

Human Response to Environmental Change in the Perspective of Future, Global Climate

KARL W. BUTZER

Departments of Anthropology and Geography, The University of Chicago, Chicago, Illinois 60637

Received June 28, 1982

Human response to severe environmental stress is conceived and implemented by individuals, but must be approved by the group. These decisions are made with respect to perceived circumstances. Societies are enmeshed within adaptive systems that provide a matrix of opportunities and constraints for a wide range of potential behavioral variability. Such systems repeatedly readjust to short-term crises, e.g., droughts, but persistent and severe environmental stress may require substantial revision of adaptive strategies. The Sahel drought of 1968-1973 is an example of a brief but severe crisis, recurring along the Saharan margins perhaps once every 30 years. Closer inspection shows links between intensified intertribal warfare and ecological stress in the lower Omo Valley. The decline of the Egyptian New Kingdom during the 12th century B.C., in response to economic stagnation, sociopolitical instability, dynastic weakness, foreign pressures, and poor Nile floods over 50-70 years, represents a more complex and fundamental modification, with systemic simplification lasting 450 years. Such insights can be applied to future, global climatic change due to increasing atmospheric CO₂. Simulation and paleoclimatic experience suggest a drier climate for the North American and Soviet breadbaskets, to threaten world food supplies at a time of maximum demographic pressures and declining resources. Public perception and remedial planning should receive the attention of Quaternary scientists, in order to preempt an involuntary, global, systemic simplification.

INTRODUCTION

To deal briefly but comprehensively with the impact of rapid environmental change on society is a difficult task. For one thing, the climatic or other environmental anomalies must first be identified and documented. Even more difficult, the human response has to be evaluated with attention to the full range of variables potentially involved in such a systemic reaction. The social sciences have only begun to develop models of human response to external or internal systemic change. Further, such responses are unpredictable, if for no other reason than that too many variables are involved (Butzer, 1980a; De Vries, 1980; Ingram *et al.*, 1981).

HUMAN RESPONSE TO RAPID ENVIRONMENTAL CHANGE

The first issue in assessing human response of any kind is whether such re-

sponse reflects individual or group decisions. Ideas and actions are conceived and implemented by individuals, but whether or not they evoke a positive community response depends on group acceptance. During the Dust Bowl of the 1930s, the rural population of seven Great Plains states declined by a half million (U.S. Dept. of Commerce, 1942). In many counties 20-50% of the farm inhabitants pulled up their stakes and moved into large towns or migrated to better farmland or expanding oilfields elsewhere (Fig. 1).

In other areas, hit equally hard by drought, most farmers stayed on, some switching to ranching, others just waiting out the bad times. This response differential depended in part on economic conditions, such as the strength of regional financial institutions, the effectiveness of government agencies, and the cohesiveness of the town and rural sectors in the face of adversity (Miewald, 1978; Lawson and Baker, 1981).

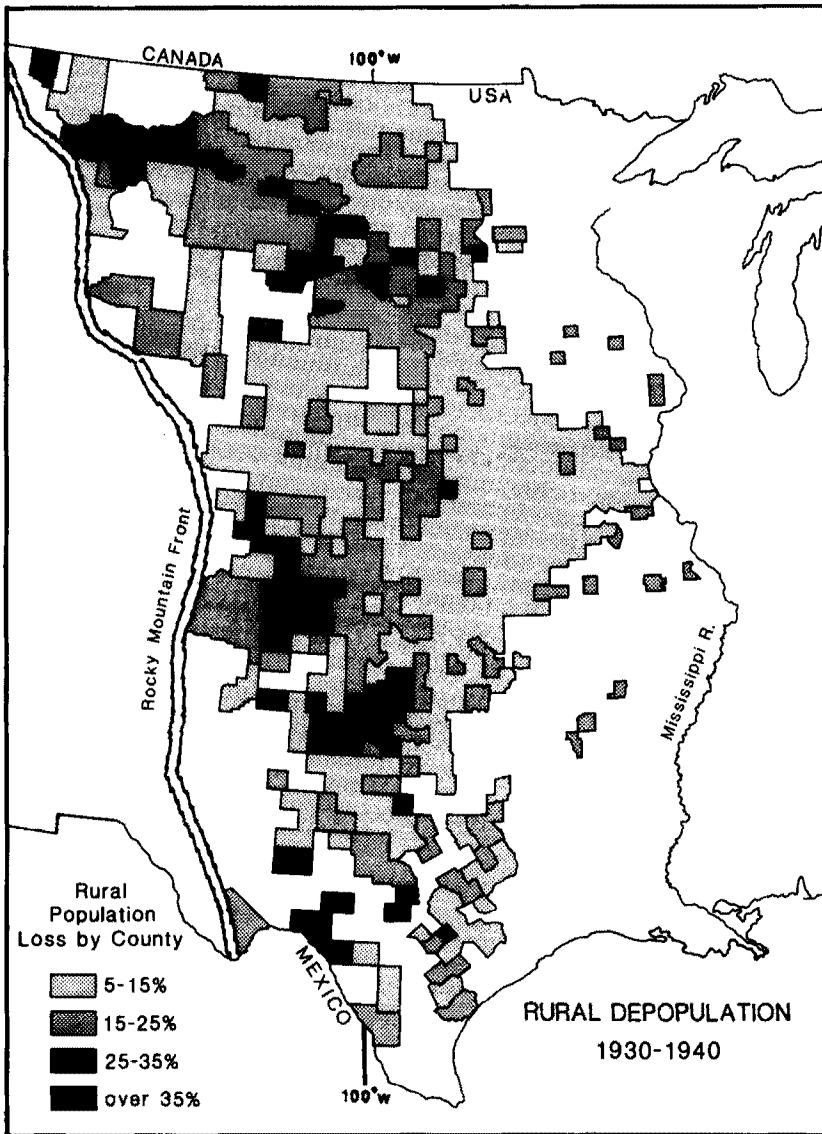


FIG. 1. Rural depopulation from the Mississippi River to the Rocky Mountains between the 1930 and 1940 census documents the most tangible impact of the Dust Bowl (county data from U.S. Dept. of Commerce, 1942). Some isolated counties with less than 5% rural population loss are not shown within the contiguous shaded area.

Overall, the destitute farmers of the Dust Bowl responded to drought in many ways, but the dominant pattern of adjustment differed, however subtly, from one area to another. The range of potential responses was similar in most regions, but the characteristic choice was probably formulated in a community context.

The second problem in examining human response is just how devastating and per-

sistent a drought is perceived to be and anticipated to last. In Kansas the drought year 1860 brought only 380 mm of rainfall at Manhattan, about half the long-term mean; the 460–480 mm received during the longer 1874–1875 drought spell consequently evoked little response, particularly since newspapers downplayed the event (Bark, 1978). Severe winters and moderately below-average rainfalls 1885–1894 con-

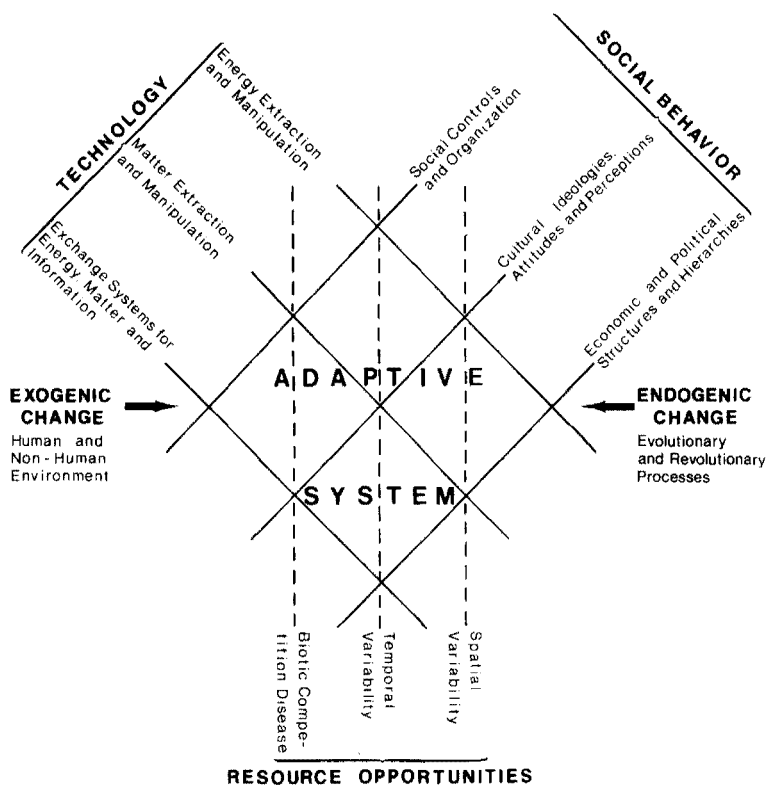


FIG. 2. A three-dimensional model for the interactive variables of an adaptive system. After Butzer (1982a, Fig. 15-2), with permission of Cambridge University Press.

vinced half the settlers of Kansas to emigrate. Then, after good or average rainfalls 1902–1931, the five driest Dust Bowl years averaged 535 mm of precipitation (see also Palmer Index values in Warrick and Bowden, 1981) but provoked a 9% decrease in the rural population of Kansas (U.S. Dept. of Commerce, 1942). It can therefore be argued that decisions are made with respect to perceived rather than real environments. This subjective perception is very much a relative one, and the flexibility of potential response is defined in the broader economic context, one that was decidedly poor in the Depression years of the 1930s (Saarinen, 1966; Warrick and Bowden, 1981).

During the 30 "fat" years that preceded the Dust Bowl, Kansas agriculture developed on the premise of good rains that supported profitable winter wheat cultivation, even in the marginal western counties of the state. This adaptation did not take into account that recurrent severe droughts were

inevitable, at unpredictable intervals, placing such a short-term maximization strategy in serious question. As a result, Kansas agriculture was forced to adjust in more diversified directions, placing greater emphasis on irrigation from deep wells in some areas, allowing the most droughty soils to revert to extensive livestock pasture and, above all, searching for socio-economic mechanisms, such as federal relief and crop insurance, to buffer the farmer from drought (Quinn, 1982). These events illustrate that adaptive strategies are in constant interchange with the environment, that economic versatility allows a progressive identification of new and more detailed variety and constraints within that environment, and that the information so gained is then incorporated into revised strategies that preserve and propagate the more successful system variables (Buckley, 1968; Kirch, 1980).

These considerations allow definition of an

adaptive system, as the three-dimensional intersection described by social behavior, technology, and resource opportunities and limitations (Butzer, 1982a, p. 285) (Fig. 2). Such a system is reflected in subsistence strategies and settlement patterns, and it responds and adjusts in relation to internal processes as well as to changes of the human and nonhuman environment. Such adjustments can be made at several scales.

(a) Some involve very long-term and fundamental, cultural transformations that eventually have continental or global repercussions for subsistence, settlement, and demography. Examples would include prehistoric agricultural origins or the historical impacts of industrialization. In the case of Kansas the applicable example is the replacement of indigenous hunting and gathering by European-style farming during the 1850s and 1860s.

(b) Other adjustments involve a substantial revision of adaptive strategies within the context of a viable and persistent adaptive system. This would be effected through technological or behavioral accommodations to new ideas and to repetitive stress situations of various kinds. The revision and elaboration of Kansas agriculture between 1860 and 1945—by crop selection, hybrid development, cultivation practices, water exploitation methods, and government intervention—provide a good example of such an adaptive modification over an intermediate time range.

(c) Finally, there are the many minor or short-term readjustments within the behavioral and technological spectrum of an adaptive system that serve to resolve economic and social crises, and so maintain a systemic steady state. Wars, epidemics, and famines are pertinent examples; when applied to the Kansas situation, the measured response to the droughts of 1952–1956 comes to mind.

In general terms, an adaptive system with its bounding environmental parameters provides a matrix of resources and constraints for the potential range of behavioral

variability (Butzer, 1982a, p. 293; 1982b). In exploiting these opportunities and confronting the fluctuating boundary conditions, the individuals within the societal subsystem have a wide choice of potential subsistence-settlement options that may be either adopted or rejected. In this sense, adaptive response, however environmentally conditioned and spatially rationalized, is explicitly the result of human perception and decision making. The constraining role of the environment is a highly generalized one, and technology as well as social organization repeatedly bend the constraints. Regardless of whether the external or internal changes are sufficiently serious to warrant massive response, cognitive perception generates positive or negative feedback that, over the longer term, represents adaptation—irrespective of whether that adaptation is ultimately successful or not. The very fact that the cognitive dimensions in an actual case study cannot be effectively quantified means that adaptive response to environmental change cannot be uniquely predicted.

SHORT AND MEDIUM-TERM RESPONSE

Two African examples serve to show that the impacts of and response to drought are difficult to anticipate. One of the more catastrophic famines unleashed by recent drought affected the Sahel margins of the Sahara during 1968–1973. The discharge of the Senegal River, which provides a good index of modal rainfall for this climatic zone, averaged 33% below the 77-year mean (Faure and Gac, 1981a) (Fig. 3). Hardest hit by this short-term anomaly were the pastoralists of the Sahel (Kates, 1981), but agricultural yields were severely curtailed through much of West Africa as well as in Ethiopia (Hussein, 1976). At least 250,000 lives (and possibly double that number) and several million cattle were lost, but the long-range costs in terms of child malnutrition, soil destruction, and

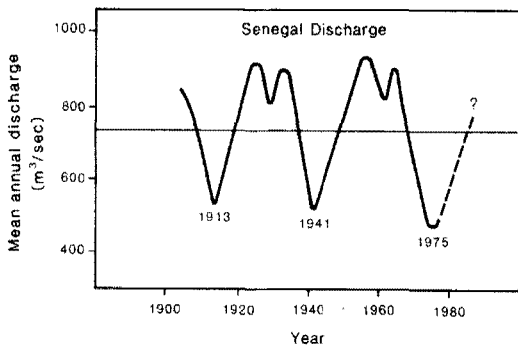


FIG. 3. Mean annual modulus (7-year running means) of the Senegal River at Bakel (after Faure and Gac, 1981a), illustrating the recurrent nature of drought. The horizontal bar represents the 1903–1979 mean.

desertification are almost impossible to assess (Kates, 1981).

The human impact of the Sahel drought was particularly severe because herds had grown unchecked since the previous great drought of 1940–1944, while agriculture had expanded into the transhumance zone, limiting the mobility essential to pastoral exploitation of marginal environments (Glantz, 1976; Dalby *et al.*, 1977; Franke and Chasin, 1980). Regional governments were slow to respond and international aid was distributed ineffectively in some areas. In Ethiopia, 10,000 unburied corpses littered the streets of the provincial capital of Dese, while 250 km away hundreds of tons of food shipments rotted in the customs compound of the Addis Ababa airport. The Sahel drought draws attention to several important characteristics of major famines.

(a) Mass starvation is more commonly linked with inadequate redistribution systems and/or overpopulation than it is with exceptionally severe environmental stress (Dando, 1980). In fact, the Bengal famine, which took over a million lives in 1943, was entirely due to British wartime manipulation of food supplies in an overpopulated part of India. Whether, on the other hand, rapid technological and social transformation (“development”) of traditional societies reduces their vulnerability to environmental stress, as is implied by Kates (1981;

Bowden *et al.*, 1981), remains an unresolved and controversial issue.

(b) Periodic stress in marginal environments generally limited the populations of traditional societies to well below carrying capacity, but progressive “westernization” has upset this ecological balance. In the Sahel, severe drought has recurred at intervals of about 30 years since at least the mid-19th century (Faure and Gac, 1981a, 1981b) (Fig. 3); it is uncertain whether the human suffering engendered by the drought of 1913–1914, which promoted epidemic disease, was greater or less than during 1968–1973 (Kates, 1981).

(c) Severe drought and starvation have tended to accelerate political devolution in unstable societies. In Ethiopia the inability of the old regime to cope with famine (Hussein, 1976) provoked the unrest that made possible the “creeping revolution” of 1974. Further, the oral history of many Ugandan tribes is fundamentally structured around major famines and other natural disasters, in turn linked to specific reigns or warlike migrations since the 14th century (Webster, 1979).

In any examination of drought repercussions there is a tendency to overgeneralize by neglecting the complex social interactions and detailed responses to environmental stress. It is therefore critical to study such events at the specific and local level, much as it is preferable to evaluate the Dust Bowl years for one state or, better yet, a single county.

East Africa provides a good case to point. The Omo River, fed by a high Ethiopian watershed, empties into Lake Rudolf (Turkana) across a broad delta surrounded by subarid lowlands plains. From the 1860s to 1890s this lake was high, flooding most of the delta until 1897–1908, when lake level fell 12.5 m during a severe drought anomaly, a trend that continued through 1960 (Butzer, 1971) (Fig. 4). The delta inhabitants, members of the pastoral and horticultural Dasanech tribe, adjusted readily by simply following the retreating lake-

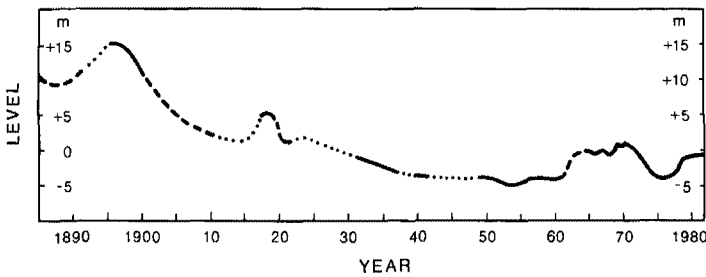


FIG. 4. Fluctuations of Lake Rudolf (Turkana) since 1888. Updated after Butzer (1971, Fig. 3–6).

shores, as an informant put it in confirmation of travelers' observations (Butzer, 1971, Chap. 4). Dasanech social structure facilitates temporary or permanent adjustment to local resource shifts, because households or settlements can easily move from one part of the tribal territory to another without regard to kinship (Almagor, 1972). As a result, the Dasanech grew in numbers and power while other, pastoral tribes were subject to protracted stress as pastures deteriorated and surface water became scarce. A little later, from 1917 until 1941, the Dasanech repeatedly took the offensive against their weakened neighbors.

In 1961–1962 lake level suddenly rose by 4 m. Some 250 km² of the Omo Delta were submerged (Fig. 5) and increased incidence of malaria forced over half the Dasanech to vacate the delta plains and switch almost entirely to pastoralism on high ground far from the river. But their traditional grazing lands had been made into a *cordon sanitaire* in 1942, when the British sealed the Ethiopian border to halt intertribal warfare (Almagor, 1974). Consequently, heavy overgrazing put the Dasanech under increasing ecological pressure, particularly as the Sahel drought spread to East Africa in 1970–1973 (Carr, 1977). As they attempted to enlarge their grazing territory, the Dasanech now turned against a once allied, neighboring tribe within Ethiopia's borders and massacred 10% of its people (Tornay, 1979). A chain reaction of intertribal pressures was set off, one part of the victimized tribe pushing far into the Sudan, others impinging on their northern neighbors, who then attacked their own next neighbors.

The tribal unrest of the lower Omo valley was conditioned by colonial borders that cut traditional transhumance lines, but it nonetheless illustrates the complex ecological relationships that underlie much of the intertribal warfare and migration in African protohistory. At the same time these episodes represent one microcosm of the wider Sahel drought phenomenon and its short-term impacts on traditional societies.

The sociopolitical impact of drought is not limited to relatively simple pastoral peoples, such as those of the Omo Delta and Saharan borderlands. The 1974 breakdown of the increasingly dysfunctional, imperial government of Ethiopia, in the wake of severe socioeconomic stress, provides one case to point. A second, historical example can be cited from pharaonic Egypt, namely the breakdown of the New Kingdom during the 12th century B.C. (Butzer, 1976, 1980a, 1983).

Archeological survey and geological study show that the Nile floodplain in Nubia had been heavily settled during the 13th century B.C., with flood levels a meter higher than today; during the next century this floodplain was totally abandoned, dune sands swept across it, and salt efflorescences began to build up. At the same time the easternmost branch of the Nile Delta failed, so that the northern capital of Egypt was shifted to another distributary. Declining Nile discharge approximately coincided with a dramatic fall of East African lake levels, reflecting large-scale and long-term climatic change in the upper Nile watershed (Butzer, 1980c).

The Egyptian situation at this time is in-

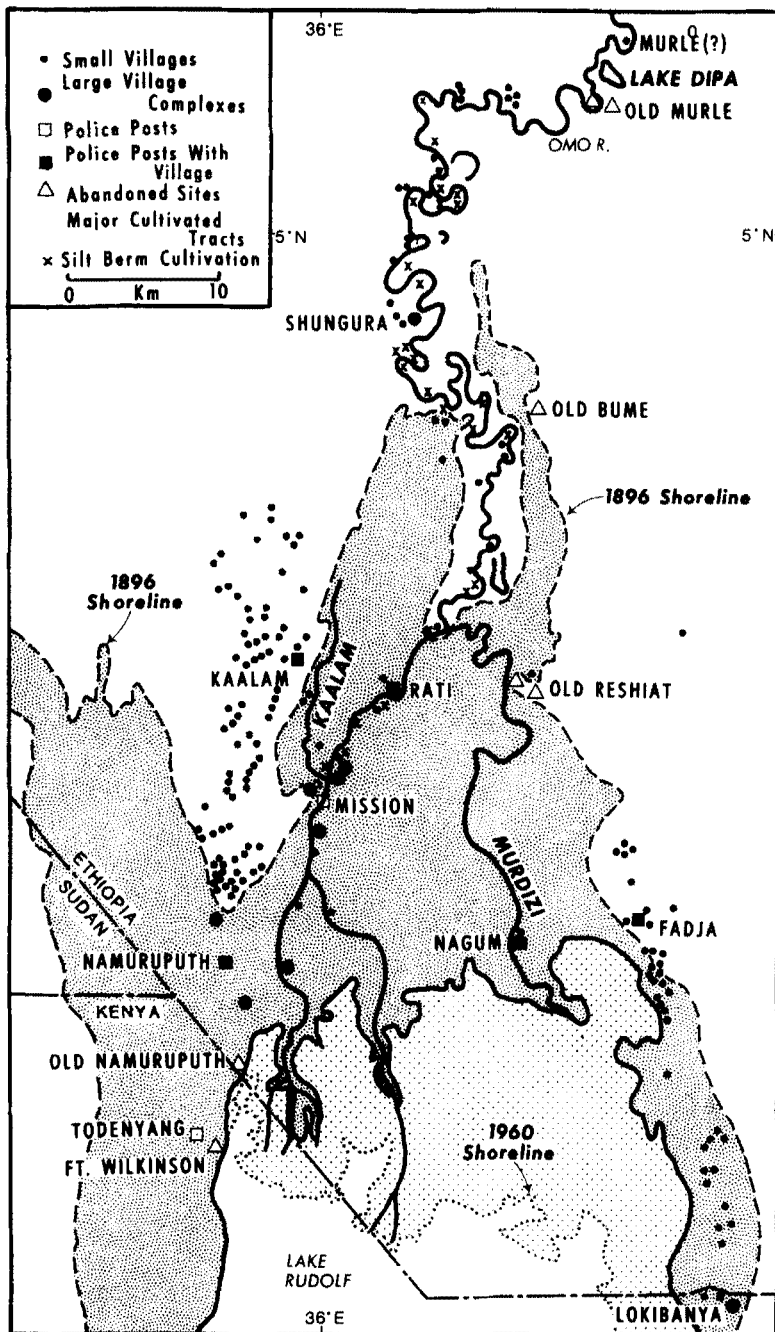


FIG. 5. The settlements of the lower Omo Valley as mapped by the writer in 1967–1968, showing the 1960, 1970, and 1896 shorelines. Submergence in 1962 drowned many villages and much horticultural land along the two distributaries; this reinforced the pastoral economy in the increasingly overgrazed area between Namuruputh and Kaalam. Dasanech settlements extend upvalley to a little below Shungura. After Butzer (1971, Fig. 4–6).

teresting because there is unusually good detail on food prices and social unrest. The king was able to provide grain to the Hittites during a famine in Asia Minor in 1210

B.C., and Egyptian grain prices remained stable until 1170 B.C. Then they began to increase rapidly, fluctuating to as much as eight times the normal price—even though

the value of precious metals, services, and livestock was unchanged. In 1153 B.C., the food supply failed so that the royal workmen in the capital rioted; the best efforts of the prime minister turned up a bare half of the wheat actually needed, indicating that the temple granaries were empty. Ramesses III, a strong pharaoh, was apparently assassinated two years later, and the subsequent reigns of weaker kings were short. Five further food strikes or riots are documented 1151–1105 B.C., and in 1130–1125 B.C. wheat prices fluctuated to as much as 24 times their earlier level, with barley and oil prices also high. Taxation pressures during this time of poor harvests then led to massive rural depopulation. Although food prices stabilized about 1110 B.C. and began to fall off after 1100 B.C., the last king of the dynasty (Ramesses XI, 1099–1070 B.C.) was explicitly disenfranchised by the priesthood as the divine provider of life and safeguard of the cosmic order, being demoted to a simple agent of the supreme Egyptian god, Amun.

It is tempting to see this usurpation of power as an indictment of the dynasty's failure to guarantee nature and thus the livelihood of Egypt. The cemetery record indicates widespread impoverishment and, possibly, a declining population. The new, priestly dynasty after 1070 B.C. was unable to hold the country together or to stave off Libyan or Ethiopian–Sudanese invasion and control. High Nile floods were only recorded again after 868 B.C. and the country was reunified under a new, Egyptian dynasty in 656 B.C. During the 450 years following the death of Ramesses III, Egypt lacked effective central authority, politico-economic structures were strongly simplified, and both subsistence and population were reduced to significantly lower equilibrium levels. It would, however, be simplistic and contrary to the historical context to attribute this devolution to a protracted decline and repeated failure of Nile floods between 1170 and 1100 B.C.

Egypt had fended off a powerful coalition of barbarian peoples in three costly battles in 1207, 1177, and 1171 B.C. Unlike other Near Eastern Kingdoms, Egypt survived intact, but its Asiatic provinces were lost and its external exchange system destroyed. The power of the priesthood of the god Amun had already competed with that of the pharaoh since about 1400 B.C. and, significantly, the end of the environmental crisis about 1100 B.C. did not reverse the continuing shift of power to the priesthood. Again, a new trend to a favorable Nile hydrology during the mid-9th century preceded political reintegration by a full two hundred years. Finally, the Egyptian state was characterized by a top-heavy sociopolitical structure since the late 15th century, with increasing energy expenditure for system maintenance, and accelerating demands on the agricultural substrate during the course of the 13th century B.C. There is then good reason to believe that sociopolitical structures were already metastable before the accession of Ramesses III, and that systemic disintegration set in immediately after his death. In this setting, severe environmental stress reinforced economic stagnation, sociopolitical instability, dynastic weakness, and foreign pressures. It was no more than one potent factor in a concatenation of negative processes in the demise of the New Kingdom.

The Egyptian breakdown is important because it represents a medium-range adaptive modification, not just a short-term readjustment such as those set in train by the Dust Bowl or the Sahel drought. Stress was maintained for 50 to 70 years, and consequently must have contributed significantly to the positive socioeconomic feedbacks already undermining the political structure of Egypt. The fact that Egypt was both a complex society and an imperial state, with extensive international linkages, suggests that the insights gained here can help to evaluate scenarios for future climatic change.

FUTURE GLOBAL CLIMATIC CHANGE

During the last 100 years or so, atmospheric CO₂ has increased between 16 and 25% as a result of fossil fuel combustion and extensive deforestation (Siegenthaler and Oeschger, 1978; Clark, 1982; MacDonald, 1982; National Research Council, 1982). This CO₂ flux has accelerated since 1950 and is widely expected to double atmospheric concentrations by mid-21st century, with the amplitude and rate of change depending on energy consumption and the development of synthetic and non-fossil fuels. Whatever the actual change within a range of available "low" and "high" projection limits, this would have a major impact on the global radiation budget and so promote a mean warming of somewhere between 2 and 3.5°C (Hansen *et al.*, 1981). Although the amplitude and configurations of the expected climatic changes cannot yet be determined with precision, increasingly sophisticated simulations of the global climate system and the carbon cycle (Manabe *et al.*, 1981) on the one hand, and paleoclimatic experience (Kellogg, 1978; Butzer, 1980b; Pittock and Salinger, 1981) on the other, suggest that the breadbaskets of North America and the Soviet Union will be increasingly threatened by summer drought.

Meteorologists and biologists can study a part of this potential global response, namely, carbon release from fossil fuels and rapid deforestation, the carbon dioxide flux of the oceans, the capacity of vegetation and soil to absorb carbon dioxide, the simulation of atmospheric latent heat flux and thermal deviations and, ultimately, their potential impact on precipitation patterns and soil moisture. But simulations are only as good as the complexity of their variables and the validity of their assumptions. A particular problem with existing simulations is that they concentrate on the steady-state response to a fixed CO₂ increase, neglecting the effects of a time-

dependent CO₂ increase conditioned by air-sea-ice interactions (Thompson and Schneider, 1982). Consequently, regional climatic response to increasing CO₂ remains uncertain.

Simulations of global warming and effective moisture change cannot anticipate the full range of possible negative and positive feedbacks of environmental systems. It therefore remains imperative to test their value in the light of historical monitoring and paleoclimatic experience. It is here that Quaternary research comes to bear. Paleoclimatic reconstructions can provide fundamental insights on the possible interrelations between higher global temperatures and regional moisture anomalies. Such an approach is, of course, no less limited by unjustified assumptions than are existing simulations. In particular, analog predictions can only claim validity if cause and effect relationships were the same in the past as they would be for a CO₂-induced planetary warming. Whether or not it is true that inferred higher temperatures for parts of the Holocene (and earlier interglacials) were primarily a result of earth orbital forcing (Kutzbach and Otto-Bliesner, 1982), such warmer intervals during the Cenozoic were certainly not due to increased atmospheric CO₂. In other words, paleoclimatic analogs are no more or less valid for predictions than are the existing simulations. It is because the assumptions of both approaches are different that they have value as essentially independent crosschecks.

Paleoclimatic attention is most usefully focused on the relatively detailed record of the early to mid-Holocene, when the paleobotanical evidence for latitudinal and vertical shifts of ecozones suggests that high latitude and high-mountain temperatures averaged 1.5 to 2.5°C above those of today. This Altithermal or Hypsithermal interval, dating from about 8000 to 5000 years ago, provides a reasonable outline of regional climatic deviations for most of the

continents. As documented in an earlier paper (Butzer, 1980b), the essential features of this mid-Holocene model (Fig. 6) are as follows.

(a) Substantially augmented growing seasons in cool environments now marginal for agriculture;

(b) distinctly drier climate in most mid-latitude arid, semiarid, and subhumid regions, with an inherent trend to desertification, including the major wheat and corn producing belts of the United States and the Soviet Union; and

(c) moderately increased precipitation in the tropical and subtropical arid zone, primarily in what are now pastoral and irrigated lands of Africa, Arabia, India-Pakistan, and Australia, but excepting the more productive mediterranean environments of Europe and South Africa.

This pattern is reasonably consistent (spatially and temporally) and moderately well documented. Quantitative assessments still are few, but negative deviations may have ranged from 20 to 50% in the hydrological balance of middle latitudes, with positive anomalies of 30 to 100% in lower latitudes.

Despite its qualitative and quantitative shortcomings, the mid-Holocene scenario of Figure 6 provides a useful preliminary model for probable climatic zonation during the mid-21st century. Comparisons with the simulations of Manabe *et al.* (1981, Figs. 22, 23) are most productive, because these explicitly consider the seasonal moisture cycle and the ratio of solid to liquid precipitation. Particularly impressive is that both models agree on substantially reduced moisture for midcontinent North America and for the Caspian and Black sea drainages of southeastern Europe. Specifically, the simulation model posits that higher temperatures in midlatitudes—whatever their ultimate cause—would reduce winter snow accumulation, increase evaporation during spring and summer, and reduce summer cyclonic activity, all with detrimental effects on soil moisture (Manabe *et al.*, 1981). Backed by convergent but independent arguments, this critical aspect of the scenario must be considered as reasonable, if not probable. Less certain is the case for increased lower latitude moisture: the Manabe *et al.* (1981) simulations are inconsistent with each other, and with the paleo-

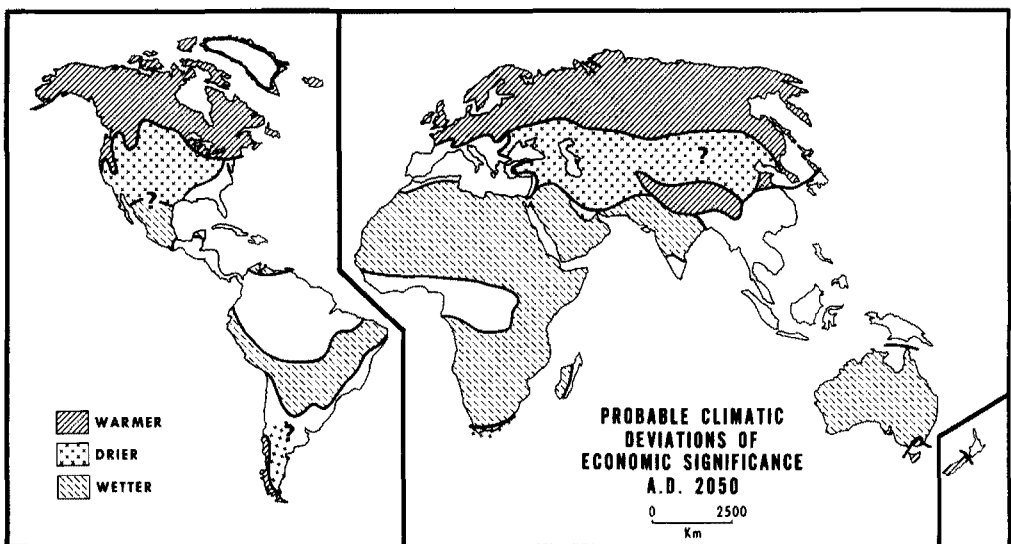


FIG. 6. Probable climatic deviations of economic significance to be expected as a result of CO_2 -induced climatic change, based on paleoclimatic experience of ca. 8000–5000 yr B.P., in the main part consonant with meteorological simulations. After Butzer (1980b, Fig. 1), with permission of the Association of American Geographers.

climatic analog model. Possibly this reflects the unique forcing of tropical monsoonal circulations by increased lower latitude radiation ca. 9000 yr B.P. (Kutzbach and Otto-Bliesner, 1982). This uncertainty would not, however, improve the economic implications of the analog scenario.

The agricultural prognosis suggested for the 21st century by the mid-Holocene model are mixed and, in important ways, negative overall (Schneider, 1976; Olson *et al.*, 1978; U.S. Dept. of Energy, 1980; Butzer, 1980b; Kellogg and Schwere, 1981). Dust Bowl conditions would become commonplace on the Great Plains, with an increased incidence of drought in the Midwest. A substantial part of the present winter-wheat belt would have to revert to grazing, with large-scale replacement on the corn-soybean production of Illinois, Iowa, and Missouri by winter wheat. The corn belt would shift, climatically, to Wisconsin, Minnesota, and Canada, where podzolized soils are poorer and drainage less than ideal. Irrigation waters in the West would be substantially reduced and less reliable. Overall United States crop acreage and average yields would plummet, and corn with its attendant livestock industry would be widely replaced by wheat of substantially lower productivity. Similar problems would plague food production in the Ukraine and Central Asia. By comparison, the potential expansion of agriculture onto the marginal soils of the present mixed-coniferous forest belt of Canada and northern Europe would be relatively insignificant.

Any increased moisture in low-latitude deserts and the semiarid zone of Africa, Asia, Australia, and parts of South America would primarily affect the productivity of low-efficiency pastoral economies, locally supplemented by irrigation agriculture. Even increased yields in the primary tropical agricultural belt would not add substantially to the world food supply, probably serving instead as a stimulus to further demographic growth. Long-range benefits in the tropics would only be assured by a

switch to labor-intensive horticulture on the Chinese model, or to a Western-style modernization, that would require heavy and sustained capital investment—in countries generally lacking both industrial capacity and energy sources.

The world food-supply prospects of this scenario, whatever its shortcomings in detail, are grim, even allowing for substantial negative feedback within both the environmental and the adaptive systems. In particular, the United States, now the world's major food exporter, would barely remain self-sufficient, while the Soviet Union would be heavily dependent upon food imports. Unless demographic trends in low-latitude, Third World nations are reversed and agricultural productivity at least doubled, Canada's and Australia's sustained capacity to export would be inadequate to meet world demand for food.

There is then substantial reason to believe that a continuation of present environmental trends points towards an economic crisis of global proportions within the next 20 to 100 years. The implications must be viewed in conjunction with the *Global 2000 Report* (Barney, 1982), summarizing the hard evidence for the Third World demographic juggernaut, the increasing global energy shortfall, and the ecological, economic, and technological limitations to everincreasing food production. In the *Global 2000* assessment, the population, food, and energy variables were examined in isolation, neglecting the systemic interactions between economic productivity, available capital, research funding, remedial technology, and food production. Compounding these problems, with climatic change and persistent drought expected to affect the major world food suppliers most, the concatenation of negative impacts has serious portents (Butzer, 1980b):

(a) a substantial reduction of the world food supply, at a time of maximum demographic pressures upon global resources and shrinking energy reserves;

(b) selective decline of productivity

among the major economic and food-producing nations, implying a fundamental sociopolitical readjustment not only between the present superpowers but also between developed and developing world regions; and

(c) differential impacts within undersupplied nations of special complexity, as resources become inadequate to maintain controlled ecosystems, raising the possibility of severe internal disruptions and confrontations within existing socioeconomic subsystems.

Complex societies, both traditional and industrialized, are to some extent buffered from environmental vicissitudes by multiple layers of technology, social organization, and exchange networks. Their adaptive strategies emphasize stability, the maintenance of a set of socioeconomic priorities, culture norms, and value systems that define a familiar cognitive universe. Unlike the instability thresholds of the increasingly simplified environmental systems to which they are linked, those of complex cultural systems tend to be high, in no small part because negative feedback mechanisms are numerous. But, in probability terms, the very multiplicity of systemic components in vertically elaborate, top-heavy sociopolitical structures also increases the chance of a concatenation of negative inputs (Butzer, 1980a). The Egyptian example showed how the coincidence of poor leadership, social pathologies, economic stagnation, external political stress, and environmental perturbation can trigger a catastrophic train of mutually reinforcing events that the system may be unable to absorb.

There is a major difference between the New Kingdom and the 21st century. We already live within a global system, increasingly tightly interlinked, so that the breakdown of one adaptive system somewhere would rapidly affect whole continents, ultimately with worldwide repercussions. To speculate on the possible nature of such repercussions would be inappropriate, but we

should realize that our global adaptive system is metastable. Systemic simplification towards a lower equilibrium level would be too expensive in human or economic terms to contemplate.

It is therefore incumbent on the scientific community not only to refine and refocus potential contributions to broadly defined ecological themes, but also to communicate its findings to the public and, directly or indirectly, to government. Only in this way can we hope to influence community perception and stimulate or influence proper remedial action, to preempt involuntary adaptive modification and systemic simplification on a global scale. "Pure" research is ultimately justified, at least in economic terms, because it frequently has unexpected applications, the importance of which may only be recognized decades later.

Quaternary researchers are ideally suited to verify, with paleoclimatic data, the paleoboundary conditions simulated by climate modelers. Equally so, they can and should contribute more to examination of the feedback systems involved, many of which can be identified or negated by careful historical monitoring. Again, Quaternary research is ideally suited for an examination of modern desertification processes in historical context, determining to what extent these are unique or cyclical within the Holocene record. In conclusion, Quaternary scientists of many different persuasions now have a unique ability, opportunity, and responsibility to contribute both multidisciplinary component data and systemic evaluations to an issue of equally unique importance.

ACKNOWLEDGMENTS

Edward S. Deevey, Jr., Merlin P. Lawson, Wayne M. Wendland, and an anonymous reviewer provided valuable suggestions for improving the manuscript.

REFERENCES

- Almagor, U. (1972). Tribal sections, territory and myth—Dassanetch responses to variable ecological conditions. *Asian and African Studies* 8, 185–206.

- Almagor, U. (1974). The war of the Ilemi Appendix. Paper, African Studies Association (United Kingdom) conference, Liverpool, September 1974.
- Bark, L. D. (1978). History of American droughts. In "North American Droughts" (N. J. Rosenberg, Ed.), pp. 9–23. Westview Press, Boulder, Colo.
- Barney, G. O. (1982). "The Global 2000 Report to the President: Entering the Twenty-First Century," Penguin, Harmondsworth.
- Bowden, M. J., Kates, R. W., Kay, P. A., Riebsame, W. E., Warrick, R. A., Johnson, D. L., Gould, H. A., and Weiner, D. (1981). The effect of climate fluctuations on human populations. In "Climate and History" (T. M. L. Wigley, M. J. Ingram, and G. Farmer, Eds.), pp. 479–513. Cambridge Univ. Press, Cambridge.
- Buckley, W. (1968). Society as a complex adaptive system. In "Modern Systems Research for the Behavioral Sciences" (W. Buckley, Ed.), pp. 490–513. Aldine, Chicago.
- Butzer, K. W. (1971). "Recent History of an Ethiopian Delta." Research Paper 136, pp. 1–184, Department of Geography, Univ. of Chicago, Chicago.
- Butzer, K. W. (1976). "Early Hydraulic Civilization in Egypt." Univ. of Chicago Press, Chicago.
- Butzer, K. W. (1980a). Civilizations: Organisms or systems? *American Scientist* 68, 517–523.
- Butzer, K. W. (1980b). Adaptation to global environmental change. *Professional Geographer* 32, 269–278.
- Butzer, K. W. (1980c). The Holocene lake plain of North Rudolf, East Africa. *Physical Geography* 1, 4–58.
- Butzer, K. W. (1982a). "Archaeology as Human Ecology: Method and Theory for a Contextual Approach," Cambridge Univ. Press, New York.
- Butzer, K. W. (1982b). Kulturanpassung: Eine Methode zur zeitlichen Untersuchung menschlicher Oekosysteme. *Geographische Zeitschrift* 70, 261–272.
- Butzer, K. W. (1983). Long-term Nile flood variation and political discontinuities in Pharaonic Egypt. In "From Hunters to Farmers" (J. D. Clark and S. Brandt, Eds.), Univ. of California Press, Berkeley.
- Carr, C. J. (1977). "Pastoralism in Crisis: The Dasanetch and their Ethiopian Lands." Research Paper 180, 1–319, Department of Geography Univ. of Chicago, Chicago.
- Clark, W. C. (Ed.) (1982). "Carbon Dioxide Review: 1982." Oxford Univ. Press, New York.
- Dalby, D., Church, R. J. H., and Bezzaz, F. (Eds.) (1977). "Drought in Africa 2," International African Institute, London.
- Dando, W. A. (1980). "The Geography of Famine," Arnold, London.
- De Vries, Jan (1980). Measuring the impact of climate on history: The search for appropriate methodologies. *Journal of Interdisciplinary History* 10, 599–630.
- Faure, H. and Gac, J. Y. (1981a). Will the Sahelian drought in 1985? *Nature (London)* 291, 475–478.
- Faure, H. and Gac, J. Y. (1981b). Senegal river runoff: Reply to J. P. Palutikof, J. H. Lough, G. Farmer. *Nature (London)* 293, 414.
- Franke, R. W. and Chasin, B. H. (1980). "Seeds of Famine: Ecological Destruction and the Development Dilemma in the West African Sahel," Littlefield, Adams, Totowa, N.J.
- Glantz, M. H. (Ed.) (1976). "The Politics of Natural Disasters: The Case of the Sahel Drought," Praeger, New York.
- Hansen, J., Johnson, D., Lacis, A., Lebedeff, S., Lee, P., Rind, D., and Russell, G. (1981). Climatic impact of increasing atmospheric carbon dioxide. *Science* 213, 957–966.
- Hussein, Abdul M. (Ed.) (1976). "Rehab: Drought and Famine in Ethiopia." African Environment Special Report No. 2, International African Institute, London.
- Ingram, M. J., Farmer, G., and Wigley, T. M. L. (1981). Past climates and their impact on man: A review. In "Climate and History" (T. M. L. Wigley, M. J. Ingram, and G. Farmer, Eds.), pp. 3–49. Cambridge Univ. Press, Cambridge.
- Kates, R. W. (1981). Drought impact in the Sahelian–Sudanic zone of West Africa: A comparative analysis of 1910–15 and 1968–74. Background Paper No. 2. Center for Technology, Environment and Development, Clark Univ., Worcester, Mass.
- Kellogg, W. W. (1978). Global influences of mankind on climate. In "Climatic Change" (J. Gribbin, Ed.), pp. 205–227. Cambridge Univ. Press, Cambridge.
- Kellogg, W. W., and Schwere, Robert (1981). "Climate Change and Society: Consequences of Increasing Carbon Dioxide," Westview Press, Boulder, Colo.
- Kirch, P. V. (1980). The archaeological study of adaptation. *Advances in Archaeological Method and Theory* 3, 101–156.
- Kutzbach, J. E., and Otto-Bliesner, B. L. (1982). The sensitivity of the African–Asian monsoonal climate to orbital parameter changes for 9000 years B.P. in a low-resolution general circulation model. *Journal of the Atmospheric Sciences* 39, 1177–1188.
- Lawson, M. P., and Baker, M. E. (Eds.) (1981). "The Great Plains: Perspectives and Prospects," University of Nebraska Center for Great Plains Studies, Lincoln.
- MacDonald, G. J. (Ed.) (1982). "The Long-term Impacts of Increasing Atmospheric Carbon Dioxide Levels," Ballinger, Cambridge, Mass.
- Manabe, S., Wetherald, R. T., and Stouffer, R. J. (1981). Summer dryness due to an increase of atmospheric CO₂ concentration. *Climatic Change* 3, 347–386.

- Miewald, R. D. (1978). Social and political impacts of drought. In "North American Droughts" (N. J. Rosenberg, Ed.), pp. 79–101. Westview Press, Boulder, Colo.
- National Research Council (1982). "Carbon Dioxide and Climate: A Second Assessment," National Academy Press, Washington, D.C.
- Olson, J. S., Pfuderer, H. A., and Chan, Y. H. (1978). "Changes in the Global Carbon Cycle and the Biosphere." Department of Energy, Environmental Sciences Division Publication 1050, Washington, D.C.
- Pittock, A. B., and Salinger, M. J. (1981). Towards regional scenarios for a CO₂-warmed earth. *Climatic Change* 3, 23–40.
- Quinn, M. L. (1982). Federal drought planning in the Great Plains—A first look. *Climatic Change* 4, 273–296.
- Saarinen, T. F. (1966). "Perception of the Drought Hazard on the Great Plains." Research Paper 106, 1–183, Department of Geography, Univ. of Chicago, Chicago.
- Schneider, S. H. (1976). "The Genesis Strategy: Climate and Global Survival," Plenum, New York.
- Siegenthaler, U., and Oeschger, H. (1978). "Predicting future atmospheric carbon dioxide levels." *Science* 199, 388–395.
- Thompson, S. L., and Schneider, S. H. (1982). Carbon dioxide and climate: The importance of realistic geography in estimating the transient temperature response. *Science* 217, 1031–1033.
- Tornay, S. (1979). Armed conflicts in the Lower Omo Valley, 1970–1976: An analysis from within Nyangatom society. *Senri Ethnological Studies* 3, 97–117.
- U.S. Dept. of Commerce (1942). Vol. 1. "Sixteenth Census of the United States, 1940. Population," Government Printing Office, Washington, D.C.
- U.S. Dept. of Energy (1980). "Environmental and Societal Consequences of possible CO₂-induced Climate Change." Energy Conference 7904143, Carbon Dioxide Effects Research and Assessment Program, Publication 009, Washington, D.C.
- Warrick, R. A., and Bowden, M. J. (1981). The changing impacts of droughts in the Great Plains. In "The Great Plains" (M. P. Lawson and M. E. Baker, Eds.), pp. 111–137. University of Nebraska Center for Great Plains Studies, Lincoln.
- Webster, J. B. (1979). Noi! Noi! Famines as an aid to interlacustrine chronology. In "Chronology, Migration and Drought in Interlacustrine Africa" (J. B. Webster, Ed.), pp. 1–37. African Pub. Co. New York.