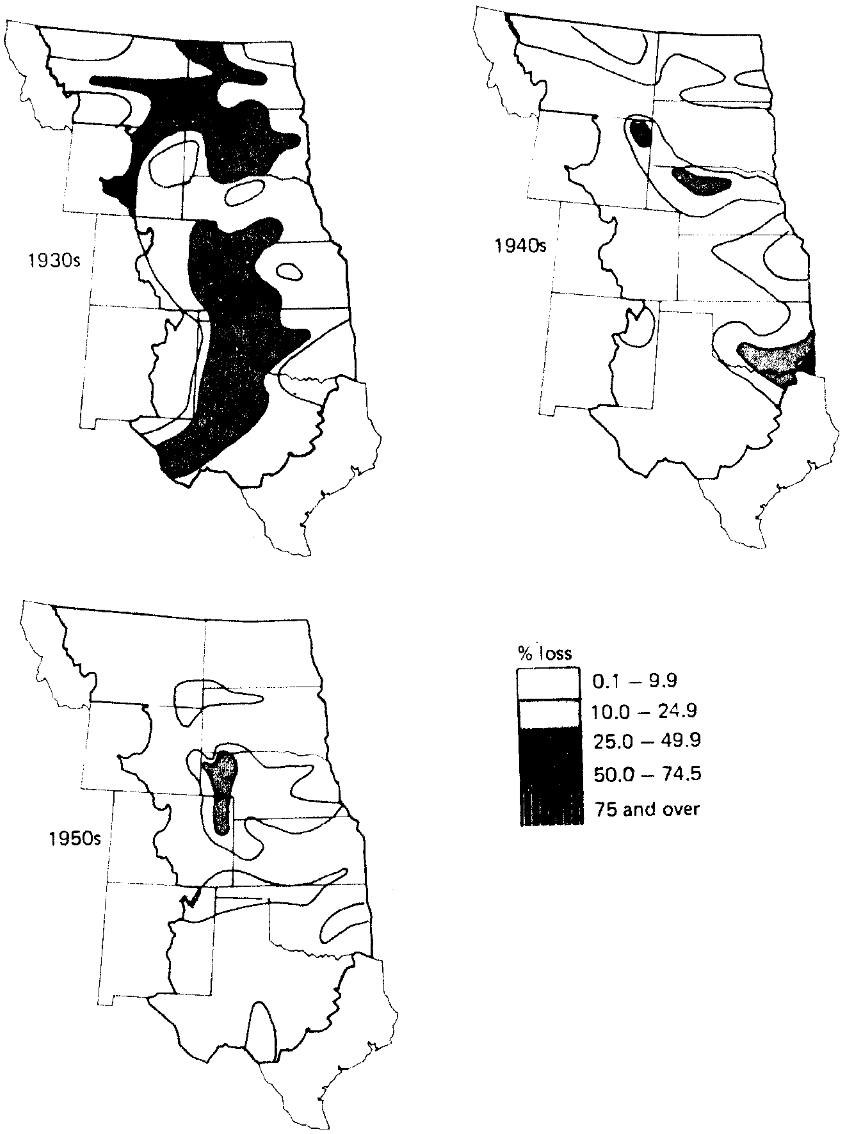



Fig. 21.7 (*continued*)

In the face of major climatic stress in the 1930s widespread system collapse like that in the western Plains in the 1890s and in the northwest Plains 1919–20 (minor climatic stresses) was averted. This apparent anomaly is explained by the fact that the Plains agricultural system was not fully integrated socially and politically into the national economy until the period 1925–34. Integration resulted from at least three significant changes in attitude and circumstance of the American people in the decade preceding the 1934–36 drought.

First, there emerged in the 1920s, following the Mississippi floods, a majority view that federal dollars should be used to aid regions beset by major natural disasters. Second, the Great Crash of 1929, the succeeding Great Depression, and the impatience of the American people with a Republican president's misplaced faith in *laissez-faire* capitalism, convinced a majority of Americans that the government should interfere constructively in the nation's economy. Third, the election of 1931 brought in Roosevelt, a Democratic president, committed to New Deal policies which made it possible for the government to disburse vast amounts of federal funds to the needy and to create agencies dedicated to bringing to the country's economic periphery the general standards of living enjoyed in the economic core.

These changes conspired to make massive federal aid to drought-impacted regions obligatory. The people of the Plains were able to call on the nation to share the impact of an extreme climatic event. Federal relief of 2.48 billion dollars (1957 dollars) ensured that the 'catastrophe' of the 1930s was a large ripple through the national economy, rather than the tidal wave of system collapse on the entire western front of the Plains as in the 1890s. This is clearly reflected in the evenly distributed loss of about 6 per cent of the population Plainswide, compared to the major population decline (more than 25 per cent) on a farming frontier 150 to 250 miles wide and 700 miles long in the 1890s.

From the evidence gathered on population migration, farm transfers, farm income, etc., we have witnessed a dramatic decrease in the effects of minor climatic stress on the society of the Great Plains at local and regional levels, and the development of strategies to mitigate 'catastrophe' at these levels during major climatic stress by devolution of vulnerability to the nation. A major issue is whether the impacts of successive major climatic stresses will be transferred outside the borders of the Great Plains to the international as well as the national level.

### *Examining the catastrophe hypothesis*

In the 1978–79 crop year, 98 per cent of global exports came from five countries, the United States (45 per cent); Canada (20 per cent); Australia (14 per cent); France (14 per cent); and Argentina (4 per cent) (USDA, 1980). This represented 16 per cent of total wheat produced. Such a concentration of available wheat supplies has led to much speculation regarding the possible global impacts of a severe production decline in the United States. What would be the global repercussions if a severe drought were to cripple the Great Plains, a region where 60 per cent of the nation's wheat is grown? Could such an event precipitate an increase in global levels of starvation and malnutrition? To examine this question, we have investigated, in preliminary fashion, the possible range of impact that a recurrence of a drought of magnitude similar to the 1930s would have on US wheat production, and ultimately, on levels of international trade in 1985.

Two estimates of a 1930s-type drought impact on 1985 US wheat production were derived from existing studies: (*a*) a lower impact which assumes 'lessening' and (*b*) a higher impact which assumes effects similar to the 1930s. The lower impact estimate is based on Newman's 1978 study which argues that wheat production has become less variable over time. This he attributes to technology, and increased geographical diversification of the US wheat crop. If a major drought were to occur, so it is argued, not all wheat growing areas would be affected adversely. Based on Newman's data and reasoning, a recurrence of a 1930s drought would result in a 17 per cent decline in production for the Great Plains only.

The high impact estimate was derived from two separate studies, those of the Institute of Ecology (1976) and NOAA (1973). Both studies examine historical yield data and reach the conclusion that yield variability has been unaffected by technology over time. Based on their calculation of deviation from expected yields (fitted trend lines), a recurrence of the worst years of the 1930s could result in about a 21 per cent decline in US wheat production.

The two drought impact estimates were then applied to two 1985 production/export demand scenarios. These were derived from the United States Department of Agriculture (1978) model of the global grain, oilseed, and livestock (GOL) economy. The high-production/export scenario assumes a high level of US participation (63 per cent of total trade) in a high level of international wheat trade (3.2 billion bushels). The low-production/export scenario assumes a low US participation (30 per cent of total trade) in a low level of international trade (2.1 billion bushels). In all cases it is assumed that domestic consumption is constant at 0.89 billion bushels per year.

Amounts of wheat available for export under drought and no drought conditions were calculated for the two scenarios and are indicated in Table 21.4. Under the high-production/export scenario – which implies a high level of dependence on US supplies – the US is predicted to contribute 2.00 billions, or 63 per cent, to total trade. This assumes favourable weather. Under the low drought impact, US exports would be cut to 1.71 billion bushels, or 54 per cent of total trade, a 9 per cent decline. Under the high drought impact, with the same trade assumptions, US wheat available for export declines even further, by 19 per cent.[4]

An assessment of US export potential assuming a low-production/export demand reveals that the US contribution to total trade declines 7 per cent under the low drought impact and 15 per cent under the high impact case. This represents a decline of 0.16 and 0.32 billion bushels respectively.

In terms of unexpected declines in the US contribution to total wheat supply, a 19 per cent decline under a high dependency situation translates into 21 days of total wheat consumption. This assumes that total world wheat utilisation is equal to 0.027 billion bushels or 27 million bushels/day.[5] A 7 per cent reduction in available supplies, under the assumptions of low drought impact on a lower US involvement in world trade translates into 6.7 days of total wheat consumption. This assumes that total world wheat utilisation is equal to 0.024 billion bushels, or 24 million bushels/day.[6]

Whether a 19 per cent decline would have serious global consequences in terms of human impact is a question which we are presently addressing. Our first step has been to set some realistic ranges of potential Great Plains drought on the global system. The next step will be to translate these declines into effect on societal well-being.

### *Great Plains conclusions*

We are not yet prepared to hand down final judgements about the lessening and catastrophe hypotheses as they apply to the Great Plains. But some of the pieces are coming together.

First, *with respect to drought–wheat-yield relationships we find no strong evidence to support the lessening effect*. Rather, the literature and our own analyses demonstrate considerable ambiguity.

Table 21.4. *Potential contribution and drought induced declines in US wheat to projected 1985 international exports, in bushels, and as a percentage of total demand*

| Production/ Export demand scenarios | Drought impact | | |
|---|---|---|---|
| | None | Low (17% decline in GP) | High (21% decline in US) |
| High dependency on US supplies | 63% of a total trade of 3.2 bil. bu. = 2.00 bil. bu. | 1.71 bil. bu. = 54% of total trade 9% decline (0.29 bil. bu.) | 1.39 bil. bu. = 44% of total trade 19% decline (0.61 bil. bu.) |
| Low dependency on US supplies | 30% of a total trade of 2.1 bil. bu. = 0.64 bil. bu. | 0.48 bil. bu. = 23% of total trade 7% decline (0.16 bil. bu.) | 0.32 bil. bu. = 15% of total trade 15% decline (0.32 bil. bu.) |

Methodologically, our findings suggest that complementary analyses at smaller scales, such as counties or crop-reporting districts, would shed light on this question.

Second, *with respect to the relationship between agricultural drought and societal impact at local and regional levels, 'lessening' appears strongly evident.* Certainly, with the comparison of population migration and farm transfers through time, lessening is the case. Additionally, since the one major drought occurrence in the Great Plains in the 1930s and the massive involvement of the nation in (drought) relief, the effects of even the minor droughts, confined to local areas before the 1930s are being diffused through space to the greater social system of national and, possibly global scope.

Our preliminary efforts at defining the range of impact of a major Great Plains drought at the global level suggest that a *recurrence of a 1930s drought could cause declines of 7 per cent to 19 per cent of total wheat export in 1985*, under varying assumptions of production, export levels, and weather impact. We do not know whether a Plains 'catastrophe' would be mitigated by the nation and controlled within its confines as it was in the 1930s or whether 'catastrophe' would ripple into other economies less able to adjust to sudden loss of (food) staples.

Ultimately, it is the answer to this question that concerns us – and the world – the most.

**Lessening and catastrophe**

At the scale of decades in the Great Plains and in the Sahel, a *lessening* in the impact of climate fluctuation upon population is evident. Following the early agricultural occupation of the Great Plains by a people who were unaware that the region was prone to regular droughts, there was a disastrous loss of population during the first drought decade (1890s). The Great Plains (during the droughts of the 1890s and 1910s) and the Sahel in the two major droughts of this century (during which intensive agriculture was replacing extensive pastoral nomadism) were not fully integrated socially and politically into the national or global economy. They were economic colonies being brought into the 'periphery' (Frank, 1970). The wider (national or global) economies in which these regional economies were embedded were neither willing nor obligated to share the two regions' vulnerability to drought and to assume responsibility for aid. Both systems had limited technological ability and social–political organisation with which to adjust to minor climatic stress, and each experienced widespread losses of population through death by starvation and by outmigration.

Technological innovations, from within and outside the system, and the development of political and economic links with systems having different climatic regimes were matched by a relative lowering in the population loss during the drought periods that followed the first one. To this point the lessening hypothesis is confirmed. But the most recent climatic fluctuations in the Great Plains, when related to population changes and to finer-grained indicators of stress suggest that after the initial phases of lessening there develops a near immunity to minor climatic stress rather than a continued history of lessening.

In our three study cases the only clear test for the catastrophe hypothesis is the major climatic stress of the 1930s in the Great Plains. Sizeable population losses occurred uniformly across the Plains, and a major population decline and related temporary collapse of the social economic system occurred in a few places in the heart of the Dust Bowl. But there was no system collapse in the 1930s, and nothing to approach the system collapse in the 1890s in which thousands of square miles on the dry margins of the Plains were effectively depopulated for at least four years. Changes in American political, economic, and disaster relief philosophies occurring in the ten years before the onset of drought (1934), and not prompted by the mid-1930s drought, ensured that the Plains were a full part of the open and enlarging national economy which directly shared the drought impact. Given the post-New Deal policy of the US Government toward its internal regions, system collapse within the Great Plains appears unlikely unless the soil and water resource is more fragile than is at present believed (Bowden, 1977). However, a serious setback in present levels of production and population could occur if major climatic stress Plainswide should coincide with a prohibitively sharp rise in the costs of energy now so necessary to maintain the increasingly irrigated Plains agriculture. This could prompt a widespread reversion to extensive ranching and dry-farming practices, and produce a ripple effect of economic/social stress into countries that depend increasingly on US grain.

There have been no '*major*' climatic stresses in the Sahel this century. Nevertheless, another '*minor*' climatic stress like that of 1910–15 or 1968–74, in conjunction with the population growth postulated in the Matlock & Cockrum (1974) model and with multifarious social, political, and economic changes could precipitate a system collapse in the Sahel, as could the continued and related exploitation of an already fragile resource base.

Of course, the climatic stresses of the last century in the Sahel and the Great Plains may prove to be events in long-term 'catastrophes' such as those that terminated the first and second cycles of population growth in the Tigris–Euphrates Valley. Attractive (and simple) as is the thesis of environmental stress as the cause of these long-term 'catastrophes', our research casts doubt on it. These two prolonged declines in population in the Tigris-Euphrates Valley constitute long-term 'catastrophes' of far greater magnitude than those experienced and foreseen in the Plains and the Sahel. They were the result, our studies maintain, of a combination of factors: political and social instability, an absence of technological innovation and, to a limited extent, climatic and hydrologic stress.

**Acknowledgements**

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## Notes

1. Pourafzal searched in Dakar the *Reports of the Governor-Generals* of the former French colonies of West Africa for the years 1910–15. Watts' unpublished report was based on field work and archival research. They are not responsible for our interpretation of their data and indeed we differ in interpretation in some instances.
2. Climatic divisions are sections of the country delimited by the US Weather Bureau for which climatological data are made available. The Palmer Index (PI) is a measure of soil moisture surplus or deficit in terms of deviation from a climatological and hydrological normal. Zero represents normal; negative deviation corresponds to moisture deficit, and positive deviation indicates surplus. PI values were obtained from the National Climatic Center, Asheville, North Carolina.
3. Colorado, Kansas, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas.
4. The low drought impact figures are calculated by adding the adjusted production for Great Plains acreage with the acres not in the region, where no drought impact is assumed. Domestic consumption (0.89 billion bushels) is then subtracted from that sum to give wheat available for export. For the high-impact scenario, a yield reduction of 21 per cent was calculated for all US acres, and domestic consumption was then subtracted out.
5. Based on USDA (1978) GOL model assumption that 1985 total wheat utilisation is 9.8 billion bushels per year for the high-production/export demand scenario.
6. Based on USDA (1978) GOL model assumption that 1985 total wheat utilisation is 8.8 billion bushels per year.

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