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(100) Paylore, Patricia; Haney, R.A.
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9. ABSTRACT

These 11 papers focused on the aridization of land discuss the process and problems associated with it. They were delivered during a 14-week seminar series at the U. of Arizona by seven faculty members and four invited speakers. The titles of the papers: Desertification: What, Where, Why, Who (by Patricia Paylore); The Consequences of Fooling Mother Nature; Atmospheric Dust and Surface Albedo: Effects on Desertification; Ecology of Desertification; Segments of a Vicious Circle: Land Degradation and Water Resources; Trends in Desertification: Interrelations between Vegetation, Erosion, and Stream Flow; Desertification of Papagueria: Cattle and the Papago; Changing Climate in the Sierra Pinacate of Sonora, Mexico; Desertification and the Salinity Problem in Australia; Desert Repaired in Southeastern Oregon: A Case Study in Range Management. Some points made by the principal author in the recap of the series of papers: Desertification is a process of environmental change characterized by increasing aridity and intensification of distinct geomorphological processes, dessication and increasing salinity of soils, and a manifest degradation of vegetative cover. While in some areas of the world this process is probably the result of long-term climatic changes, in many less developed countries it is the result of well-intentioned but unwise interference with natural water-use and land-use practices; short-term technological inputs produce longer-term problems that tend to accelerate the desertification process. This can be reversed only through enlightened and broad-scale governmental commitments in the affected countries, along with better organized international efforts.

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Arid/Semi-Arid Natural Resources Program

DESERTIFICATION:
Process, Problems, Perspectives

Papers Presented During
A 14-Week Seminar Series
November 1975-April 1976

Edited for Publication by
Patricia Paylore and Richard A. Haney, Jr.
Office of Arid Lands Studies
University of Arizona

The University of Arizona
Tucson
September 1976

FOREWORD

This specialized series of seminars, given between November 1975 and April 1976, on

DESERTIFICATION: Process, Problems, Perspectives

was part of a continuing program of seminars sponsored by a 211(d) institutional grant to the University of Arizona for an Arid/Semi-Arid Natural Resources Program, designed to support the goal of increased knowledge and expanded research capability of the University's faculty and students.

Of the several talks presented here in published form, seven were given by University faculty, the others by visiting and invited scholars with a particular interest in the topic.

The first seven address the process of desertification from the viewpoint of the generalist, and the following four appear as case studies illustrating some of the theses advanced by these generalists. While the papers were not actually delivered in this sequence, we have arranged them in this order herein to carry out this design.

The talks were recorded, transcribed, and reviewed in manuscript by the speakers, then edited to insure a reasonable degree of format consistency. The discussions following some of the papers were often difficult to interpret because of poor recording from the floor, but wherever they could be deciphered and whenever they appeared to elaborate significantly on points discussed by the speaker, we have included them.

CONTENTS

November 12, 1975

DESERTIFICATION: WHAT, WHERE, WHY, WHO

by

Patricia Paylore*

What:

While the widespread phenomenon of desertification is finally being recognized internationally, now far beyond the single voices crying in the desert wilderness as recently as 1973 when we published an OALS paper** on World Desertification: Cause and Effect, its identification is still somewhat in dispute. Because of recent events in the Sahel, the word itself unfortunately has become — shall we say, fashionable? — heard now throughout the world but employed in such a loose way that one is never quite sure that its use is based on any understanding of its true meaning.

We have a word under intense review, then, with many world experts in disagreement as to whether desertisation is preferable to desertification, or indeed if they are synonymous. While the United Nations itself continues to call for a program of international cooperation to combat desertification, as set forth in its General Assembly Resolution 3337, the United Nations Environment Programme, sponsoring a meeting in Tehran last spring on desertisation, compounded the confusion by calling for de-desertisation, though admittedly they were presumably talking about reversing desertisation. The International Geographical Union's Working Group on Desertification, meeting recently in Cambridge, England, spent an unconscionably long time attempting definitions that would satisfy the geographers, and finally, in a burst of exasperation, asked us why we should not call it aridization, or any number of other awkward and unpronounceable terms. A recent letter from Germany was addressed to me in care of the Office of Dried Lands Studies. This might be interpreted in a number of ways, but I chose to assume that instead of the inference that our Office was drying up and about to blow away on the desert winds, it was simply a random choice in translation from the German "trocken", which can mean either dry or arid — but also dull or uninteresting.

*Assistant Director, Office of Arid Lands Studies, University of Arizona
**Sherbrooke, W.C./Paylore, P. World Desertification: Cause and Effect. A Literature Review and Annotated Bibliography. University of Arizona, Office of Arid Lands Studies, Arid Lands Resource Information Paper No. 3. 1973. 168 p.

But as a rose by any other name smells as sweet, they tell us, so as with the phenomenon we are going to be discussing in this current seminar series on desertification. I leave it to those who follow me to choose their own terminology, but I shall be using the terms interchangeably to mean a process that deals with the extension of typical desert landscapes and landforms to areas where they did not occur in the recent past, one taking place for our purposes in marginal arid zones bordering deserts under average annual rainfalls of approximately 50-300 mm, areas characterized by increasing aridity and intensification of distinct geomorphological processes, desiccation and increasing salinity of soils, and a manifest degradation of vegetative cover.

The term implies a change, whether by long-term (in the geologic sense) climatic change or by short-term climatic fluctuation, or by man's intervention through careless extension of agricultural developments, burning, overgrazing, urbanization, and increasing population pressures. Such latter developments may be those undertaken either during historical periods (nomadism, for instance), or single historical events (Libya's Kufra experiment, for instance, though we may have to wait a hundred years before we know the long-term irreversible effects of that undertaking).

Webster defines drought as "a prolonged period of dryness," or alternatively, "a prolonged or chronic shortage [emphasis mine]." In defining our term, then, we should take care to make the distinction between desertification — i.e. a long-established and complex process of the degradation of arid lands — and drought, an occasional but natural and recurrent (or, in Webster's sense, chronic) phenomenon in arid areas which suddenly reveals the considerable extent of this degradation and exacerbates its effect. While there may seem to be no direct causal relationship between desertification and drought, there are indirect links between both factors as their mutual interactions tend to magnify their effects on man and on arid ecosystems.

Climatologists warn us to take care in the use of the word drought, to remember that it may be a period characterized by the intervals between rains, and that by extension the mean annual rainfall statistics are not really adequate. Rather, drought can be a number of things, such as the failure of early rains or below "normal" rainfall, in other words what we call variability. We need to understand the concept of drought, too, as it relates to our expectations — our perceptions of drought. In England, fifteen days without rain is called a drought. In another place, 500 mm annual rainfall is called a drought year, in another 100.

Some experts believe that desertification is merely a popular term that is not useful scientifically, that the process should be defined in biological terms. Perhaps ecosystem degradation as a definition could cover the issue succinctly. But to accept any of these catchwords, or others not offered, is to commit ourselves to establishing that threshold of damage, from whatever cause, beyond which irreversibility sets in, a concept that might be the most useful framework of all in which to consider the process. But to waste more time on the semantics would serve only to delay what needs to be done to reverse the intensification of conditions recognized as desertic or desert-like. It is to be hoped that newcomers to an interest in the process we are speaking of will accept the fact that a standard term has not been adopted universally, that any attempt to do so by the United Nations or the IGU or OPEC or the Office of Dried Lands Studies is not apt to work, scientists being the contentious persons they are, and that therefore, call it what you will but agree that we are talking about the same phenomenon.

Where:

Do not assume for a moment because I have thus dismissed somewhat summarily the matter of nomenclature, that there is worldwide unanimity on where the process, by whatever name, is taking place. To begin at home, we may ask about the Sonoran Desert. Dr. Andrew Wilson of the University of Arizona's Department of Geography, Regional Development, and Urban Planning is, with me, a member of the IGU's Working Group on Desertification. The regional contributor for the Sonoran Desert to the Bibliography we are preparing, about which I will brief you later, is telling us that there is no evidence of this process here. He should fly over the extreme southwestern part of Arizona, as I did recently, and see from 40,000 feet the sand drifts over the cultivated fields, laid out synoptically, unmistakably, uncontestably. So how do we reconcile our divergent points of view? Are we not using the same standard of measurement? Obviously not. Like the poor English major that I am, I am using my eyes. Wilson's collaborator is using the library. You would think it would be the other way around, would you not? But exactly what was I seeing? A temporary result of some aberrant winds accompanying our late summer monsoon-type rains? and the farmer will get out there pretty soon — and what? shovel the drifting sand out of the furrows? where? back to the edge of the field? and? or was there actually no change whatever from the historic configuration of that particular piece of land so that the farmer therefore erred in attempting to cultivate it at all, no matter how much water he could bring to it from the Wellton-Mohawk canal? that the dunes had always been there from Alarcon's time at least, if not from the time of those prehistoric ancestors unknown to us? or, back beyond that, to a time when Baja was not even the island that some early explorers believed it to be? Who can say? These latter questions are those that Wilson's friend answered through his library research. He says: "I just do not believe that desertification occurred in significant measure in historic time...If you believed the late 19th century promotional literature on the Magdalena Bay area [for instance], you could be convinced that Baja had been desertified enormously in the last 100 years. I, of course, do not believe it, relying with much more confidence on the Jesuit accounts of the 18th century which describe the peninsula as I see it today."

The American dust bowl of the 1930s, whatever its origins, is another example close to home of the problem of identification. Was the dust bowl a temporary demonstration of desertification? that we, with our vast resources of manpower, machine power, financing, and research capabilities were able to reverse in a phenomenally brief time? But what if we had been, instead, one of this generation's Third World countries, now beset as we were two generations ago but lacking our capital and commitment and trained field technicians? We do not even need to speculate. The evidence is there. If we had not taken prompt action then, we should have crossed that threshold of damage beyond which irreversibility sets in. Or at best, except at an untenable cost. Can we hope that elsewhere in the world, it is not too late? Perhaps later speakers in this series will have some forecasts for us.

As for the Sahel, in addition to A. T. Grove, Department of Geography, Cambridge University, who will not be moved from his position that man-induced desertification in tropical North Africa is a fact of life, German arid lands experts agree with Grove, their conclusions based on long first-hand experience in various countries there. Henri Le Houérou, known personally to many of us, formerly with FAO and with long experience in Tunisia, now Director of the Department of Environmental Sciences of the International Livestock Centre for Africa, based in Addis Ababa, says boldly that "...desertisation affects huge areas in North Africa...tens of thousands of hectares in the Sahel in recent years, [that] the semi-desert region in Sudan, extending between 14° and 16° latitude, and occupying 350,000 square kilometers, is by now converted to a true desert. The situation is not different in East Africa, especially in Somalia, Ethiopia, and in northern Kenya, as well as south in the Kalahari." To support this conviction he cites the large-scale projects established in such countries as Tunisia and Sudan to struggle with the phenomenon that threatens to take out of production such large areas of both countries.*

There are pockets of desert encroachment in Iran, also being dealt with intelligently by the Iranian Government; in southern Argentina; and in Jordan. Iraq is another country attempting on the highest official levels to reverse the effects on its semi-deserts along the Euphrates of the surface water shortages created there by the Syrian dam upstream, manipulated at will, in the Iraqi view, without regard for the consequences downstream.

Generally speaking, while climatic fluctuations in the semiarid zone between the desert plains and the uplands in the Middle East have occurred to increase the evidence of desertification there, most of the evidence indicates that the main responsibility for the process there is attributable to man-aided degradation through deforestation in the uplands of Lebanon, Turkey, Iran, and particularly Jordan.

Further east, we run into controversy. While the concept of desert encroachment in Rajasthan has long been widely accepted, Dr. Mann, Director of the Central Indian Arid Zone Research Station at Jodhpur, at a recent meeting on desertification in Alice Springs, tested that popular

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*see his "The Nature and Causes of Desertization," <u>Arid Lands Newsletter</u>, No. 3, March 1976, p. 1-7.

assumption by several hypotheses and determined to his satisfaction, at least, if not to others', that in no case can evidence be found to indicate that the Indian desert in recent years has spread into the marginal areas under consideration.

In sum, then, what can we say in answer to the question "Where"? We can generalize certainly, and say that despite differences of opinion, mostly in degree, desertification is visible and even measurable in large areas of northern and tropical Africa from the Atlantic to the Indian Ocean, in the Middle East, and in portions of the Indian subcontinent. The Australians believe that matters are more or less under control down under, due in part to the dynamic and vigorous program underway there by CSIRO which has fielded topnotch teams of specialists in soil erosion, range management, land use, and groundwater.

Evidence is not yet in on South America, but thanks to the efforts of Professor Hans J. Schneider, formerly a resident of Chile, and now Professor of Geography at the University of New South Wales, we hope before our bibliography is complete to have enough documentation to begin making some assessment of the extent of desertification in Chile-Peru, northeastern Brazil, and the Monte-Patagonian areas of Argentina. At the moment, political instability prevents an open exchange of information, so we are also depending on our Arid Lands Information System's stockpile of earlier references. It is hoped that with the Natural Resources Program's new linkage with Peru, at least, there will be a breakthrough in what is now a somewhat cloudy — not meteorologically but in another sense — a somewhat cloudy picture.

Why:

Ah, there we have the crux of the matter. Why? The worldwide dichotomy between the climatologists (and even among climatologists themselves) and the rest of us, however we may classify ourselves, is one that is diminishing somewhat, I believe, with both sides acknowledging that the evidence is in to support both schools to a point, and that we can no longer accept the earlier somewhat simplistic either-or explanation. Even the climatologists now acknowledge that though climatic change, plus climatic fluctuations, have historically altered the face of Earth, the acceleration induced by man's occupance thereof is undeniable. On our part, the rest of us, as I refer to everyone else for lack of an umbrella term to cover us all, have also acknowledged that the inevitability of climatic fluctuations at the very least is a factor that must be reckoned with in our attempts to overcome desertification.

I would caution us, however, against making climatic fluctuation the scapegoat for our current problems, for in a sense that is a "cop-out," a relinquishing of our responsibility for what is taking place. "World weather is always erratic," says Jerome Namias, research meteorologist at the Scripps Institution of Oceanography, "normality is a figment of the imagination. Weather is never 'normal' over large areas." So why are we surprised when so much rain fell for so long in the interior of Australia beginning in 1973 that it filled a lake that had been dry since the last Ice Age? or that the current drought in Great Britain is the most severe in two hundred years? or that thirteen inches of rain swamped Houston, Texas, in one 24-hour period? or that now Australia's wheat crop is threatened by drought again? The many changes that may occur during erratic weather events include those affecting landforms, due either to water action such as channel cutting and filling, slope erosion, deposition; or to wind action. such as the mobilization and advance of dunes and sand sheets, or dust storms and deflation, or deposition of dust and loess. Climatic fluctuations can initiate changes in soils by wind and water erosion, salinity or a decline in fertility, or structural changes. And climatic change can initiate changes in natural vegetation, either in structure and composition, or by death or failure to regenerate.

Nevertheless, some of these changes can be identified, prevented perhaps, reversed perhaps, by better understanding of meteorological and biological processes. Under UNEP auspices, for instance, climatologists are investigating a number of these processes in an effort to scale down earlier studies that were divorced from the realities of the effects of climatic change and/or climatic fluctuations on the human populations of the areas so affected, by addressing themselves in time for the 1977 meeting to such problems as agricultural planning including weather-crop relationships and an early warning system of potential poor harvests, weather modification, statistical analysis of climate-desert relationships based on estimates of probabilities of the magnitude, duration and areal extent of drought and flood, as derived from historical records and the possible use of such analyses in deriving inferences for future climate; and finally, analysis of the impact of increased population and agricultural pressure on arid and semiarid lands during times of climatic stress, and management requirements to avert ecosystem collapse as a result of Garrett Hardin's "tragedy of the commons."

The response time of ecosystems to climatic change, or, put another way, biotic adaptation to climatic variability, is such that these systems are usually not in equilibrium with the climate during times of such variations. Increases of vegetation and population during times of climatic amelioration mean that the ecosystem is thus more susceptible to degradation during times of climatic deterioration. This may result in rapid desertification and feedback into further climatic modification, or, more simply, the wet spells are long enough for populations of people and animals to grow beyond the carrying capacity of the ecosystem in the following dry spells.

More immediate to our concerns, and more amenable to control — in the abstract if not in fact — is, of course, man's influence on the processes of desertification. His abuses are well-known and the subject of a good portion of the Sherbrooke paper from our own OALS referred to earlier, as well as the focus of all the sudden flurry of international activities now underway for what one of the Cambridge meeting geographers called informally an "International Desertification Decade." These include such a wide-ranging catechism as both dryland and irrigated agriculture, pastoralism, forestry and the collection of fuel, rural settlement and nomadism, urbanization, population changes, mining, transportation, and tourism and recreation, in short, the full spectrum of man's activities worldwide. It is only the imposition of such activities on an environment too fragile to withstand the impact that creates the peculiar phenomenon we call desertification.

So we have the anomaly of that bugaboo of many of us willing to speak that unmentionable word overpopulation aloud but equally the private bugaboo of those on an international level who agree with us but who are still too timid to come out in any dynamic way which, by virtue of their position, authority, and influence, might actually bring about a change — we have this overpopulation problem, then, most acute in the very areas where the process of desertification is downgrading the ability of the environment to support life.

The process may be triggered by unsystematic or excessive use of sparse vegetation by grazing, cultivation of marginal lands resulting in complete destruction of adapted natural vegetation, cutting down trees and shrubs for fuel and timber, and burning, accidental or deliberate. The end result varies, depending upon the stage of the process, the number of processes at work, their extent and intensity, the original form of surface deposits, the geomorphology, site characteristics, and an awareness of what is happening.

The old ways of survival upon the lands we are talking about were often wasteful, because when the land was used up, the inhabitants could move on. Now we know that there is less and less any new frontier (except in John F. Kennedy's meaning), that it is hardly an exaggeration to say that there is no place to go. A more sophisticated analogy is our own American frontier, where we pushed on relentlessly to the Pacific, and now are turning back upon ourselves to create new problems of overcrowding, wasted resources, economic hardships, and environmental degradation. How much less able, we should ask ourselves, are the human populations of Mali, for instance, or the southern Sudan, to cope with the consequences of their own activities? There is a contemporary school of thought which holds that perhaps these less sophisticated peoples are more capable of coping, as they have been from time immemorial, for the very reason that they are not so dependent on the intensive technology that sustains us here in the West, that they are closer to more primitive responses to events, less psychologically vulnerable to doing without.

But however we react to the process of desertification, whether it be in Phoenix after it is completely paved over, or in Upper Volta, I believe most thinking people now recognize that Earth is finite, that there is no time for those now in such tragic want to wait for the future's space colonies, that we must deal boldly and promptly by a number of perfectly logical, acceptable, and feasible preservational as well as preventive and remedial measures, with the process of desertification. Whether those we seek to help will look upon these measures as logical, acceptable, and feasible is the problem of sociologists and anthropologists. But to fail is to invoke triage, at best; at worst, catastrophic hunger, famine, death on a scale never known, and beyond, anarchy and revolution.

I shall try to summarize here some of these measures as they appear to me from a decade-long analysis of the literature on desertification. They are not new or very exciting, just the same old-fashioned measures we all know in the bottom of our little black hearts are basic: soil conservation and stabilization, water conservation and storage, water management, water augmentation, improvement of plant cover and vegetation management, salinity control, closed environments, energy sources, population control, population control, and population control.

The application of what we already know about climatic stress, weather modification, evaporation suppression, and shelterbelts, as well as remote sensing for natural resources inventories so desperately needed is also necessary. The establishment of natural parks and reserves cannot be expected to originate with the people most affected by desertification, because every exclosure deprives them of pasture, field, water, homes, but it can be done by government, as it is in Iran, where provision is made to compensate for loss of these supportive necessities.

I hope that speakers to follow me in the weeks to come will develop some of these measures in detail.

Who:

As I have gone along I have mentioned several world experts on various aspects of the topic, and there are others, particularly in the ex-colonial countries of Great Britain and France: Mme. Monique Mainguet, the distinguished French geomorphologist at Reims, an authority on the use of weather satellite information to trace active aeolian sand currents in the Sahara; Jean Dresch of the Centre National de la Recherche Scientifique, Paris; Peter Beaumont of England's Durham University, an outstanding authority on the countries of the Middle East, particularly Iran; Jeremy Swift, University of Sussex, best known recently for his stunning book on the Sahara; A.T. Grove, Cambridge University; Ronald Cooke, Bedford College, University of London; Ronald Peel, University of Bristol; Andrew Warren, University College, London; Henri Le Houérou, mentioned earlier; D.E. Tsuriell, Haifa, Chairman of the International Cooperation Group on Sand Dune Reclamation; the lively group at Clark University, Worcester, Massachusetts; Professor J.W. Mabbutt, Chairman of the IGU's Working Group on Desertification, and his colleagues in CSIRO, knowledgeable not only about the Australian deserts but other areas as well, where they are constantly and eagerly sought for assignments as consultants, particularly in Israel, Africa, and India; Soviet Academician M.P. Petrov, one of a very few authorities on the Chinese deserts, though his experiences were some fifteen or more years ago. (It is to be regretted that news of activities many of us are convinced are going forward in the western deserts of China are denied us, despite attempts on the part of numerous researchers to unlock the information. Latest news is that an Australian team is now inside China, possibly in Sinkiang, whose return we await with great interest for the kind of knowledge we need to round out our overview.) Friend Antonio J. Prego in Argentina, an officer of the Instituto Nacional de Technología Agropecuaria (INTA), has long been interested in attempts at afforestation of the dunes of the Pampas. The Germans are active in Africa again, especially Horst Mensching of the University of Hamburg's Institute of Geography, along with his Egyptian colleague F.N. Ibrahim, now a German citizen; and Wolfgang Meckelein of the University of Stuttgart's Institute of Geography. The great German expert H. Schiffers, editor of the definitive multi-volume work on the Sahara, must be reckoned with, and Henno Martin, German author of one of the most moving philosophical discussions of desert life ever written, Doughty and T.E. Lawrence notwithstanding, is still active in Namibia. In America, mention of Namibia brings to mind Richard Logan, also an authoritative expert on Namibia. Friend M. Kassas in Egypt and the Sudan is putting his outstanding knowledge and experience to work for SCOPE.

Other American experts called on by the United Nations to help develop the 1977 conference include Harold Dregne, Texas Tech University; Reid Bryson, Wisconsin; Walter Roberts, Boulder; Michael Horowitz, Binghampton.

It is risky to mention a few names, and several of those I have singled out here were for the most part in attendance at the Cambridge meeting mentioned earlier. They are diverse in background, training, experience, bound together only by their obsession with the desertification process. Together they constitute a formidable array of experts, which is why the opportunity to be associated with this Working Group has been such an exciting and stimulating experience for me.

The Bibliography I am preparing for publication* under the aegis of this Group will be a comprehensive one that takes off from the previous bibliography that accompanied the Sherbrooke paper published in 1973, as mentioned earlier. My willingness to accept this assignment derived from the fact that our 1973 paper quickly went out-of-print, and the sustained demand for it seemed to indicate a need for updating. At the very time I was confronted with some kind of decision as to reprinting or revising this OALS paper, the opportunity to undertake the IGU's paper came from Mabbutt, so that under the IGU's sponsorship we went forward here on this project, with IGU collaborators from around the world sending us the raw documentation.

The 1977 United Nations desertification conference, ordered by the General Assembly resolution referred to earlier, calls for a global priority program to combat desertification, and for the conference to give impetus to long-range efforts on which a program of action will be presented

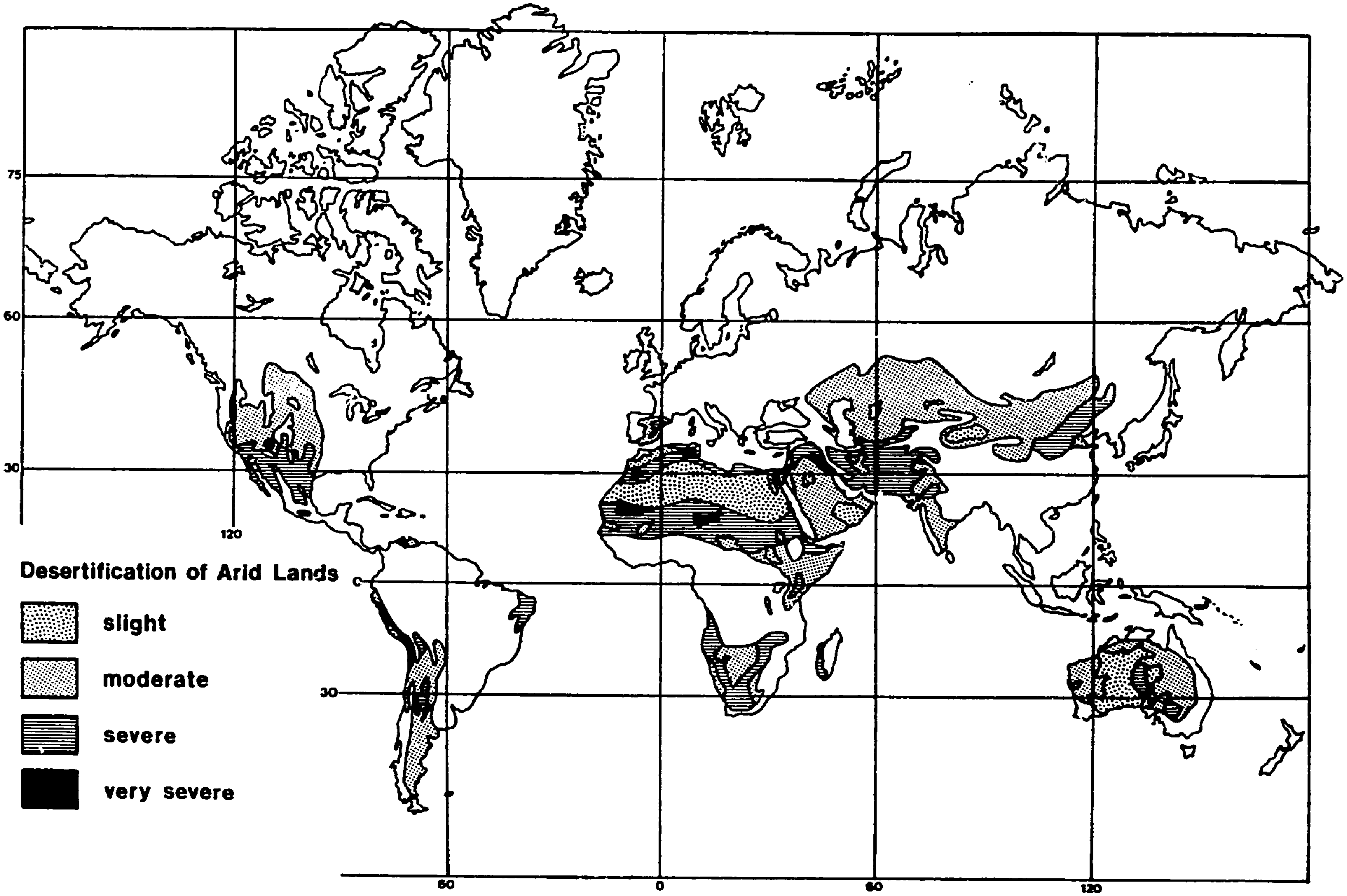
*Issued July 1976 under the title: Desertification, a World Bibliography, 1750 citations, 644 pages, Office of Arid Lands Studies, University Of Arizona, c1976.

for consideration and adoption. This priority program will include four inter-related studies: ecological change; desert technology; climate; and demographic, social, and behavioral aspects. It is expected that these studies will be synthesized by a general presentation.

In addition, the UN Institute for Training and Research is preparing to participate by discussing "Alternative Economic Strategies for the Development of Arid and Semi-Arid Lands."

Whether the cumbersome often pompous deliberations of such international organizations as the UN with its specialized agencies FAO, WMO, UNEP, as well as the IGU, and yes, U.S. AID, to say nothing of the proliferating institutional conferences, meetings, papers, seminars, etc., etc., seemingly ad infinitum, many of which are simply riding the desertification fad, can act in time to prevent many of the areas under consideration from regressing beyond that threshold of damage is anybody's guess.

So tune in next year, folks, same network, for another episode in this thrilling cliff-hanger entitled "Will It Rain?"


Desertification of Arid Lands
slight
moderate
severe
very severe
75
60
30
120
0
30
60
0
60
120

February 26, 1976

DESERTIFICATION: SYMPTOM OF A CRISIS

by

Harold E. Dregne*

Desertification is a process of change in the physical environment of the earth that has serious adverse implications for the human population. For the purposes of this paper, desertification refers to environmental deterioration in the arid regions of the world only. While humid regions, too, suffer desertification, they will not be considered here. The restriction of desertification (or desertization) to arid regions conforms to the limits implicitly imposed upon the organizers of the 1977 United Nations Desertification Conference by the U.N. General Assembly.

Definition of Desertification

Intuitively, nearly everyone probably has a similar idea of what desertification is. Translating that general agreement into acceptance of a written definition turns out to be a difficult task. A definition that seems to include the pertinent considerations is the following:

> Desertification is the process of impoverishment of arid, semiarid, and some subhumid ecosystems by the combined impacts of man's activities and drought. It is the process of change in these ecosystems that can be measured by reduced productivity of desirable plants, alterations in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration, and increased hazards for human occupancy.

While climatic changes toward greater aridity may be occurring, leading to accelerated desertification, the effect of man appears to be dominant. Man is responsible for desertification for two reasons: 1) too many people, and 2) poor management of natural resources. Poor management falls into two categories, the first being willful and careless

*Horn Professor and Director, International Center for Arid and Semi-Arid Land Studies (ICASALS), Texas Tech University, Lubbock, Texas

exploitation of resources and the second is overutilization of resources because of pressures for survival exerted by large human and livestock populations and exacerbated during periods of drought.

Rate of Desertification

Several estimates have been made of desertification progression, particularly north and south of the Sahara. A frequently reported figure is 30 kilometers per year* on the south side of the Sahara, while on the north side 100,000 hectares per year are lost to production. Little or no data are available on which to base these estimates. Nevertheless, there is no reason to doubt that in many places productivity of land bordering the Sahara has deteriorated in recent decades. And the rate of deterioration undoubtedly increased during the early years of the protracted Sahelian drought that began in the late 1960s.

It should be noted that desertification does not frontally assault more productive lands in a manner similar to spreading ripples in a pond. Rather, desertification spreads in a spotty fashion, the spots eventually coalescing into an extensive desertified area if resources overutilization is widespread. Individual land areas essentially may be destroyed with respect to vegetation production whereas around them soil conditions may be quite good. Or the opposite situation may exist as exemplified by a satellite photograph of a sharply bounded green area in a sea of abused land in eastern Niger.

The end result of unchecked desertification is the irreversible destruction of land. Fortunately, most desertification is reversible without employing uneconomic means. Desertification may not be economically reversible when vegetation destruction has occurred and sandy soils have formed moving dunes or when shale-derived soils have become excessively gullied. Reversibility is more difficult in the drier part of an arid zone.

Factors Contributing to Desertification

Droughts are obvious contributors to desertification. During drought periods when vegetative growth is impaired and soil cover is depleted grazing and cultivation become more precarious. In the absence of man's intervention, however, land destruction probably would be minimal even during severe droughts.

Increased human population is attended by increased livestock population in grazing lands and by shorter soil-rejuvenating fallow periods in cultivated lands. It is ironic that life-saving health services can actually promote misery in a rapidly growing population if land resources can no longer be managed conservatively. Such has been the fate of cultivators in drought-stricken countries.

*Office of Science and Technology. Desert Encroachment on Arable Lands. TA/OST 72, Agency for International Development, Washington, D.C. 1972

Pastoralists have increased their herds following a number of mutually-supportive measures taken by governments such as the following which have had particularly significant effects in increasing livestock numbers*: improved veterinary services, better water supplies, decreased animal predators, and increased security against raiders. Individually, each of these measures is desirable. Unfortunately the successful combination of these factors produces increased livestock numbers on each unit of land but without any improvement in management techniques. Many water wells drilled around the Saharan borders constitute laudatory efforts. These efforts, however, are frequently counterproductive because land around the wells is denuded of vegetation when livestock concentrates there.

The complexity of introducing range management techniques compatible with plant resources is well illustrated by the quandary of pastoralists in developing countries. Obviously, the number one range management need is to reduce livestock numbers in overgrazed areas. This need is contrary to the pastoralist's own experience which has proven to him that survival in times of stress depends upon having as large a herd of livestock as possible. The more animals he has at the beginning of a drought, the better are his chances of surviving on his own resources. As long as the only way to accumulate capital is by investing in cattle, camels, goats, and sheep, no prudent pastoralist will do otherwise. The harmful effect such practices have on vegetation is obvious. But, it is equally obvious that reduction in grazing pressure will not occur unless other powerful incentives are introduced.

Population increases have pushed sedentary farming into drier and drier areas where crop production risks are great and fallow periods during which land could recover from cropping have been shortened. Governments have in other instances encouraged growth of cash crops on better land and left poorer land for local food production. The net result is cultivating more marginal land and allowing less time for fertility recovery.** When inevitable droughts recur, disaster strikes.

Fire, goats and woodcutting have been widely blamed for environmental deterioration. And indeed they do. What is overlooked, however, is that people resort to burning grass, expanding goat herds and overcutting trees only when they are forced to. By that time desertification already is well advanced and last-ditch measures are needed to survive under increasingly adverse conditions. Edicts to ban fire, goats and woodcutting may help halt desertification. But edicts only increase misery unless alternate food and fuel sources are provided. One of the world's

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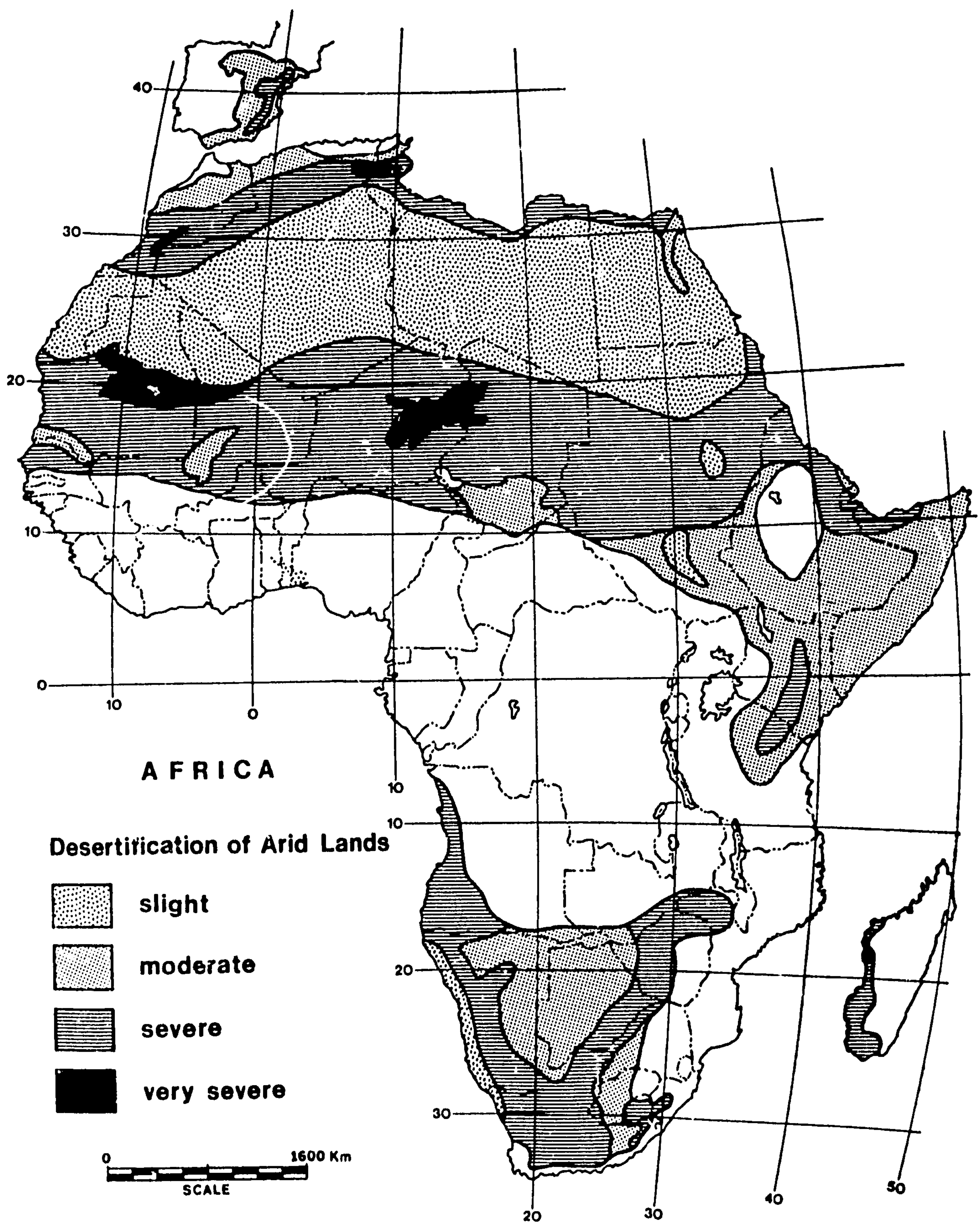
*Rapp, Anders. A Review of Desertification in Africa - Water, Vegetation, and Man. SIES Report No. 1, Secretariat for International Ecology, Stockholm, Sweden.1974

**Caldwell, John C. The Sahelian Drought and Its Demographic Implications. OLC Paper No. 8, American Council on Education, Washington, D.C. 1975


40
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40
50
AFRICA
Desertification of Arid Lands
slight
moderate
severe
very severe
0
1600 Km
SCALE

greatest needs in the battle against desertification is finding cheap and acceptable substitutes for wood for heating and cooking. Reforestation of abused land will never succeed as long as people must use every last stick of wood for fuel.

Impact of Desertification

The seeds of desertification are sown during favorable climatic and economic periods; the harvest occurs during times of drought. Environmental degradation in arid regions is occurring in the absence of droughts but its effects generally are not noticed until drought exacerbates conditions.

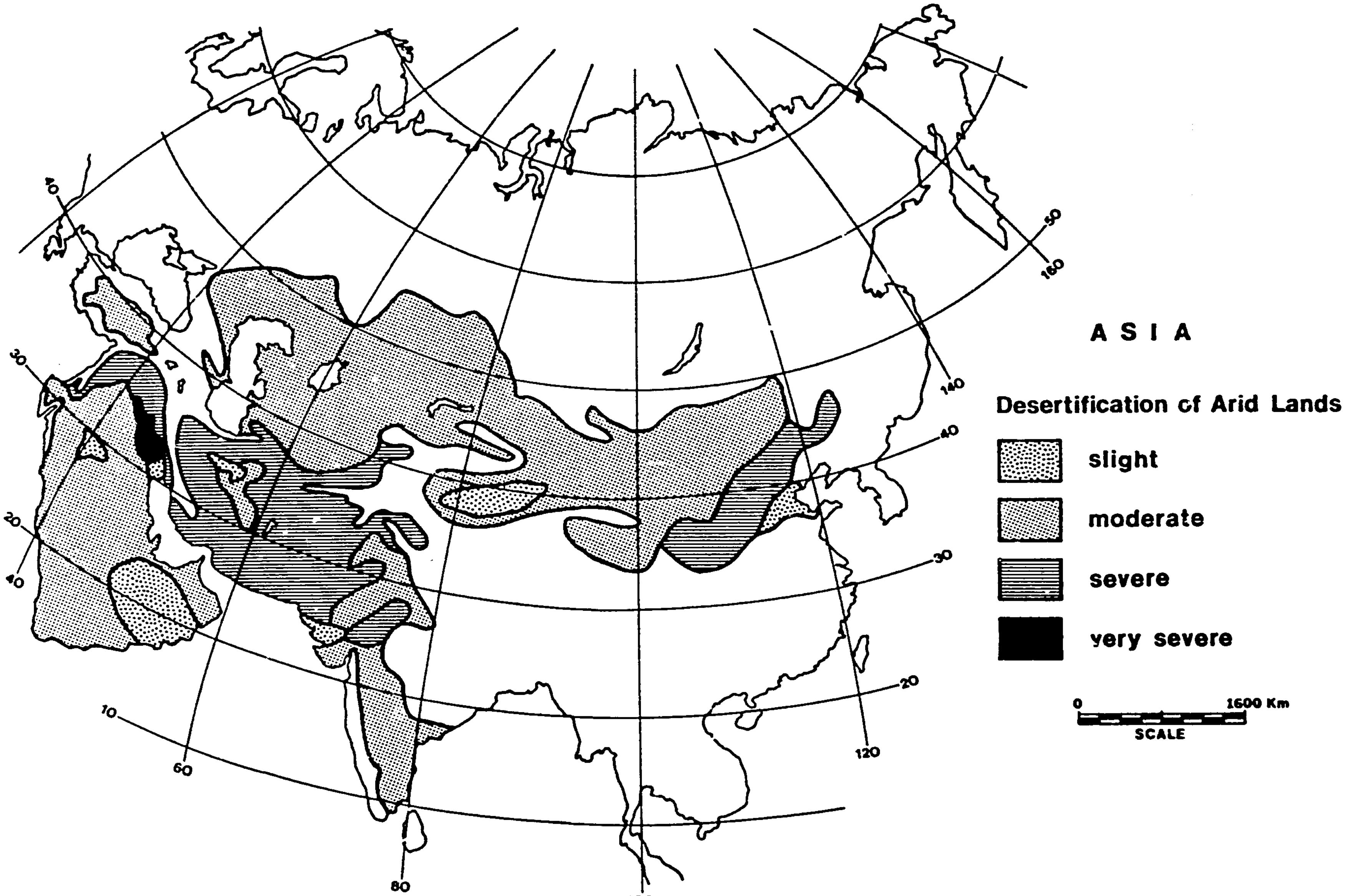
The impacts of desertification and drought on poor farmers and herders in developing nations take several forms. Take the Sahelian drought of the late 1960s and early 1970s as an example: A few people may die and large numbers of livestock will succumb to hunger and thirst. Urban populations will increase precipitously as rural people flee to cities seeking relief. Social unrest increases with the influx of people who occupy substandard housing, compete for jobs and impose heavy burdens on municipal services. Tensions between nations rise when masses of people from stricken areas cross borders while fleeing the effects of drought.

Furthermore, resources of drought-affected nations are strained by the influx of displaced people. Development programs are curtailed because funds are diverted to cope with new problems. Livestock die or are slaughtered, and meat prices fall. While urban dwellers benefit from lower prices, pastoralists face economic ruin in the panic to sell while they can. At the end of the drought, livestock are in short supply, so animal prices rise. It is costly for pastoralists to rebuild their herds and their return to grazing areas is delayed. Many of them do not return at all, but for those who do, grazing conditions are now favorable and so the livestock buildup begins anew and environmental degradation begins once more, ultimately leading to the familiar disastrous sequence of events that follows when a drought recurs.

Combatting Desertification

The fight to stop, then reverse, desertification is very difficult when a nation is mostly arid and possesses few resources. Nations having significant areas of humid climate within their borders, strong industrial bases, or high-demand resources such as oil are the fortunate ones. They are probably able to generate funds to pay for ameliorating measures. Rich nations can use high-cost technology or expensive subsidy programs to combat desertification; poor nations cannot. Poor nations, therefore, must resort to other measures and realize that improvements will be slow and require long-term commitments.

My program for combatting desertification in poor nations has four components. The first is a national commitment to initiate the task and


A S I A
Desertification of Arid Lands
slight
moderate
severe
very severe
0
1600 Km
SCALE

carry it through to completion. As long as political leaders see development in terms of a national airline, dams, buildings, superhighways and other prestige projects, prospects for improving the land resource are slight. Only when a firm decision has been made to see the job done can significant progress be made.

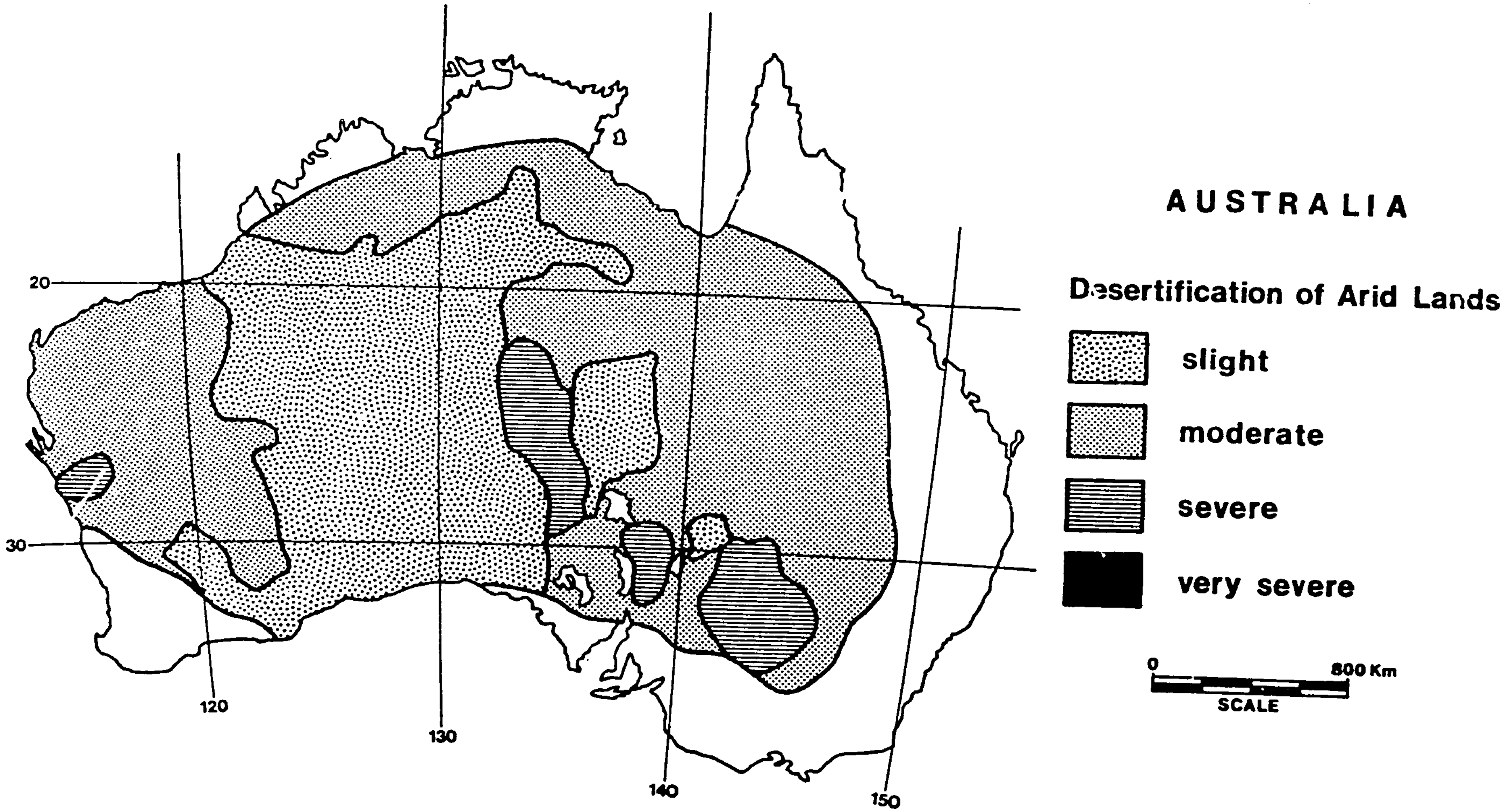
The second component consists of directing rehabilitation efforts at the most favorable areas. Prospects for success in combatting desertification are greatest in areas presently most intensively farmed (dryland or irrigated) where cost-benefit ratios are lowest. Starting the battle in badly deteriorated low-acre-value grazing lands would be a costly, long-term effort with modest returns. Morale of people involved would suffer because of meager impacts on the national economy. Beginning with better-endowed areas, on the other hand, would increase chances for success and would have greater immediate impacts on the economy, if successful. There are other reasons for preferring to start in more heavily settled areas, including greater availability of education and health facilities and social amenities for the persons conducting the rehabilitation program. However favorable the setting, there is little chance of success unless the local people are involved in the planning and execution from the beginning.

Developing small-scale (cottage) agriculture-based industries is the third essential component of a successful program to combat desertification in poor nations. Expansion of the virtually nonexistent industrial base is needed for the development of nearly every nation. Importing steel mills will not do the job. Intermediate technology holds the highest promise of effectively increasing land productivity. Local artisans therefore are the logical persons to manufacture the equipment. As technological improvements become increasingly complex in future years, a labor force qualified to build and maintain equipment can be developed gradually.

The fourth component is related to general improvement of the nation's economic and education base. It calls for expanding the transportation network, improving education and applied research systems, establishing effective credit institutions, providing price incentives, encouraging better marketing procedures, and providing other infrastructure aids to crop and livestock production in an environmentally acceptable manner.

Emphasis on combatting desertification alone is not enough to assure continuing success. It must be seen as a part of broader national development efforts. If headway is made in combatting desertification, increased land productivity will follow. And increased productivity will be accompanied by what should be the delightful problem of dealing with local crop and livestock surpluses. Unfortunately, it usually turns out to be less than delightful because of inadequate preparation.

Sequentially, the first imperative in combatting desertification is government commitment. The second step is initiating work on selected favorable areas. After that, the third and fourth components should be incorporated into the operation. Each of them is important; none can be omitted.


AUSTRALIA
Desertification of Arid Lands
slight
moderate
severe
very severe
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800 Km
SCALE
20
30
120
130
140
150

Extent of Desertification

Approximations of desertification maps of the world's arid regions are presented in Figures 1-6. Degrees of desertification are qualitatively described as slight, moderate, severe, and very severe. Very severe desertification also can be said to be economically irreversible desertification, recognizing that, in theory, any condition of desertification can be reversed if sufficient funds are expended. The only kind of desertification considered here is man-made.

On these maps, slight desertification refers to slight deterioration of plant cover or soil because of man's activities. The moderate desertification means that 1) the plant cover has been degraded to a point where the range condition would be only fair, or 2) there are indications of accelerated wind or water erosion in the form of hummocks, noticeable small dunes, and noticeable small gullies, or soil salinity is reducing crop yields moderately. Severe desertification indicates that 1) undesirable forbs and shrubs have replaced desirable grasses or have spread so to such an extent that they dominate the flora, or 2) sheet wind and water erosion have largely denuded the land of vegetation, or 3) salinity controllable by drainage and leaching has made the land unsuitable for crop production. The very severe category of irreversible desertification includes land covered with large shifting sand dunes, large and numerous gullies, or salt crusts on nearly impermeable soils.

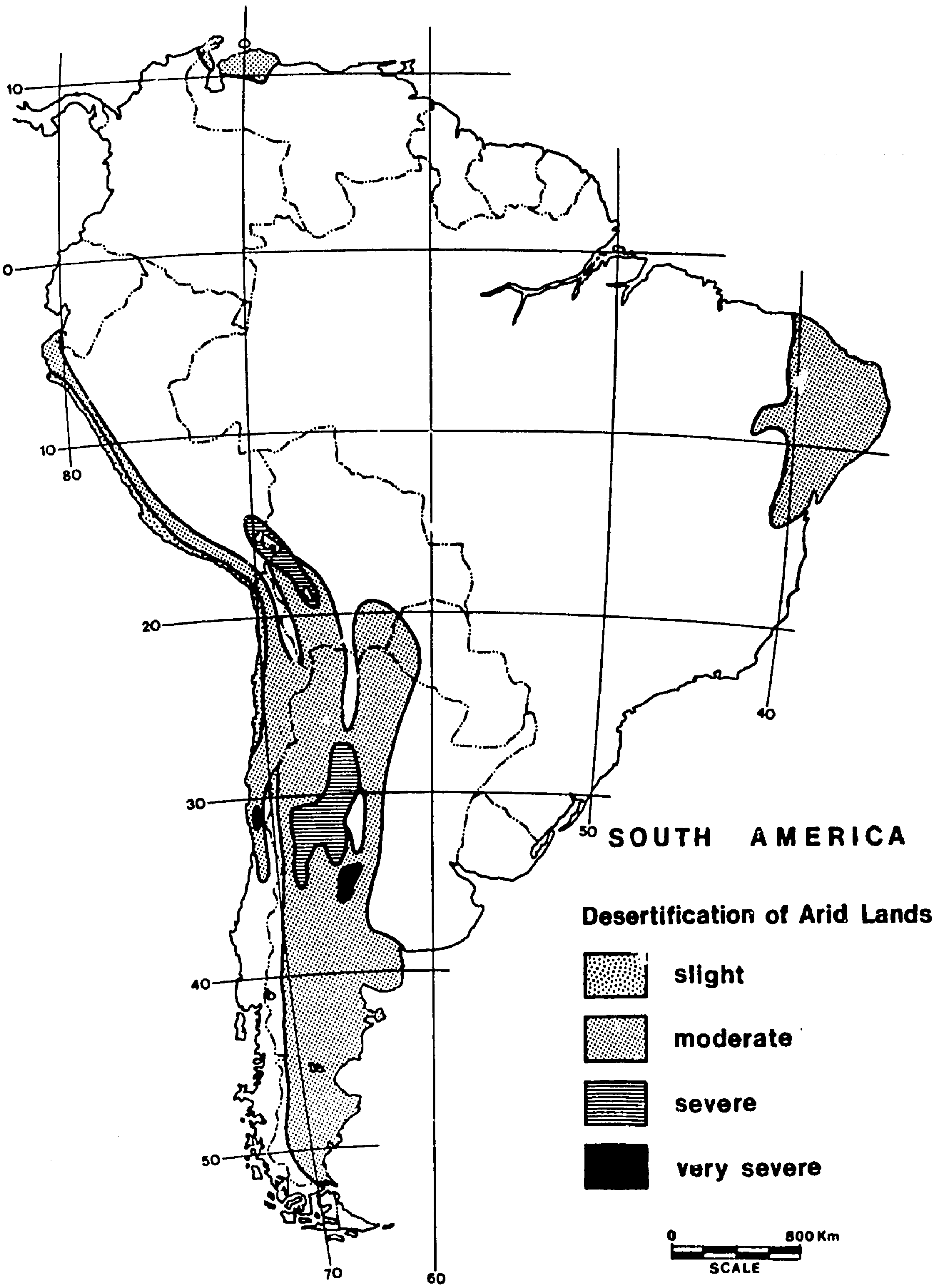
A logical consequence of the desertification criteria described above is what may seem to be an anomalous situation: climatic deserts show only slight desertification, if any. The reason is that deserts naturally exhibit a low state of plant productivity and man cannot do much to make things worse.

As the maps indicate, only a few areas in the arid world are irreversibly desertified. And there is doubt in my mind that as many areas shown by the maps actually should be so categorized. The two most questionable areas are the large ones located mainly in eastern Niger and eastern Mauritania (Fig. 1). They apparently consist of shifting sand dunes nearly devoid of vegetation. How much influence man has had on the present condition is conjectural although he undoubtedly has had some adverse impact because the areas are traversed by nomads and caravan trails.

Another area in the very severe category that may be exaggerated is the previously irrigated lower Tigris-Euphrates region in Iraq. Some land probably belongs in that category because reclamation of the salt-affected soils with low permeability is extremely difficult. Whether or not most of it fits that category is open to question.

Criteria for Estimating Desertification Hazard

Under any one level of population pressure, the desertification hazard varies, principally as a function of six climatic, vegetation, soil and topographic factors. Those six factors are listed in Table 1.


SOUTH AMERICA
Desertification of Arid Lands
slight
moderate
severe
very severe
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800 Km
SCALE
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80
70
60
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Table 1. Criteria for Estimating Desertification Hazard

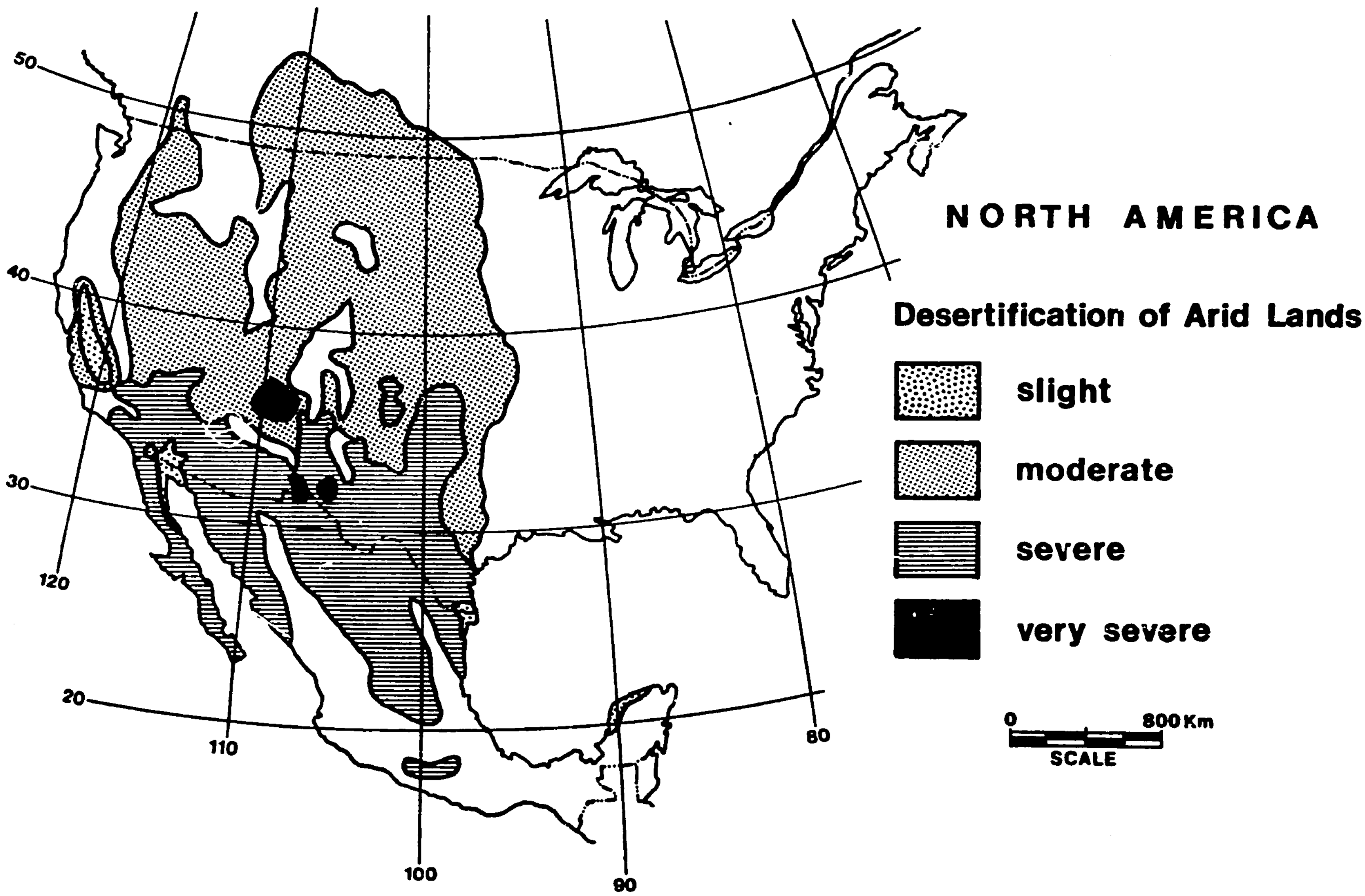
Factor	Classes
1. Average annual precipitation	0-100, 100-250, 250-500, 500-750 mm
2. Vegetative cover	excellent, good, fair, poor
3. Soil depth	deep, shallow
4. Soil stability	stable, unstable
5. Topography	favorable, unfavorable
6. Rainfall distribution	cool season, warm season

It has not been possible, thus far, to quantify the criteria. They are interrelated, sometimes in a fairly complex manner. Evaluation of the average annual precipitation factor is made difficult because the desertification hazard does not increase regularly with increased precipitation, even when all other factors are held constant. A hazard curve would show a minimum in the lowest precipitation class, a maximum in the 250-500 mm class, and a dropoff in the highest class. This is because plant cover is so little in the driest zone that even man cannot reduce it enough to adversely influence productivity and plant recovery is sufficiently rapid in the wettest zone that most desertification scars are capable of being healed in a short time. The semiarid zone (250-500 mm) is most susceptible to significant and long-lasting deterioration from unwise use.

Designating only two classes for the last four factors is too simplistic but is probably all that is justified in a first approach intended only to point out what appear to be important considerations.

The rainfall distribution factor calls for some explanation. It is based on the premise that cool season rains tend to be gentle whereas warm season rains tend to be of high intensity. Water erosion is less severe and the effectiveness of precipitation is greater under the former condition than the latter.

A climatic factor which may deserve inclusion as a criterion for establishing the desertification hazard is length of frost-free season. The reasoning behind such an inclusion is that the water erosion hazard, and perhaps the wind erosion hazard as well, is greater when soils are frost-


NORTH AMERICA
Desertification of Arid Lands
slight
moderate
severe
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SCALE
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100
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80

free for most or all of the year. Why is not completely clear but it does seem to be generally true on a worldwide basis.

Conclusion

Desertification leads ultimately to an increase in human misery. Combatting it is no easy task because it is primarily a social, not technological, problem in the worst-affected areas. Rich nations can cope with the problem by subsidizing costly development and welfare programs; poor nations are unable to do so. That being the case, poor nations face a long, hard struggle to reverse the desertification process with the limited resources at their disposal. The key social problem is what to do with the large numbers of people occupying desertified grazing land and marginal cropland if a reduction in population pressure on the land is necessary to reverse desertification.

Given their inability to mount a massive campaign to combat desertification on a broad scale, poor nations may be well-advised to adopt a strategy of selective development. That tactic seeks to use the experience gained and the higher level of economic activity attained during development of better-endowed regions to gradually expand the development program to less-favored regions. The "gradualist" approach makes good sense in a nation lacking trained people, good transportation and communication networks, social services, effective credit and marketing institutions and research capability. It carries the hazard of alienating politically strong groups in areas not chosen for immediate development. And there is always the possibility that donor agencies or nations will undercut this approach by insisting on working in an area of their own choice. Selective development also does not support the recent international emphasis on improving the lot of the "poorest of the poor."

It should be obvious that combatting desertification effectively in selected dryland and irrigated areas will lead to increased crop production. Provisions must be made to handle excess production. If a localized increase in sorghum, for example, causes sorghum prices to fall so there is no profit advantage from increased yield, cultivators will not produce sorghum in excess of their own needs. Activities required for integrated development plans call for working out the inevitable problems in small-scale development projects before implementing them nationally.

The challenge of desertification is great, and conditions will get worse before they get better. But that same statement will be made ten years from now, after new droughts have wreaked additional havoc, unless we begin now to cope with the problem. The phenomenon is worldwide; it calls for worldwide cooperation to combat it.

November 20, 1975

THE CONSEQUENCES OF FOOLING MOTHER NATURE

by

Terah L. Smiley*

Mother Nature has created on this planet an incredible variety of arid and semiarid regional regimens, a variety to satisfy even the most fertile imagination. There are those regions where one can fry an egg on the sidewalk at high noon. In other arid and semiarid areas parkas must be worn to protect against intense cold. In still other locales, the climate is balmy and bathing suits are the apparel of the day. There are arid regions at sea level and below, where the air is oppressive. At the other extreme are arid and semiarid areas at such heights that oxygen deficiency promotes giddiness. The only common characteristics these various regions share are those by which man identifies arid or semiarid areas: scarcity of precipitation and available water.

The surface of this globe is approximately 30 percent land and 70 percent water. One to two percent of the land surface is covered by ice, and 18 to 20 percent is underlain with permafrost which limits in many ways its use by humans. Of the remaining land, 20 percent is described as arid and 15 percent as semiarid. The desert and semidesert areas are found not only in a variety of geographical and altitudinal locations, but also in considerable size and shape variations. The Sahara covers many million hectares of surface whereas on the leeward side of Oahu, Hawaii, there is a tiny desert covering but several square kilometers of land. There are long slender deserts such as the Atacama of western South America and short fat desert areas such as the small one in south-central India. No matter whether you swelter in the Hejaz Asir area of Saudi Arabia or freeze in Peary Land of northern Greenland, an arid climate must be coped with.

The terms arid and semiarid are relative in terms of precipitation. The Sahara Desert has an annual average precipitation of 20 centimeters, and the continent of Antarctica has an annual average of 8 to 9 centimeters—but what a difference! Because of high temperature and low atmospheric humidity the Sahara has a large water deficit, whereas Antarctica is cold and its accumulated snow and ice give it a good water surplus.

*Professor of Geosciences, University of Arizona

It is also necessary to consider the rate at which precipitation is received. A number of years ago, a friend of mine on assignment in Algeria told me a story that illustrates a major problem in working with measured precipitation amounts. He had set up several stream gauging stations in the Algerian wadis to determine exactly how much water passed those points, and had hired several local people to stay at the stations and keep watch on the instruments. The project had gone on for about two years with no water passing the gauges. There was a celebration one day in a nearby village and all of his employees went to the festivities. When they returned 24 hours lager, there were no gauges or any sign of equipment. The heavy run-off from a thunderstorm upstream had washed away gauges and all. He saw both a blessing and a curse in the situation — a blessing that all would probably have drowned if they had been at the stations, and a curse in that there were still no measurements at those particular points.

But how has Mother Nature made certain areas of this planet climatically arid and other areas climatically wet? This particular discussion will be concerned in part with why certain areas are dry — the other half of the question must be answered elsewhere. Some knowledge of meteorology is necessary to answer such a question.

In brief, the study of climate is one aspect of meteorology in that it is concerned with the statistical average of all weather conditions for a given area over a long period of time. But one cannot isolate meteorologically any specific area from the remaining part of the globe because the atmosphere and the oceans do not recognize or stop at political or geographic boundaries. Thus the climate of a given area is a product of local conditions plus the global atomospheric and oceanic circulation patterns.

One of the sun-earth relationships is defined by the tilt of the Earth's axis in relation to the solar equatorial plane which give us polar "days" and "nights" of about six months' duration. Radiation coming from the sun reaches the Earth's upper atmosphere in unequal amounts — less for the polar areas and more for the equatorial. During the course of a year, the equator receives roughly two and a half times as much radiation (heat) as do the polar areas. One thermodynamic principle demands that the global atmosphere must act like a gas because it is a gas and the temperature of a gaseous system must strive to equalize itself throughout all its parts. Thus the hot air tries to mix with or give off its heat to cooler air, or the cooler air tries to absorb heat until it reaches equilibrium.

Solar radiation at the equator heats air. The air expands and loses much of its relative density causing it to rise forming what is called the "intertropical convergence zone." After reaching a height of 15 to 18 kilometers, the air is approximately the same relative temperature and density as surrounding air and it begins to move toward the poles. Where this occurs is the area of highest mean annual temperature. In other words, it is the equator between the northern and southern climatic hemispheres.

Because this cooled and condensed upper air is heavy it sinks along both poleward sides of the rising air in the intertropical convergence zone. The sinking air warms and expands, absorbing moisture during the process. In areas on both sides of the intertropical convergence zone, where the subsiding warm air reaches ground level, arid conditions prevail — the sub-tropical deserts. Other air continues to move toward the poles in a complex pattern which constantly changes with the seasons and with storm conditions. Thus excessive tropical heat is transported toward the cold polar areas by what is generally called the meridional heat (or energy) transport system.

Land surfaces exposed to solar radiation and air quickly absorb and conversely give off heat. Oceans absorb and give off heat much more slowly than land. The Southern Hemisphere is 70 percent water and thus has a greater long-range stability than the Northern Hemisphere which has most of the Earth's land surface. This configuration of oceans-continents has strong influence on air and water circulation patterns and causes global climatic zones to be quite distorted. The greater land surface in the Northern Hemisphere plus several other lesser important factors causes the "climatic equator" or the Intertropical Convergence Zone to be located about 10° North Latitude. At the longitude of Tucson, for example, this equator is 18° to 20° North in the summar and thus we are only 11° to 13° north of the climatic equator. In other areas this equator may be located south of the geographical equator.

Nature's warm and cold ocean currents strongly effect local climatic conditions. The Gulf Stream in the Atlantic brings reasonably warm conditions far north in Europe. Cool currents or up-welling waters cause the California coast to remain cool. Cool or cold currents moving along shorelines keep overhead atmospheric temperatures at approximately the same degree. The Humboldt Current's movement northward along the Peruvian coast is an example. As cool winds move inland over hot land their temperature increases and they absorb moisture from the land. The coastal Atacama Desert of Peru is a result of this ocean-land relationship.

In other areas, warm moist air is forced to rise over mountain ranges such as occurs along the High Sierras of California. As air rises it cools and moisture is condensed causing rainfall on the higher windward side of the mountains. Cooled air clears the mountain tops and descends on the downwind side, warming and absorbing moisture which creates a "rain-shadow" area. The Great Basin of Nevada is an example of rain-shadow condition.

The actual causes of desert areas generally are numerous and complex in their inter- and intra-actions. No two areas are exactly the same. Although local terrain plays a role, the major roles are still played by Mother Nature's global atmospheric and oceanic circulation patterns. Before we can understand any specific arid area, we must look at its relation to global conditions.

Centers of major climatic regions or areas such as those in forests, steppes, prairies, woodlands, polar icecaps, and even deserts, remain essentially constant over reasonably long periods of normal time. But where the borders of these areas interface with neighboring regimes constant changes take place because of meteorological dynamics. Any climatic region can wax or wane depending on the particular change taking place, even though there is little danger of the middle of the Sahara becoming anything but a desert or the middle of Antarctica becoming anything but a cold area.

Where two major zones meet, however, there are often rather rapid changes caused by constantly shifting atmospheric conditions. These must be considered more as oscillations than changes. An example of two major regimes meeting can be found in the Catalina Mountains northeast of Tucson and the Santa Rita Mountains 30 miles south. Both areas are roughly the same elevation and the same size, yet the biota is different on the two mountain masses because the Santa Rita Mountains generally are more affected by the Mexican Highland climate whereas the Catalina Mountains generally are affected by the northern Plateau type. At times, however, the Mexican Highland regimen is stronger than the Plateau regimen and consequently its influence reaches northward to the Catalinas. At other times, the reverse is true and the Santa Rita Mountains are affected by the Plateau regimen. If one regimen has control over a sufficiently long time, the biota will reflect that control, but if the control is of short duration, no change in the biota will be found.

A problem illustrating the need for long-term records of Mother Nature's activities is that of the San Carlos Reservoir on the Gila River in eastern Arizona. The dam was constructed in the early 1920s to store irrigation water for use down stream. The size of the dam and reservoir was computed on stream flow and weather records over the previous 20 or so years for that area because that was all that was available. Since its construction the San Carlos reservoir has never been more than 67 percent full. Why? The period of record on which the computations were based, we now know, was one of the wettest periods in many hundreds of years in this area. Thus the duration used was abnormal in being well above average. Records, then, need careful evaluation in terms of the problem being attacked.

My topic in this series of discussions on desertification, in the context of the foregoing, is man's contribution to the phenomenon which I prefer to refer to as "the consequences of fooling Mother Nature."

As a people, we are rather short-lived impatient organisms, capable of dreaming of what we want and also of making those dreams come true, although sometimes at great cost in resources, energy and even other people's lives. We often forget to project the long-range consequences of our actions on the area we inherited from our ancestors.

Our major battle is probably not so much with Mother Nature as it is with ourselves in our firm belief that we can outwit and out-maneuver her by manipulating her processes so that they serve only us — not her. We do so by damming and directing free water in streams, or by pumping water from underground to irrigate crops in areas where evapotranspiration is so great that 80 to 90 percent of the water is lost back to the atmosphere, leaving behind salts and other minerals which gradually destroy soil fertiliy. We destroy sparse vegetation and disturb crustal surfaces which took Mother Nature millennia to develop. Then we curse the blowing sand and dust laying underneath the cover which is soon redistributed by the wind. These are but a few of the methods we have employed that currently produce worldwide approximately 2 million hectares of additional wasteland each year. This human process I refer to as desertification.

Until recently as our ancestors destroyed an area for habitation, they could move into an uninhabited region or take the land away from a less well organized population. Now because our population has grown so large and such expansion is no longer possible we have to live with our problems — we cannot move on and leave our mistakes behind.

Examining archaeological records of the Fertile Crescent in the Near East shows that several millennia ago people laid waste to thousands of hectares of forests to feed their crude ore smelters. So intensive was the wood gathering that reforestation was not possible and erosion gradually destroyed the land for habitation. The Roman historian, Pliny the Elder, whom I believe could be called an ecologist, wrote of the destruction of the forests for shipbuilding. He also noted that erosion soon reduced to land to bare rock.

Closer to home in time as well as place looking at photographs taken in Tombstone, Arizona, between 1870 and 1890 one sees in them wagonload after wagonload of fresh-cut oak being brought in to fuel smelters and shore up mine shafts.

With deforestation, one needs to study carefully each situation to determine the exact role humans played. Did man or changing climates or both cause the destruction? In the early 1930s a fire destroyed about a hundred hectares of pinyon-juniper forest on a mesa in Mesa Verde National Park in southwestern Colorado. Later, about 1936, the Civilian Conservation Corps went into the area to plant thousands of seedling trees in a reforestation program. When I visited the area in 1939, of all the seedlings planted apparently the only ones alive were those extra seedlings some weary young man earlier had placed under a rock. Why this failure? Pine seedlings need approximately 10 years of favorable conditions to attain a size to withstand water shortage, otherwise they do not survive. Climatic records at Mesa Verde for that period indicate that there was little water and small chance for reforestation. We still have little data on actual and long-term changes being caused by fire and in this case, the present climatic conditions were not able to overcome the effects of the burning.

Livestock overgrazing has been a "whipping boy" for almost everyone connected with erosional studies. In certain cases, overgrazing has done considerable damage. But it is generally very difficult to prove overgrazing the sole cause. One scientist went so far as to state that the Sonoran and Chihuahuan Deserts were actually the result of overgrazing by cattle 300 to 400 years ago. This is carrying the concept to absurdity.

A survey was made in northwestern India during a 1956 overgrazing study. The animal population was set at 32.4 million. Nine million were goats and camels, both noted for their ability to destroy all types of grasses and shrubs. The resulting denudation led to severe wind-caused soil erosion especially during pre-monsoonal times when winds were strongest and vegetation was weakest because of water stress.

Cereal cultivation also has come under fire for causing encroachment of desert conditions into better areas. Destruction of natural ground cover is necessary for cultivation. Why it is I do not know, but it seems that when most people look at virgin territory the first thing they want to do is plow under native vegetation and turn the area into a cultivated field. The High Plains in the central United States are excellent examples of such practices. During the 1920s and 1930s the native sod cover was plowed under and wheat, corn and other cereals were planted. Later dry years caused crop failures. With no ground cover, the entire area became a dust bowl as winds whipped the exposed soil into billowing clouds of dust.

But even the worst dust bowl days of the 1930s could not begin to compare with the loess deposits of some 10,000 years ago covering parts of Nebraska, Kansas and Iowa to a depth of many tens of meters. If such an event were to take place today most of Omaha, Nebraska, would be buried under the thick mantle of dust. Mother Nature, too has been causing erosion and deposition on thisplanet since it was first formed so let us not blame <u>all</u> of our troubles on people.

Because cereal cultivation is much needed, we are told, to feed the ever-growing hungry, it has been pushed into marginal rainfall areas through dryland farming practices. But these marginal areas are now undergoing climatic change and many can no longer be farmed, so the many people dependent on these food supplies will undoubtedly still go hungry.

Lowering water tables by pumping from underground sources is causing changes in surface vegetation dependent on groundwater. This pumping takes even the capillary zone to a depth beyond the penetration ability plants. A good example of this was brought to light ten or so years ago when workers in the Pima Mine Pit encountered at a depth of 85 meters what they thought was the root of some type of tree. Analysis of the root indicated that it was a living mesquite root (genus <u>Prosopis</u>). The only interpretation we could offer was that as the water table in that area lowered the tree had the tenacity to continue pushing its tap root downward in search of water. Denudation of an area by this means allows excessive erosion and consequently the winds cause excessive and dangerous dust storms.

Another way we have attempted to fool Mother Nature is through the practice of irrigating dry lands to grow commercial crops — to "make the desert bloom" as people often say. Irrigation creates many long-range problems. Evaporating water leaves a residue of salts and other minerals. Soil water-logging becomes a problem. Continued replenishment of nutrients creates still other problems. No irrigated area in past history has continued more than four to five centuries. I am not at all convinced that we have yet the necessary knowledge in soil and water chemistry and physics, minerology, plant physiology, and other necessary "-ologies" to extend the longevity of irrigated areas without prohibitive costs in energy and dollars.

There are many other illustrations available of people trying to evade the consequences of fooling Mother Nature, but in the end she always reminds us of the futility of the attempt. Such actions always have been at a high cost of resources, energy and even lives. We can hold rain dances, we can call in rainmakers, we can seed clouds for additional moisture and we can pray that Mother Nature will relent and send ample precipitation to all parts of the Earth. But there is no single, simple, sweeping answer to any of these problems in any area. Rather, each area has its own particular environmental characteristics, and these must be known and understood in detail before we can find long-lasting solutions to its problems.

Allow me to propose a "principle" in closing, one which I have failed to locate in literature. The principle is: Man by compulsion, through propagation and economic greed, must occupy all available space and utilize all available resources at a rate consonant with his degree of sophistication.

And so we are in trouble.

March 4, 1976

ATMOSPHERIC DUST AND SURFACE ALBEDO: EFFECTS ON DESERTIFICATION

by

Sherwood B. Idso*

In keeping with the theme of this series of seminars, it seemed appropriate to begin by reviewing the literature concerned with the process of desertification, then presenting some of the ideas that have been prominent during the last decade, and finally evaluating them within the context of personal research experience.

A good beginning point is about 10 years ago when Bryson and Baerreis (1967) from the University of Wisconsin conducted a study in northwestern India on the Rajasthan Desert. This area has apparently experienced an oscillating climate over the last 4,000 years, alternating between periods of rather severe desert characteristics and a milder type of environment conducive to developing fairly advanced civilizations. These investigators worked out a theory of man-environment interaction for this area starting with favorable circumstances sustaining a significant population, then hypothesizing that agriculture would proliferate along with livestock grazing leading to a denudation of the land, and that as this happened more and more dust would be injected into the atmosphere. They measured radiative divergence of the atmosphere and calculated the cooling rate, comparing their results with observed air subsidence. They found that particles in the air apparently were causing enhanced cooling to the extent that mid-tropospheric air subsidence was about 50 percent greater than what they had calculated it would be in the absence of the particles. Subsidence, they claimed, may be assumed to dampen convective activity, restrict monsoon rainfall and intensify land degradation with respect to vegetation. They thus proposed a mechanism where these events intensify and feed back upon themselves, one very common to most desertification theories.

When this chain of events occurred in the past the indigenous civilizations were assumed to collapse and be driven out of the area. Once this took place, Bryson and Baerreis theorized that grasses would slowly

*Research Physicist, U.S. Department of Agriculture, Agricultural Research Service, U.S. Water Conservation Laboratory, Phoenix, Arizona

make a comeback into the area and begin to stabilize the soil. The process would then start to reverse itself, leading to a long-term cyclic behavior.

The next idea advanced was Schaefer's in a book on "Global Effects of Environmental Pollution," edited by S.F. Singer (Schaefer, 1968). Starting again with favorable conditions, this desertification scenario is initiated by denudation of the land by events such as overgrazing. With more soil particles susceptible to becoming airborne, as in the previous mechanism, Schaefer projected cloud over-seeding so that raindrops could not coalesce into droplets large enough to fall as readily as would happen in the absence of this overabundance of soil particles. Although this idea dated back to at least 1958 in a series of papers by Squires, apparently nobody became too excited about it because little further mention of it is made in the following years. In fact few ideas of any kind really were introduced until the Sahelian drought developed when Bryson began publishing on the subject again (1973, 1974), this time conjuring up a new global mechanism instead of invoking a regional mechanism as before.

He began by citing atmospheric buildup of carbon dioxide pointing to the modeling work of Manabe and Wetherald (1967) that indicated that the greenhouse effect of enhanced carbon dioxide is felt at the surface of the atmosphere but not at the top. Thus, as the concentration of carbon dioxide increases the temperature gradient also increases upwards through the atmosphere.

Bryson next introduced his ideas about atmospheric buildup of particulates: that 1) soil particulates tend to cool the earth's surface due to enhanced solar radiation reflection into space, citing evidence for particulate buildup in northern latitudes since the mid-1940s, and that 2) the sun shines through the atmosphere at a lower angle at higher latitudes, implying that there is greater cooling in higher latitudes because of atmospheric dust, increasing the pole-to-equator temperature gradient.

Bryson pulled these two thoughts together by further citing work of Smagorinsky (1963). Introducing a numerical simulation of the global atmospheric circulation Smagorinsky developed what Bryson referred to as the "Z" criterion, "a determinant of the latitudinal location of the transition zone between the convective Hadley circulation to the south and the meandering lateral Rossby circulation to the north. At this transition zone there are descending air currents, high pressure, and anticyclonic motions of the air, all characteristics of desert environments.

The latitude of this transition zone is dependent on both the pole-to equator temperature gradient and the lapse rate of temperature in the atmosphere. Increases in either of these gradients shifts the transition zone south. Since Bryson postulated that both increasing atmospheric dust and carbon dioxide content would increase both gradients, he saw global influences as being responsible for shifting the transition zone southward

In 1974 other ideas appeared, beginning with Otterman (1974), that were more regional in nature. He named surface albedo instead of dust as the prime mechanism, believing that as an area is denuded of vegetation to expose high-albedo soil it will naturally reflect more solar radiation and therefore cool. In cooling it will cool the lower atmosphere in contact with it, also suppressing convection leading to rainshowers. Again, this process would intensify surface denudation. Here is another feedback mechanism operating.

At this time Dr. R. D. Jackson and I entered the picture. We had done research indicating that bare soil surface temperatures are in line with Otterman's reasoning with respect to albedo. But his hypothesis was not well founded. He did not consider different evaporative effects between a moist surface and a dry surface. Data we had accumulated indicated that even though the albedo of an area may be considerably increased and more solar radiation reflected, it still will remain hotter than a vegetative surface being evaporatively cooled (Jackson and Idso, 1975). Even before our note on the subject appeared, however, Charney, Stone and Quirk (1975) published an article that grew out of some ideas Charney had presented in a lecture, subsequently published (1975), on the dynamics of deserts and droughts in the Sahel. These investigators, too, said that Otterman's approach was not valid for the simple reason that it applied only to areas much smaller than the Sahel.

In perusing Charney's presentations, I gathered that he also started with overgrazing as a factor in exposing high-albedo soil. Although he may have realized that during the afternoon high-albedo soil would become warmer than an evaporating vegetation surface, he nevertheless apparently felt that on diurnal and annual bases it would have to be cooler. Charney tested his ideas on a general atmospheric circulation model developed at the Goddard Institute for Space Studies. Of course it agreed with his expectations.

Shortly thereafter another group at the Lawrence Livermore Laboratory in California, using a zonal atmospheric model developed there in 1974 to test the same idea, predicted about the same end result: If surface albedo is increased, on diurnal and annual bases, cooling follows as a consequence. Their work with the computer model indicated a subsequent rainfall reduction in the Sahel and a southward displacement of the intertropical convergence zone.

The only other significant desertification theory of which I am aware is one introduced by Schnell (1975) at an American Geophysical Union meeting. He felt that the "unprecedented massive over-grazing" in the Sahel before the drought may have actually instigated it by reducing the amount of biogenic ice nuclei that evolve from organic matter produced by plants. Apparently these particles are more magical than soil particles, for they are supposed to produce rainfall, whereas soil particles apparently tend to suppress it. Since this idea emerged fairly recently, I do not know what cloud physicists are saying about it so far.

To review some of these ideas in the context of personal research experience, we may begin with Bryson and Baerreis and the Rajasthan Desert. The desertification mechanism, they said, is reduced rainfall due to increased atmospheric subsidence because of increased radiative divergence and cooling aloft, but decreased radiative divergence and heating near the surface.

Now I have done a little research that applies to this mechanism. Specifically, I have investigated three special cases of dust effects on long-wave thermal radiation from the atmosphere. The first instance occurred in February 1971 during an intense dust storm that suddenly whipped up in Phoenix about noon one day. I quickly got operative equipment I had in the field to measure both incoming solar and thermal radiation to find, as expected, that the solar radiation was significantly reduced, but that thermal radiation was greatly increased (Idso, 1972) in terms of the emissivity of the atmosphere. In fact, it more than made up for solar radiation loss, effectively increasing net radiant surface heating.

Another time a dust storm visited the city at night and quietly exhausted itself over the area. The next day a huge dust suspension filled the air. Again, taking measurements of thermal radiation received at the earth's surface, I found that they indicated the atmosphere had been turned into a virtual blackbody in the thermal region of the electromagnetic spectrum (Idso, 1973).

A couple of years later another dust storm coming through the area gave me a third opportunity to make solar and thermal radiation measurements. This time the dust was so diffuse it did not reduce incoming solar radiation to any measureable degree, but it increased the incoming thermal radiation by 10 percent (Idso, 1975).

Finally, I conducted one further study. I calculated that if my measurements were correct and that if airborne dust could increase the atmospheric thermal radiation received at the earth's surface, it should blanket the earth to reduce escape of long-wave radiation out through the atmospheric window and make its influence felt by increasing near-surface air temperatures.

Thus, having made a long-term study of air temperatures in Phoenix, correlating certain of them such as maximum and minimum in summer and winter with respect to the amount of time that dust-trapping inversions were present, I found that as this amount of time increased, the "thermal blanketing" effect of the dust actually did tend to increase surface temperatures in a monotonic fashion (Idso, 1974). In light of this corroborative evidence obtained first-hand, it is my feeling that the mechanism Bryson and Baerreis developed is reasonable where increased atmospheric dust creates warmer temperatures near the earth's surface, but cooling aloft and mid-tropospheric subsidence.

Perhaps I am skating on rather thin ice with respect to particles in the air and the role they may play in cloud physics, but from my admittedly limited point of view it seems possible that as a surface is denuded and more soil particles make their way into the atmosphere, they indeed may overseed clouds and suppress rainfall. Similarly, it seems reasonable that biogenic ice nuclei reduction also may decrease rainfall. Those mechanisms would seem to be at least plausible.

Let us now consider the effects of surface albedo mechanisms. We can lump together the theories of Otterman, Charney, and the Livermore group, as they all imply that increased surface albedo leads to cooling either on mid-day, diurnal or annual bases.

At the U.S. Water Conservation Laboratory we made many measurements that indicate that this is just not the case. Let me first mention soil moisture effects on albedo. We surveyed many soils and found that when a soil dries, its albedo generally doubles (Idso and Reginato, 1974). Thus, we can use the analogy that a moist soil represents a potentially evaporating vegetative canopy, and that as the soil dries and its albedo doubles, it represents a transition to the type of high albedo desert surface that Otterman, Charney, and the Livermore group have specified may result from overgrazing. In such circumstances we have found that at all times of the year on both mid-day and diurnal bases, when such soil dries, it is always warmer than wet soil in spite of its greatly increased albedo. That is just the way the real world is. Therefore, it seems to me that those mechanisms based on baring high-albedo soil are not internally correct.

Let us go back, however, and consider another effect of albedo. When dust is injected into the atmosphere, it not only alters the thermal regime, but also alters the solar radiation regime. As more dust fills the air one naturally thinks at first that the solar radiation to the earth's surface will be reduced and that the surface will become cooler. Indeed, this is Bryson's idea. I think he still holds to this belief. However, at the end of 1969, Charlson and Pilat (1969) presented what at the time was a revolutionary new idea. They theorized that the climatic effect of atmospheric dust in the region of the solar spectrum may be either to cool or warm the earth's surface, depending on the ratio of absorption to backscattering coefficients of the particles.

In the subsequent papers that discussed this topic the trend seems to have moved away from Bryson's point of view. The consensus is that it is very possible that the earth's surface either may be heated or cooled as a result of atmospheric dust in the region of the solar spectrum. Additionally most of the studies tend to lean towards heating. Furthermore, the various equations that have been developed to describe this effect indicate that as the albedo of the underlying surface increases, the ratio of absorption to backscatter required for heating decreases. In fact, for the high albedos often exhibited by desert surfaces, the critical ratio required for heating decreases to a value where it is more likely than not that heating will occur at the surface if the dust content of the atmosphere is increased. I tend to believe that this is what happens and as it occurs surface heating will be compensated by upper atmospheric cooling and consequent increased subsidence, which supposedly will reduce rainfall.

In conclusion, as I view the problem, practically every natural mechanism following denudation of land surfaces implies a push toward desert conditions, that is, every mechanism except those currently receiving the most attention in the literature. These latter mechanisms imply the same end result, but I think that they do it for the wrong reason. In any event, that is the conclusion that I have come to after reviewing the literature and trying to understand the various hypotheses found there.

Questions and Answers

Q: Does the hypothesis of cloud overseeding by soil particles have any more substance to it than just being an interesting idea? Also, how localized would the effects be, considering that seeding and storm location would have a lot to do with each other?

A: You may well know much more about this aspect of the problem than I do. I gathered that the mechanisms were fairly well worked out, although I understand them only superficially. And, of course, they are regional. Their effects will be felt downwind which brings up another interesting point about whether or not we are ever going to do anything about Sahelian desertification.

It seems to me the global scenario that Bryson most recently has championed is not correct. This is implied in the varied climatic characteristics observed over the years. For one thing, the oscillation in the Rajasthan Desert seems to be well described by his earlier proposed local mechanism for that area. Also, if Bryson's recent hypothesis is correct, Sahelian desertification should be increasing. The most recent study of the long-term rainfall record (Bunting, 1976) appeared a couple of weeks ago indicating that the present succession of drought years falls within the expected realm of variability for Sahelian "normal" climate, perhaps evidence of fluctuations there of a local nature that are not tied to global events.

What does this mean? It seems to imply that if desertification occurs in different areas of the world and if man has a role in it, perhaps by overgrazing his livestock, it is then those people living in the afflicted areas, or at least close to them, who are responsible at the most direct cause-and-effect level. To me this is fortunate. Let us say, for example, that Bryson's ideas were correct about the world's industrial buildup being responsible for desertification in the Sahel. If that were so, there would be little hope that the entire world would change to save a few areas, especially if it meant decreasing industrialization or massive restructuring of waste disposal techniques. If, however, the causes are to be found near the area afflicted, amelioration is possible and perhaps even feasible. This would seem to be one favorable conclusion that proposed in situ remedial action programs for drought-stricken areas should be given careful consideration.

Q: How big a difference was Bryson talking about when he indicated that carbon dioxide concentration in the atmosphere was increasing?

A: I don't recall specifically. I think he was talking only about increases observed since the early 1900s and only that that there have been increases. However, I'll make another comment at this point. Bryson would see in the current context a run-away effect where both increasing carbon dioxide and increasing atmospheric dust are going to enhance the southward displacement of the Hadley-Rossby transition zone. It is my opinion, and I think the opinion of most atmospheric scientists, that dust effects are the opposite, which would put a breaking effect on the carbon dioxide effects. Thus, from this point of view we find that global dust pollution may be acting as the savior of the Sahel rather than its downfall.

Q: Do you suggest that another round of volcanism might be a way of reversing Bryson's carbon dioxide hypothesis, if it is correct?

A: No, because there is practically unanimous agreement among atmospheric scientists that the injection of high level dust into the stratosphere indeed will tend to cool the earth's surface, contrary to the low-level type of tropospheric dust that we have been discussing here today. However, even with this topic one cannot be too cautious. I was surprised to find in an article by Diermendjian (1973) that he felt there has been no good experimental evidence for reductions in total incoming solar radiation clearly attributable to even the noteworthy erruptions of Krakatoa, Katmai or Agung, whereas I had been of the opinion that such cases were well documented.

While today's subject deserves much attention, it must be approached quite gingerly because it indeed is an area where many of us may be falling prey to the old adage "Fools rush in, where angels fear to tread!" And with that I perhaps had best step down and readjust my halo.

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March 8, 1976

ECOLOGY OF DESERTIFICATION

by

William G. McGinnies*

Sometime ago I started to look for an acceptable definition of desertification. Many people talk about desertification but usually do not limit themselves to a definite definition. It was not until two weeks ago when Dr. Harold Dregne gave a definition at his seminar that I found one that might serve my needs for discussion of the ecology of desertification. In the meantime, I had adopted one of my own which is compatible with his definition, but I think points up the situation for my purposes more precisely than his. The definition I want to propose for this discussion is as follows:

> Desertification is the product of processes leading toward impoverishment of biota, soil depletion, and the establishment of altered erosional surfaces.

In this connection it should be noted that erosion is a natural phenomenon, but it may be altered by the parameters leading toward desertification. Common manifestations are: development of sand dunes and desert pavement, and impairments of the habitat as related to moisture conditions. Unfavorable soil changes such as the development of salinity, salts, and carbonates may also occur.

Ecology means various things to the many people using the term. On the one hand there is the somewhat loose use by many amateur conservationists whose ecology is based on fact, fiction, and sometimes fancy. On the other hand it may be strictly limited by those concerned with basic research such as determining biomass, energy relations, and trophic levels. For this reason it appears to be essential to specify the usage of the term as related to this discussion of desertification.

For my purpose I elected to limit the discussion to what has been termed vegetation ecology, and based my definition on a modification of one in a recently published book entitled <u>Aims and Methods of Vegetation Ecology</u>:**

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*Director Emeritus, Office of Arid Lands Studies, University of Arizona
**Mueller-Dombois, D./Ellenberg, H. (1974) Aims and methods of vegetation ecology. Wiley, N.Y. 547 p.

Vegetation ecology includes the investigation of species composition and the sociological interaction of species in communities. It is very much concerned with correlations between environment and vegetation and the causes of community changes.

The unit of vegetation ecology is the plant community which may be defined as a combination of plants that are dependent on their environment and influence one another and modify their environment. Together with their common habitat and associated organism they form an ecosystem.

An ecosystem may be indefinite in size, ranging from units as small as a terrarium to extensive biotic communities. We are mostly concerned with the latter when considering desertification. In terms of energy the input balances output, but in the case of desertification the input may be progressively less efficiently used in the ecosystem and by constituent organisms.

The plant community is made up of species having varied relationships to environmental parameters and individually distributed in relation to controlling parameters.

This is an important concept in relation to desertification. It was once held by some ecologists that a biotic community as a whole was like an organism in its reaction to the environment, with very little individual independence among constituent species. The modern concept, however, follows the belief that each species has its own distribution which may or may not overlap community boundaries. Within a community in an arid or sub-arid region each species has a range that is limited on the dry side by its ability to survive under existing moisture conditions, and on the more moist side by its ability to compete with species normal to the more moist regime. This can be clearly observed in the Santa Catalina mountains, the desert species dropping out one by one with increasing altitude and greater precipitation, with other species normal to the increased precipitation taking their places.

Another important ecological principle relating to desertification is that although the environment controlling the distribution of species is made up a variety of parameters it may be dominated by one. The observation of this leads to the expression of Leibig's law of the minimum which can be stated as follows: "When a multiplicity of factors is present and only one is near the limits of toleration, this one factor will be the controlling one."*

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*Taylor, W.P. (1934) Significance of extreme or intermittent conditions in distribution of species and management of natural resources with a restatement of Leibig's law of the minimum. Ecology 15:374-379.

In the process of desertification, water is the controlling factor, not simply precipitation, but rather the moisture available to plants, and this moisture, reaching the plant largely through the soil, is thus affected by soil conditions.

Climatically, the line marking the location where evaporation exceeds precipitation is the boundary between sub-humid and arid regions. This is the line separating B (dry climate) from C and D (humid climates) and A (tropical rainy climates) according to Köppen,* and the D (semidesert) and C (sub-humid) by Thornthwaite and shown on the global maps of Meigs.**

Although the process of desertification is more frequently encountered on the arid side of this line, it is not necessarily confined to the arid zone. The critical condition is that moisture is "near the limit of toleration." This may occur on very sandy or impervious clay soils in a humid area.

The effects of climate are not evenly distributed within the environment. Variations in slope, exposure, and soil texture all influence the water cycle, and habitat differences result in local variation of plant cover. Furthemore, there is usually a moisture gradient within the area occupied by a community. These conditions make it more difficult to recognize desertification processes on the basis of vegetation, as naturally dry habitats and those impoverished by overuse may be similar in appearance. Furthermore, not all portions of the larger environmental area will respond the same to perturbations. Dry ridges, steep slopes, and coarse soils are more vulnerable to moisture depletion than moderate slopes and bottom lands.

Within broad environmental areas, individual plant species occupy an area niche in which conditions are less favorable for its competitors. Because of this, distribution of plant species within plant community and between communities is subject to variations in local and regional habitats, in each case with competition playing a major part in determining distribution limits.

Shreve*** made note of this in a study of the boundary between desert and chaparral in Baja California. He observed that while desert species found environmental conditions favorable in the chaparral zone, they were prevented from entering the chaparral because the various chaparral species were better able to utilize the available moisture. When moisture conditions were depleted because of perturbations, the chaparral species gave way to desert species.

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*Koeppen, W. (1954) Classification of climates and the world patterns. In G. T. Trewartha, An introduction to climate. 3d ed., p. 225-226, 381-383. McGraw-Hill, N.Y. 402 p.
**Meigs, P. (1967) In W.G. McGinnies, B.J. Goldman, and P. Paylore, eds., Deserts of the world. University of Arizona Press, Tucson. 788 p.
***Shreve, F. (1940) The edge of the desert. Association of Pacific Coast Geographers, Yearbook 6: 6-11.

Another prime example of the ability of plants to keep out invaders is to be found on the Navajo Indian Reservation. Russian thistle may be the dominant species where overgrazing has reduced the grass cover, but where a good grass cover is maintained Russian thistle is absent even though it lurks in borrow pits and on denuded areas, ready to take over when the grass stand becomes depleted. Much the same thing has taken place in the central valleys of California, where annuals have replaced the former perennial grass cover.

In a simplified expression the moisture conditions of the habitat might be shown as follows:

$$\text{Climate} \pm \text{vegetation (biota)} \pm \text{soils} = \text{habitat}$$

Precipitation and the physical parameters that influence the net amount of moisture at the vegetation level are subject to plus and minus effects on vegetation which in turn affect soil moisture conditions. Climatic changes will cause changes in vegetation, and anything that alters the efficiency of precipitation in relation to soil moisture will also result in vegetation changes.

Vegetation consumes moisture in carrying out transpiration and growth processes, but by shading the soil and reducing runoff, it may increase the moisture that would otherwise be lost by evaporation and runoff. Hence the plus and minus indicators. Again, soil has plus and minus effects on the habitat. The entire biota is important in these processes and relationships but in considering moisture as the limiting factor, vegetation is the dominant item in the ecosystem. Soil is the product of parent materials, climate, and the biota. Since organic matter holds the key to moisture relations, removal of vegetation directly influences the ability of the soil to support vegetation.

The above describes the interrelationship under so called "natural" conditions. When subject to perturbations, there is a chain reaction. The vegetation is first affected, usually resulting in lower vigor or even death, followed by a change in the capability of the soil to absorb and hold moisture. Finally, the reduction in moisture efficiency results in still further depletion of vegetation. In some cases, such as fire and removal of woody plants, the reaction may be reversed.

The influence of perturbations on vegetation may be shown as follows:

$$\text{Perturbations} \rightarrow \text{plants} \rightarrow \text{soils} \rightarrow \text{moisture} = \text{vegetation} \downarrow$$

The principal perturbations are grazing, fire, vegetation removal, cultivation, and erosion. Heavy grazing nearly always results in vegetation impoverishment beyond the direct effects of the simple physiological removal of plant tissue. The habitat may be changed more or less as shown in the equation.

Vegetation removal may benefit the habitat or cause deterioration. In the case where woody plants have invaded grassland, for example, their removal may lead to improvement of the habitat for grasses. On the other hand, frequent removal of trees from forest or woodland areas usually results in deterioration. Fire may be beneficial or destructive, but it is always traumatic. The effects depend on a multiplicity of factors and usually can be determined only by experiment or careful observation. Cultivation destroys the natural vegetation and the effects are determined by later events. Continuous cultivation may improve habitat conditions or they may become worse, depending upon cultural practices. Abandonment always results in a deteriorated habitat which if left alone will be slow to return to the former habitat conditions. Erosion results in depletion of vegetation and deterioration of the habitat. Sometimes erosional products, when dispersed over an area without burying the vegetation, may improve the habitat. The improvement if any is at the expense of the eroded area. As the habitat changes it will be noted that some species decrease in numbers of individuals, while others may increase and invaders may enter from outside the community. These "decreases" are usually the more desirable species from the viewpoint of man. While the "increases" may at first appear to maintain the plant cover, it soon becomes apparent that there has been a loss in habitat capability.

Perennial grasses where they occur generally decrease in numbers. Less palatable taller grasses may decrease more rapidly than palatable short grasses as a result of decreased moisture.

Annual grasses and weeds are common increasers because of their ability to complete their life cycles during periods of available moisture. Woody plants find decreased competition on the part of perennial grasses to their advantage because of their deeper root systems and ability to endure drought. Invaders also find favorable conditions and once established may retard the growth of native species. The Russian thistle (Salsola kali) and cheat grass (Bromus tectorum) are good examples.

Recapitulating: According to Leibig's law of the minimum, moisture which is near the limits of toleration in arid regions is the controlling factor within the ecosystem. Plant communities undergo desertification as a result of perturbations that alter the amount, duration, or availability of soil moisture. The ecological processes involve interaction of species within the plant community related to changes in habitats mainly resulting from changes in moisture conditions. The individual species react differently to the various parameters of the environment and hence are individually distributed within the community.

Changes in the habitat are directly traceable to plus-or-minus changes in vegetation which in turn may increase or decrease, thus further contributing to habitat changes. The end result is an altered environment in which soil depletion and erosion play a major role. The more mesic species give way to more xeric species which in turn may be further impoverished and the desert creeps outward from its original locale.

As one final observation another "law" might be suggested: "Whenever man enters an environment he exerts a controlling force on the effects of all other parameters, usually to the detriment of the ecosystem."

February 19, 1976

SEGMENTS OF A VICIOUS CIRCLE:
LAND DEGRADATION AND WATER RESOURCES

by

W. Gerald Matlock*

Land degradation, a term I prefer to "desertification" because of the latter's emotional connotations, has unquestionably become a problem of increasing concern around the world. An insidious process by any name, it may be defined as the cumulative effect of a series of actions all of which may or may not be evident in every instance. Let us review four of these:

1) reduction and ultimate removal of vegetation
2) increased runoff rate and reduced surface moisture infiltration
3) increased soil erosion and ultimately some loss of soil fertility
4) formation of mobile sand dunes and desert pavement

In its final stages, the land may resemble a desert, but is it a desert? In some cases, I think not, which is why I believe land degradation rather than desertification is a more exact term, even though carried to its logical extreme the product of land degradation may give the appearance of a desert.

Previous speakers in this seminar series discussed problems of desertification in general terms and presented examples in Australia, Iran, and the Papago Indian Reservation. While their presentations have suggested that arid lands can bloom through application of technology, none deny there will be some costs.

There is another point of view, however, that I think is of extreme importance, one presented earlier by Professor Smiley who pointed out that Nature also contributes to the land degradation process. Sediments deposited by wind and water over centuries, moving from one place to another to create the landforms we now live with, are in essence a part of the land degradation process.

*Professor of Soils, Water, and Engineering, University of Arizona

Today I will discuss the macro relationships between land degradation and water resources. In the center of my vicious circle I have to place people because it is people and their actions that lend power to this vicious circle. We find between land degradation and water resources developments many complex interactions. Does water resources development cause land degradation or does land degradation have an initial impact on the capability for water resources development? Additionally, there are a number of problems regarding jurisdiction in these situations. For example, many land degradation problems are in the upstream part of the watershed but are manifested in the downstream portion. In addition to the technical aspects, therefore, they raise legal and political questions.

One of the difficulties of assessing land degradation and water resources relationships is determining the true magnitude of the problems. There are many estimates on the quantity of sediment transferred. For example, I have a figure showing the total sediment moving to the world's oceans each year at about 20 billion tons, much of topsoil quality. On the North American continent alone an estimated 245 tons of sediment per square mile of drainage area is carried to the oceans each year. It is difficult to know just exactly what that means though, is it not ? In the 1953 Tigres River flood 14 million tons of sediment went past Baghdad in one day. Fourteen million tons! That is a good deal of material transported by water, and certainly land degradation contributed to its magnitude.

Another interesting aspect is the impact of land degradation on rainfall, which, if it is, in fact, significant, will affect both surface water and groundwater resources. One researcher presents a very convincing case to show that the lack of atmospheric vegetative particulate matter has resulted in less rainfall nucleation, and therefore less rainfall. He studied that relationship in the Sahel-Sudan region of West Africa and concluded that vegetation loss is contributing to rainfall reduction.

Other researchers are evaluating effects of change in albedo, the reflective nature of ground surface. Altered albedo produces changes in atmospheric thermodynamics, which in turn causes change in rainfall patterns.

Now there may be something to these studies, but I think they beg the question, "Why does it ever rain again?" We know that it does rain again. I suspect the answer in a simple sense is that our atmosphere is so dynamic with so many factors interacting that changes in a few of these factors alone are not enough to stop the process completely.

Now, let us look at specific effects of land degradation on surface water resources, one relating to problems of increased sediment reaching stream channels, the second relating to the problem of more violent floods, higher peaks, and shorter durations. There have been many studies of runoff-infiltration-vegetation relationships. We know that vegetative ground cover is an important infiltration factor. In southern Arizona, for example, infiltration is twice as great with a cover of 68 percent as one of three percent. Furthermore, we know that the interception of moisture by vegetation has an effect on infiltration and that without this time delay factor there is less opportunity for infiltration. Another important factor is the surface layer — whether it is open and rough or closed and smooth.

To give you some numbers relative to increased sediment load (I mentioned earlier that the average for the North American continent is about 250 tons per square mile per year), badly eroded land has been reported to contribute 5,000 tons per square mile per year, 20 times the North American average. Other studies show that after fires on watersheds, sediment load in runoff increased from 100 to 1,000 times. What does this do to a river? First, changing river sediment load changes the river regime. It is going to change the river's character in relation to slope, depth, and velocity. It is going to result in deposition of sediment in some places. Perhaps it is going to result in reduced flow capacity and, in some instances, in forcing the river to seek a new channel location. Structures in the river system will be affected. Bridges may be destroyed or become useless and culverts will be overtopped and damaged.

It is not just deposition that is affected. Scour is going to occur in different locations than in the past because all alluvial channels are dynamic. While some things about these new relationships can be foreseen, they are not clearly predictable. For example, if there is more sediment in the river, I can safely predict that some deposition problems will occur, though I cannot tell you exactly where.

Another aspect of increased sediment load relates to reservoir filling. Usually the problem of sediment deposition that occurs in all large and small reservoirs is considered in the design life of the reservoir. The extensive literature referring to a 100-year life reservoir is often probably a guess. Filling data vary considerably, from .5 percent per year to as high as 2 to 5 percent per year. One of the new projects in Ghana anticipates building reservoirs with only a 20-year life. Reservoir filling is a rather complex process. Filling rates depend on particle size and the wetting and drying cycles. And in some cases we know that sediment even flows through the reservoir. Sediment of the size to be maintained in suspension may go through the reservoir without creating much of a problem. But if the reservoir already is being filled with sediment, an increased sediment load is going to fill it faster. Obviously then, the land degradation problem as it affects sediment rates must be of concern to those dealing with reservoir design and construction. Dam construction is expensive and its economic feasibility already marginal in many cases; a shorter life expectation for dams is going to further reduce that feasibility.

A study in India showed the rate of sediment carried to that country's dams varied from a low of .07 acre foot per square mile of drainage area per year to a high of 17 acre feet. If each acre foot of sediment weighs approximately 2,000 tons, we may estimate that from 140 tons to 34,000 per square mile is washed into India's reservoirs annually. Unfortunately this study did not indicate what watershed conditions produced these varying sediment rates, but it is likely the watershed that produced 34,000 tons per square mile obviously was different in character from the one that produced only 140 tons.

In many cases, in addition to reservoir problems, there are those of sediment accumulation in irrigation works, canals, and diversion structures. A problem for municipalities is the increasing sediment load in stream channels that makes it more difficult to clean up water for domestic and industrial uses.

All sediment is not bad. Some material moving relentlessly from the mountaintops to the oceans is building deltas. And delta areas are frequently those areas of high fertility that contribute substantially to the agricultural production in some countries. In other areas annual floods bring new fertility to floodplains. A study of the Nile River, before the Aswan Dam was built, showed that about 7 million cubic yards of silt estimated to be worth about $500,000 a year for its fertilizer value were contributed annually from the Nile to the floodplain area. This study also pointed out that the cost of dredging irrigation canals, which now has been eliminated, is only slightly less than the value of the fertilizer, so in fairness we have to look at more than one aspect of the problem.

One of the other problems resulting from land degradation is more violent floods, floods that become higher in peak flow and shorter in duration. While there is not a great deal of data relating flooding to land degradation problems, I did find two numbers of interest. After fire on a watershed, runoff flow was increased ten times, whether peak or total flow is not stated. In another study clear-felling trees on a watershed resulted in a 17 percent flow-rate increase. What this means is that we now have a difficult management problem: How do you manage a raging torrent? It complicates flood routing problems and flood control reservoir operations, as well as disrupting the lives of people who live along the watercourse.

And what effect does land degradation have on groundwater resources? First, there will be reduced direct recharge to groundwater aquifers. This occurs for two reasons: 1) decreased infiltration brought about by decreased opportunity time and by change in soil surface characteristics, and 2) there will be decreased aquifer recharge from river flow. Inversely, there will be decreased support of perennial river flow from the groundwater aquifer. Perennial streams will become intermittent or ephemeral. Sharp peaked floods allow little recharge opportunity. Following the flood, less groundwater exists to sustain the river flow. In West Africa thousands of square miles have been affected by these phenomena. In the literature, changes that make ephemeral streams of those that have been perennial are attributed to land degradation.

Finally, consider the effects of water resources development on land degradation. Surface water development may lead to land degradation. Water withdrawal changes river regimes, probably affecting riparian vegetation and permitting erosion of the bank area. We know that dam construction has a similar but perhaps greater effect. But I think one of the major problems is overdevelopment of surface water resources often leading to abandonment of irrigated land during periods of reduced rainfall, a problem we are well acquainted with in Arizona. Dam proponents are more often over-optimistic about the potential for irrigation. For example, Lake Pleasant on Central Arizona's Agua Fria River is supposed to supply about 20,000 acres with irrigation rights to water in the reservoir, but in fact the water is sufficient for only a small fraction of that area in most years, and during some years there is no water available for irrigation. The reservoir situation in Northeast Brazil, on the other hand, is exactly the opposite, where there is more water in storage than irrigable land. There is seldom a balance between irrigable land and water in storage.

Groundwater development, also a contributor to land degradation, may be more common in the United States than in many developing countries. Two classes of groundwater may be considered: near surface, and deep. Water levels near the surface generally produce fairly dense vegetation, either grasses, shrubs, or trees, and consequently the first observable result of declining water levels will appear as a decrease first in growth of grasses, and finally the shrubs and trees.

As an example of how the loss of vegetative cover may be responsible for land degradation, we may cite the area of dense mesquite groves that flourished until the 1960s along the Santa Cruz River bottom land in the Tucson basin south of San Xavier Mission. Although the water table in that area had been falling for some time prior to 1960, mesquite roots were still able to reach the declining water level. When water levels reached a range of 60 to 80 feet below the surface about 1962, however, this more rapid lowering resulted in a complete dieback of mesquite when the roots no longer could keep pace. Regrowth of mesquite began on a xerophytic basis, that is, new mesquite was adequately spaced for available moisture from rainfall. It is estimated that tree spacing is from 10 to 15 meters between viable mesquite trees as opposed to an almost impenetrable thicket before then.

This type of problem again clearly demonstrates the vicious circle relationship of water resources development and land degradation: We lower the water levels. This results in decreased vegetative cover. This contributes to erosion. There then follows decreased recharge. This lowers groundwater availability. Assuming that groundwater is being pumped at the same rate, there is then an accelerating rate of decline. When the trees die root deterioration begins immediately. And as soon as the roots have deteriorated, usually within three to five years, their ability to support the soil and prevent the erosion process is lost.

Regarding deep groundwater, the problem is generally one of over exploitation, resulting in declining water levels to the extent that water is completely used or becomes uneconomic to pump. If irrigation is involved, farmland may then be abandoned. At first abandoned farmland is a good seedbed and there is weed growth. Ultimately even the weeds do not grow well and only the bare soil remains. There are numerous examples of this process in Arizona, particularly in Avra Valley west of Tucson and the area along Interstate 10 in the Casa Grande Valley. In these areas extensive irrigation development occurred during 1930-1950. There was overuse of groundwater supplies almost from the beginning which resulted in water levels declining by as much as 200 feet. Some of the farmland then was abandoned for economic reasons. Now the problem of dust blowing from these abandoned lands contributes to fatal highway accidents. Unfortunately this pattern of over exploitation of groundwater basins exists throughout the southwestern United States. One contributing factor was the invention of the deep-well turbine pump which made it all possible.

I ask, "Was this appropriate technology?" Though I may seem to have concentrated today on the mistakes that have been made, I am basically optimistic. Good planning and the right kinds of data can help prevent many of these problems, together with a recognition of the natural resource development limitations in arid and semiarid areas. Above all is the necessity to promote a more rational use of water. Rehabilitation of watersheds will not be achieved by waving a magic wand. There is no way we can devise short-term solutions to the problems of land degradation that have been a long time in the making. To have any impact on these conditions, programs will have to be organized that take into account such things as the role of trees in soil stabilization, either as windbreaks or as a means of stabilizing steeper slopes. This one idea alone will take several years before the effects can be seen, and so it will be with other attempts at reversing those processes that have led to land degradation — or desertification, if you will.

Questions and Answers

Q: You did not mention salt accumulation. Is that not land degradation, and important?

A: I think it is extremely important.

Q: What do you think of the possibility of growing vegetation on strip-mined areas or places like Wyoming where there is high wind velocity?

A: We already have learned that it is difficult to grow vegetation in these areas. One estimate by a power company official revealed that vegetation of strip-mined areas is adding about 50 percent to the cost of coal mined. My answer would be, "Yes, we could do it. We could grow plants in these areas, but we have to recognize that it will not be cheap."

Q: Is that 50 percent of the total cost, or just the mining operation?

A: That is 50 percent of the cost of the coal the power company buys from the mining company, according to his estimate. I do not have any data to support that figure.

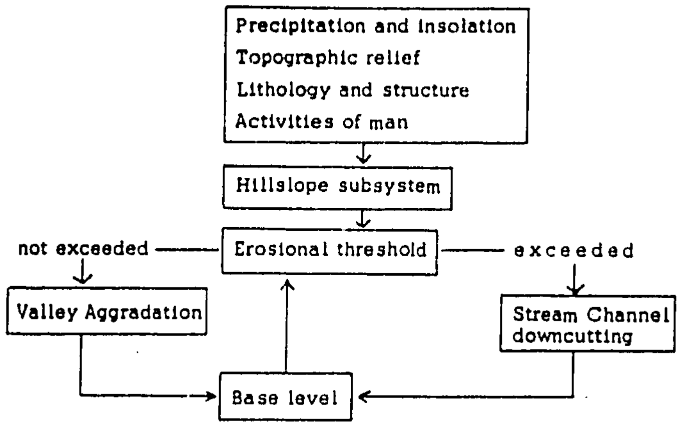

Figure 1.--Basic components of an arid fluvial system.

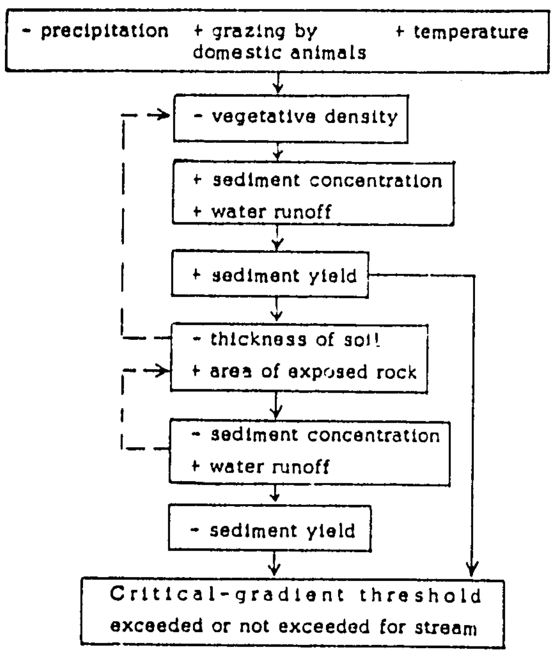

Figure 2.-Increases (+) and decreases (-) in elements of arid hillslope subsystem. Self-enhancing feedbacks (←--→)

April 8, 1976

TRENDS IN DESERTIFICATION:

INTER-RELATIONS BETWEEN VEGETATION, EROSION, AND STREAM FLOW

[A Summary]

by

William B. Bull*

Desertification is the impoverishment of ecosystems due to man's activities and to aridity, involving substantial changes in geomorphic systems. The activities of man and changes in the degree of aridity both influence vegetative cover, the amount of sediment available for erosion, and the amount and rate of water that runs off hills for a given precipitation event. It is difficult to separate the concurrent effects of man and climatic change, but both have similar effects on the fluvial systems of arid lands.

The purpose of this paper is to discuss the interrelations of variables in geomorphic open systems in order to 1) better understand basic trends in desertification, 2) apply our knowledge and resources to the alleviation of desertification, and 3) realize when it is possible, or hopeless, to reverse the adverse geomorphic trends that cause desertification. The scope emphasizes hillslope and stream subsystems, feedback mechanisms, thresholds, and complex response patterns.

The basic components of an arid fluvial system are outlined in Figure 1. Variables such as climate, the activities of man, and lithology may be regarded as independent of each other, whereas variables such as soil, vegetation, and streamflow are dependent not only on the independent variables, but also on interactions between the dependent variables. Of central importance is the threshold that separates the erosional and depositional modes of operation of the fluvial system -- the critical-gradient threshold. Base level is simply the altitude of the downstream end of the stream being considered, but changes in base level introduce feedback mechanisms into the system by changing the slope of the stream. Desertification is promoted or alleviated through other feedback mechanisms that increase the effect of the causative perturbation with time, and thus may be regarded as being self-enhancing. Man also is a dependent variable where he suffers the damage of natural events, or through his having tampered with the operation of the fluvial system.

Changes in a rocky hillslope subsystem are outlined in Figure 2. Decreased precipitation, increased grazing, or increased temperature all tend to impoverish the ecosystem by decreasing vegetative density. Increased unprotected soil increases both sediment concentration and runoff from the slopes, producing increased sediment yield. Accelerated erosion decreases soil thickness and increases the area of bare bedrock. With continued increases in bare rock, runoff will increase for a given precipitation event, but the decrease of available soil will result in decreased sediment concentration and yield. Both self-enhancing feedbacks shown in Figure 2 accelerate vegetative cover losses.

*Professor of Geosciences, University of Arizona, Tucson

Whether or not the valley at the foot of the hillslopes aggrades or degrades is dependent largely on changes in sediment yielded from the slopes. Large increases in sediment yield may cause extensive alluviation, but later decreases may reverse the operation of the stream to a downcutting mode. Thus, both alluviation and down-cutting may be attributed to a single change in the independent variables of the system. Such behavior has been termed "complex response" by Schumm (1973)*.

The critical-gradient threshold is where:

$$\frac{\text{stream gradient}}{\text{critical gradient}} = 1.0$$

The critical gradient is the stream energy gradient needed to transport the sediment load supplied to a reach of a stream over a period of years. Critical gradients change rapidly relative to stream gradients because of changes in discharge of water and sediment, hydraulic roughness, and channel pattern. Where stream gradients exceed critical gradients, additional sediment load is obtained by vertical erosion. Where stream gradients are less than critical gradients, selective sedimentation decreases sediment load and size as well as both gradients. Lateral erosion predominates over vertical erosion during times of high discharge in reaches near the threshold.

The two modes of operation of arid streams are outlined in Figure 3. If the stream energy gradient is insufficient to transport the imposed sediment load, valley aggradation will result. As streamflow spreads out, vegetative growth increases which further decreases flow velocity. Such trends enhance further aggradation. Tending to offset these aggradation trends are concurrent increases in channel slope and decreases in sediment load, changes that tend to move the operation of the system back toward the critical-gradient threshold. The opposite is true of a reach of a stream that has exceeded the threshold. Self-enhancing feedbacks will favor continuation of arroyo cutting, but the decrease in slope and increase in sediment load will tend to move the system back toward the threshold.

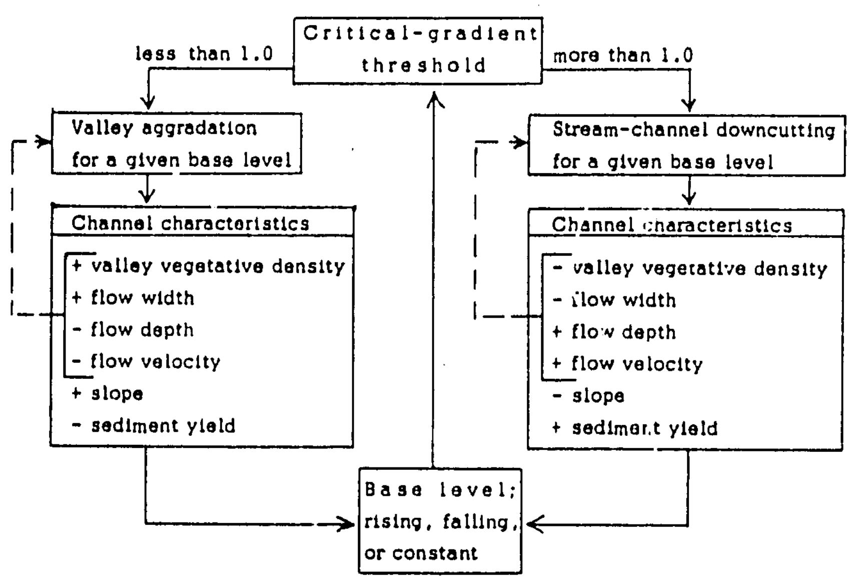

Figure 3.--Increases (+) and decreases (-) in elements of an arid stream subsystem. Self-enhancing feedbacks (— — — — →)

*Schumm, S.A. (1973) Geomorphic thresholds and complex response of drainage systems. In M. Morisawa, ed., Fluvial geomorphology. Geomorphology Symposium, 4th, Binghampton, New York, Proceedings, p. 299-310.

These concepts may be applied to a variety of desert terrains. In the countries of the Middle East and elsewhere the impact of the Pleistocene-Holocene climatic change has affected the rocky hillslopes in a manner similar to that outlined in Figure 2. Feedback mechanisms have made the hills progressively bare of vegetation. Channel downcutting has followed valley aggradation. It would be next to hopeless to reverse the operations of these fluvial systems in view of the strength of the feedback mechanisms and the magnitude of the initial perturbation.

The discontinuous ephemeral streams of the southwestern United States are much different. Fine-grained sediment is trapped by vegetation, which promotes favorable feedback mechanisms of added soil and moisture to promote vegetative growth. In these areas it is important that man is able to identify those reaches that are close to the critical-gradient threshold. Experience has shown that even lushly vegetated areas may cross the threshold as vegetation is grazed and destructive feedback mechanisms are initiated.

Many schemes have been proposed to alleviate the effects of desertification. From a geomorphologist's point of view, however, some questions need to be answered before remedies are applied to a given desertification problem:

- What are the present trends in the different reaches of the fluvial system being studied?
- How close are the different reaches to the critical-gradient threshold?
- What will the proposed change in man's activity have on the hillslope and stream subsystems?
- What will be the impact of the action on the critical-gradient threshold?
- Will the feedback mechanisms that will be created promote or alleviate desertification?

When these questions are answered, we will be in a better position to determine whether or not a given desertification situation can be reversed, and what the best methods of alleviating the problem are.

April 1, 1976

ROLES FOR SPACE SENSING IN STUDYING DESERTIFICATION

by

David S. Simonett*

Because desertification is such a large-scale process and shows such a variety of forms of surface expression, it seems reasonable to believe that some aspects of the process may be amenable to observation with spacecraft sensors, with their multiple sensors and multiple scales of observation, so I shall try to give you first an overview of present technology plus a look into the future, and follow this with my conception of the ways in which these sensors may possibly aid in evaluations of the progress of desertification or the success of efforts to combat it.

PRESENT SATELLITES

The first group of instruments and spacecraft I shall treat briefly is the LANDSAT series, launched first in June 1972 and followed in January 1975 by LANDSAT 2, nine days out of phase with LANDSAT 1. Both satellites have an 18-day recurrent cycle, with an overpass about 9:30 a.m. local sun time. Effective spatial resolution varies from 80 to 150 meters, depending on the scene contrast and the spectral band used.

Because of altitude and narrow instrument field of view (11 1/2 degrees), LANDSAT imagery is nearly orthographic. The sun-synchronous character of the orbit means that adjacent areas, which partially overlap the previous day's coverage, may be seen with virtually no change in either solar illumination angle or azimuth, leading to mosaicking of very large areas with essentially the same sun angle and direction if cloud free conditions are encountered on a series of successive days.

A further advantage of this satellite is the use of a four-channel Multi-spectral Scanning System (MSS), which covers a width of 185 km at right angles to the orbit. The four channels are 0.5-0.6 μm (Green), 0.6-0.7 μm (Yellow), 0.7-0.8 μm (Red and Near Infrared), and 0.8-1.1 μm (Near Infrared). These channels are in close geometric congruence, thus enabling color combination images to be made as well as facilitating computer pattern recognition.

A further consequence of the high geometric fidelity of the MSS imagery and, for areas of undulating to moderate relief, its near orthographic character

* Chairman, Department of Geography, University of California, Santa Barbara

is the ability to combine images of different dates. The relevance of this capability in observing changes related to desertification is critical. Many of the countries where desertification appears now to be underway are LDCs in Africa and Asia. Most if not all are inadequately mapped at any scale, and are seriously lacking in basic natural resource inventories, all essential as a base for observation of desertification.

It is necessary, therefore, to inventory the present situation and to re-inventory at intervals. LANDSAT can play useful roles in these inventories. For example, soil reconnaissance mapping appears feasible in many savanna areas employing LANDSAT multi-season data in conjunction with ground observations. The dynamics of vegetation can be monitored with LANDSAT satellites following a basic inventory; density and apparent vigor can be observed and sensitive areas thereby determined. Similarly, surface water extent and residence times, areas of sand dunes, and loss of surface stability should be detectable with repeated observations.

Because a 9-day interval is generally needed to capture the changes in a timely fashion as well as to accommodate the problem of cloudiness, to some degree, the 18-day LANDSAT 2 cycle is inadequate for observing rapid changes in a vegetative state. Nevertheless, LANDSAT has proved extremely useful for many LDCs for the observation of vegetative changes, and in semiarid to sub-humid areas for delineation of primary plant communities.

Since desertification is expressed principally through reduction in soil stability, initiation of soil blowing, reduced vegetative cover, and altered surface water supplies, the utility of space observations with LANDSAT over widely separated areas is apparent, especially when these changes take place over a number of years or even decades.

Meteorological Satellites

Meteorological satellites also have useful roles to play in observing areas where desertification is suspected. One of the major problems there is the delineation of areas affected and the determination of the true magnitude of any accompanying variability or reduction of rainfall. Rain gauges are frequently very widely spaced in LDCs, most notably in the Sahel. Consequently, there is considerable uncertainty, because of the spatial variation of cumuliform precipitation, as to whether there is a genuine and widespread reduction in rainfall.

Present meteorological satellites may be used in a number of ways to improve the areal prediction reliability of scattered rainfall observations. They can be used to estimate where it is raining, how much moisture is in the surface soil, and, with a suitable budgeting procedure for estimating evapotranspiration and runoff, may be used to improve our knowledge of aspects of the hydrological cycle.

A valuable historical base for studying desertification is represented by meteorological satellite images from the NOAA series of operational satellites and the recently declassified U. S. Air Force DAPP system. The latter consists of four - time daily observations of clouds in the visible region of the spectrum and cloud-top temperatures measured in the thermal infrared region. These measurements, at a spatial resolution of 2 to 3 nautical miles, are adequate for estimating precipitation likelihood and amounts from typical cloud formations of tropical desert fringes.

NOAA satellites have accumulated a significant historical record of about ten years. Thermal imaging is obtained at a 4-nautical-mile resolution. A very high resolution scanning radiometer is also carried on most NOAA satellites, with 0.5-nautical-mile resolution in both visible and thermal regions.

Within the tropics and to about 30^{o} latitude, an even more useful meteorological satellite series is the Synchronous Meteorological Satellites (SMS), so-called because they are synchronized to remain stationary at a given longitude and at 36,000 km altitude over the equator. SMS-GOES (Geostationary Orbiting Environmental Satellite) can observe the cloud systems with resolutions of 0.5 nautical miles (visible) and 2 nautical miles (Thermal IR), at 20-minute intervals. Thus the exact location and growth of potentially precipitating cloud systems can be monitored. Cloud top temperatures are a useful guide to intensity of precipitation. Studies by Amorocho in Colombia, Sabattini in Venezuela and in the Dakotas have documented the value of the SMS-GOES satellite data for estimating rainfall. These satellite data will be increasingly useful since both digital tape and image format is available.

FUTURE SATELLITES

Future satellites of value in studying desertification will be LANDSAT C and LANDSAT D. Results from analyses of the Heat Capacity Mapping Mission Experiment may lead to operational satellites of high value for this purpose. Finally, observations made from instruments on a SPACE SHUTTLE and future Meteorological Satellites should also be of considerable value. The following is a brief summary of the prospects for both the near term (through 1980) and the longer term (1980-1985).

1. The Near Term (1977-1980)

a. LANDSAT Series. First in line among upcoming remote sensing satellites is LANDSAT C, to be launched in 1977 or 1978, depending on the performance of LANDSAT 2. This satellite is largely a duplicate of LANDSATs 1 and 2, with two important sensor system changes:

In the Multispectral Scanner System (MSS), a fifth thermal infrared band will be added. This infrared band will have coarser spatial resolution (300 to 400 meters as opposed to 80 meters for the other MSS channels) but will be useful in improving crop and natural plant community identification, and the location of thermal anomalies. Its temperature sensitivity (accuracy of measurement) will be 0.5^{o}C.

The Return Beam Vidicon (RBV) system of LANDSAT C will be reduced from three to two identical panchromatic cameras operating in the .5 to .7 micrometer range. These cameras will be fitted with new optics to focus on 50-by-50 nautical mile areas. This arrangement will improve the

RBV resolution from 80 meters at present to approximately 40 meters. Contiguous frames will be obtained along the path, covering the same swath as the MSS. They will be used to produce planimetric photo-maps on a scale of 1:100,000 or smaller. These photo-maps could then serve as a base on which the MSS thematic information can be registered.

The effect of the combination of the additional thermal channel in the MSS and the improved spatial resoltuion in the RBV will be to improve studies of desertification in which improved observation of vegetation, surface water, and bare sand is needed.

b. Heat Capacity Mapping Mission Satellite (HCMM). The Experimental Heat Capacity Mapping Mission Satellite carrying a near-infrared (.8 to 1.1 μm) and a thermal infrared channel (10.5 to 12.5 μm) will be launched in 1977 or 1978. Its main objectives will be to investigate in the U. S. the feasibility of identifying surface soil and rock composition (principally in arid and semiarid areas), and measuring surface and sub-surface soil moisture, through use of heat capacity and thermal inertia. The greatest value of the satellite is likely to be for geologic, hydrologic, and agricultural uses on a broad scale since the spatial resolution will be 500 meters. It will be sun-synchronous with a 1:30 p.m. local sun time passage over the U. S. and a 2:30 a.m. nighttime passage.

These passage times are a compromise between technical and orbital requirements and are as close as possible to the optimum times of 1:30 p.m. and 4:30 a.m., when the highest and lowest points are reached in the daily surface soil temperature heating curve.

The data to be obtained should enable inferences to be made as to surface rock and soil composition (sand versus clay, bare solid acid igneous rock versus basic igneous rock, etc.), variations in contained soil water content, and estimates of plant transpiration and plant stress. If the HCMM is successful, it may lead to the later development of special purpose operational satellites of potential value to LDCs subject to drought hazards.

2. The Longer-Term (1981-1985) Technology

The technology is likely to advance in the following ways of interest in desertification studies:

- Significant advances in the sensitivities and spatial resolution of multispectral scanners
- Use of microwave sensors (radar) to make observations through clouds
- Wide coverage with SMS type satellites

a. LANDSAT D, or LANDSAT Follow-On, tentatively scheduled for launch in 1980, will carry an advanced multispectral scanner known as a thematic mapper. The satellite may be in sun-synchronous orbit with a repeat cycle of 9 days. It will achieve its greatest use after 1980.

The first LANDSAT was decidedly an early experimental satellite, and the band selection and orbital parameters involved a series of compromises principally among agricultural, hydrologic, and geologic uses. The Thematic Mapper in the LANDSAT D satellite, on the other hand, may be optimized for vegetation, principally agricultural use, with preliminary band locations, widths, radiometric resolutions, and spatial resolutions approximately as given in Table 1.

In comparison with LANDSATs 1 and 2, with their four broad channels and LANDSAT C, with its fifth thermal infrared channel, the Thematic Mapper on LANDSAT D thus will have six (possibly seven) channels, more sharply defined and of higher radiometric and spatial resolution. The narrower bands in LANDSAT D, by concentrating more clearly on single energy/matter interactions such as the chlorophyll absorption band, should provide more suitable coverage for natural resource sensing in developing countries than the earlier mappers of the LANDSAT series. Similarly, the better spatial resolution will lead to superior identification in the areas of small-field agriculture so common in the Sahel.

Although the exact band numbers, widths, and other performance criteria of the LANDSAT D sensors are still under review by NASA and the National Academy of Sciences, from what is known now of their approximate ranges as shown in Table 1, the new bands, in addition to providing more accurate crop identification, will have improved capability to perform such functions of value in areas of low and hazardous rainfall as the following:

- Delineating water/land boundaries, and contributing to studies of water bodies and coastal bodies
- Recognizing soil/crop contrast, and discriminating soil boundaries
- Detecting surface soil moisture shortly after rainfall
- Detecting crop stress

TABLE 1*

Proposed Configuration of the LANDSAT D (EOS) Thematic Mapper (Multispectral Scanner) For Agricultural Targets

Band (μm)**	Dynamic Range (Range from Minimum to Maximum Reflectance)	Sensitivity (Radiometric Resolution)	Spatial Resolution
.52-.60	4-58%	.5%	30-40m
.63-.69	4-53%	.5%	30-40m
.74-.80	2-75%	.5%	30-40m
.80-.91	2-75%	.5%	30-40m
1.55-1.75	2-50%	1.0%	30-40m
10.2-12.5	270^oK-330^oK	$.5^oK$	120m

* Harnege, J. and D. Landgrebe (1975) LANDSAT-D Thematic Mapper Technical Working Group, Final Report. J.S.C. 0979. NASA, Houston.

** Consideration may be given to a possible seventh band from .45 to .52 μm.

- Discriminating active green vegetation, accurately classifying green vegetation with full ground cover
- Estimating moisture in fire-prone wildland vegetation
- Assessing range feed conditions
- Identifying geologic strata and improved identification of fracture

These much-improved capabilities will enable quite detailed studies of areas of reduced vegetation count and soil movement in areas of desertification, particularly since present plans include launching of two satellites to give 9-day 9:30 a.m. coverage.

b. Space Shuttle. Space Shuttle, a manned space aircraft, is expected to be operational by 1982. With a capacity almost as large as a Boeing 707, it will be capable of carrying an extraordinarily diverse array of instruments needed for different experiments. The missions will be launched about once a month and will last from 7 to 14 days.

The Shuttle will be a convenient vehicle for placing in orbit earth resources satellites, meteorological satellites, and communications satellites, as parts of an integrated system. Potential applications will be available in agriculture, geology, energy, minerals, forestry, land use, oceanography, and hydrology. The orbits may be tailored to the individual uses and experiments of prime concern during an individual mission.

The high resolution cameras and imaging radars which may be carried on SPACE SHUTTLE will further improve the knowledge of areas subjected to earlier study on dune movement, erosion, loss of vegetation, etc., as part of a study of desertification.

Resolutions of the cameras are expected to be from 10 to 20 meters, and the multifrequency radar imagers to be 30 meters. There is a high likelihood that the radar imager will be optimized for surface soil moisture detection, and for vegetation detection, both of central concern in monitoring the progress of desertification.

c. Meteorological Satellite (SEOS). SEOS (Synchronous Earth Observing Satellite) is a 1981-1985 satellite which will be placed in Earth-synchronous (36,000 km) orbit to sense the entire hemisphere. High-powered telescopes will allow for high resolution with long dwell times and repeated imaging of particular areas and will have a useful life of 24 months. Instrumentation for SEOS includes solid-state cameras, new generation telemetry, and spectrometers for pollution detection. The satellite is intended principally for studying short-lived phenomena of meteorological hazards such as extensive flooding, violent storms, and features such as estuarine dynamics, major fires, etc. Equivalent satellites of potential value in desertification studies are likely to be launched by a European Consortium over Africa. Others may be launched by the Soviet Union and Japan during the same period to cover Southwest and Southeast Asia, as well as the launch countries.

At the same time, the usual SMS satellites should continue. The significance of these satellites in studying the large-scale aspects of desertification is clearly speculative.

February 12, 1976

DESERTIFICATION OF PAPAGUERIA: CATTLE AND THE PAPAGO

by

Bernard L. Fontana*

The Papago country of southern Arizona, defined by three noncontiguous but administratively-unified Indian reservations, spreads over more than 2,700,000 acres of land. Taken in total, it is the second largest Indian reservation in the United States. Aboriginal Papago lands included more acreage, probably five times more, lying on both sides of the International Boundary in Arizona and Sonora. Their domain, and that of the culturally-related Pimas living on the Gila River just above its junction with the Salt River, comprised what the Spaniards referred to as "Pimería Alta," the home of the Upper Piman Indians. These were bands of desert peoples, all of whom spoke mutually intelligible dialects of the same language, "Piman," as it is known to outsiders.

The Papago country is a stark land. It is desert. It is a part of the Sonoran Desert. There are few trees. There is little underbrush. Giant saguaro cactuses spring skyward from precarious platforms on the sides of chocolate-brown rock hills. Paloverde and mesquite spread their thin shade over arroyos; creosote bushes and bursage provide the only greenery for miles of intermontane valleys.

The western third of this great region is the driest portion. The native peoples who lived here were esentially hunting-gathering nomads. The central portion, although lacking perennial streams, gets enough summer rainfall to make flash-flood farming possible, and the Papagos who lived here did, indeed, grow corn, squash, and teparies in the flood plains of arroyos. In the winter these same people moved away from their field settlements to winter homes near permanent springs at the bases of mountain ranges. Thus they were "two-village people."

The perimeters of Papago country are marked by what were formerly rivers that ran year around. The flow was intermittent for most months, but there was usually enough water in the summer to make it possible for

*Ethnologist, Arizona State Museum, Tucson

people who lived along the banks of these desert streams to grow crops either by flood plain farming or through irrigation. Because the streams offered a permanent water supply, there was no need for a major seasonal move from a village next to a spring or well to a village next to an agricultural field. These Pimans, therefore, were "one-village people."

This is not the place to attempt to recount changes in the desert environment of Papago people that have taken place in the last three hundred years. Suffice it to say that the process we think of as "desertification" has been taking place here, especially in the years since the 1880s. Where there were valleys filled with tall native grasses there are now mesquite trees, chollas, and deeply-cut arroyos. The carrying capacity of the range has been reduced almost year by year.

The causes of this phenomenon are doubtless many. Hastings and Turner (1965: 284-289), noting vegetation changes in southern Arizona during the past eighty or ninety years — some of which might be called "desertification" — have said (p. 289):

> About the cause, then, the best answer seems to be that the new vegetation — if one may call it that — has not arisen from climatic variation alone, but in response to the unique combination of climatic and cultural stress imposed by the events of the past eighty years; that climate and cattle have united to produce it.

It should be made clear that I am neither a range management specialist nor biologist. My view of the Papago country as a progressively wasted desert is that of a layman, an anthropologist who has had occasion to spend a considerable amount of time in this country since 1955. My interest is in the history and nature of Papago economics, in the present instance specifically in Papago cattle economy. What are the cultural causes of desertification? How and why do human beings, who happen to be Papago Indians in this case, carry on an economic activity which would appear to be doomed eventually to self destruct? What is the role of the pastoralist in the process of desertification?

Father Eusebio Kino, S.J., was the introducer of cattle to Pimería Alta. Between 1687 and his death in 1711, Kino worked tirelessly among some 30,000 Upper Piman Indians, establishing more than 25 missions and mission visiting stations — largely in villages on the riverine perimeters of his mission territory — stocking mission ranches with cattle, horses, oxen, pigs, mules, burros, chickens, and domestic sheep and goats. Kino's Jesuit and Franciscan successors continued to be involved in animal husbandry and to concern themselves with the mission's herds, but in the Franciscan period (1768-1830s) these came increasingly to be concentrated in a few of the larger missions on rivers in the eastern and southern portions of the Pimería. In 1821, for example, Tumacacori Mission, by then a mixed Pima-Papago settlement on the Middle Santa Cruz River in Arizona, had 5,500 head of cattle, 2,500 sheep and goats and 600 horses (Kessell, 1969: 57). How many of these animals made their way into the central parts of the Papago country, however, is an open question. Their influence on the two-village people was probably minimal; on the western nomads it was virtually non-existent.

Toward the end of the Spanish period and continuing in increasing numbers in the Mexican period, Spaniards began to apply for grants as a means of securing title to their ranch lands. Papagos, of course, did not apply for land which they probably felt already belonged to them, even though they were regarded as citizens under Mexican law. By the 1830s, Mexican rancheros were raising stock throughout Sonora, as far north as Tucson, concentrating in well-watered valleys and in higher grasslands. This left portions of central and western Papaguería to Papagos, but it squeezed out most riverine-dwelling Indians, or at least pre-empted legal title to their lands. Between 1821 and 1850 there were 18 land grants issued covering most of eastern Papaguería in Arizona. These grants spread through the Santa Cruz, Sonoita, Babocomari, San Pedro, and Arivaca valleys, and included more than 800,000 acres of land. The United States eventually confirmed title to about 100,000 acres (see Mattison, 1946).

Mexican cattlemen were not content to graze their stock on lands issued under a formal grant. They also used what were called "overplus" lands, those which they could eventually acquire by paying the current market price for acreage. Whatever aboriginal Papago domain that existed in eastern Papaguería ended by having herds of Mexican cattle wander freely over it.

The effects of Spanish and, subsequently, Mexican ranching on Papagos' lives are difficult to assess in the absence of more and better documentation. It is clear that the southern and eastern riverine perimeters of Papago country eventually filled with Mexican ranchers. We can speculate that Papagos became dependent on these ranchers for employment for at least part of each year. It seems likely that when Papagos were not tending their own little fields, they were trading their labor to Mexican rancheros for food or for money. Aboriginally they would have been off trading with other Indians or out hunting and gathering. But with large Mexican ranches on their borders and in their midst, some Papagos seem to have developed a part-time dependency relationship with non-Indians. It is presently impossible to estimate how many Papagos had acquired their own cattle by the 1850s and had themselves become ranchers. The logic of geography suggest that the first Papagos to own cattle were those along the river valleys and in the immediately adjacent desert, that the two-village people were the last to acquire livestock. There are no data to hint that the western nomads ever became herders.

Rolf Bauer (1971: 87), who has considered most recently the implications of the Papago cattle industry, notes that some investigators believe that for most of the 18th and 19th centuries, cattle comprised only a minor part of Papagos' subsistence, and that before the 1870s cattle in the Papago country and beyond the pale of mission or presidio influence were semi-wild. Bauer also points out that Papago family hunters, who were always males, began to hunt and kill half-wild cattle and to distribute the meat precisely as they had distributed venison. In time, hunting shifted to grazing, but with males still in charge.

In addition to livestock introduced into Papago country by Spaniards and Mexicans, a second wave of cattle was brought in during the 1870s and 1880s, largely by Texans and other Anglo cattlemen. This served to increase Papago herds even as it brought about trouble between Indian and non-Indian livestock men.

By 1871 the Arizona Superintendent of Indian Affairs was able to assert that stock raising had become the Papago specialty. In 1876, the year the Papago agency was temporarily closed, the agent on the Gila River Indian Reservation noted that the Papagos had many more cattle and horses than the Pimas, and that the herds were growing yearly. By the late 1870s most observers agreed that livestock raising had become the most important means of Papago livelihood, and many non-Indians agreed that Papago independence related directly to their ability to manage cattle.

By the 1880s there were increasing numbers of complaints lodged against Papagos for stealing cattle, an almost sure sign that more and more cattle belonging to white men were being grazed in Papago country.

The "problem" came to a head in 1895, when non-Indian cattlemen threatened to take armed action against Papagos. They claimed that Indians had cost them more than $300,000 in damages, that Papago thievery had put some livestock operators out of business, and they asserted that they, and not Indians, had legal compensable interest in grazing lands. They said that unless the Federal government did something to bring Papago cattle stealing to a halt they would take matters into their own hands.

Fortunately, there was no shooting war and the status quo in Papago and non-Indian cattle industries persisted for several more years. In 1902 the agent for the Papagos wrote that they were still in danger of "...being driven out of their present possessions and holdings, which most of them have held since time immemorial, by white cattlemen, either by threats or otherwise...It will be the usual process of freezing out the red man from the public domain" (Berger, 1903: 168).

A drought in 1904 seriously damaged Papagos' herds of stock, but by 1915 their numbers were sufficiently replenished to convince Federal officials and members of the Indian Rights Association that steps should be taken at last to secure Papagos in the cattle industry once and for all.

An Act of Congress of August 1, 1914, provided $5,000 for "...development of a water supply for domestic and stock purposes and for irrigation for nomadic Papago Indians in Pima County, Arizona." The same Act appropriated additional money to be used in part, "for improvement and sinking of wells, installation of pumping machinery, [and] construction of tanks for domestic and stock water..." All this was for Indians who as yet had no "legal" title to their lands.

When the 2,750,000-acre Papago (Sells) Reservation was set aside by Executive Order in January, 1916, its extraordinarily large size was at least partially occasioned by the fact that each head of cattle needed about 140 acres for grazing. The subsequent reduction in the size of the reservation by Executive Order of February 1, 1917, was largely because non-Indian cattlemen succeeded in having their range in the heart of Papago land restored to the public domain.

Reviewing this history of the introduction of cattle among Papagos, what seems to have happened is that most Papago families who acquired cattle did so on very small-scale terms. Their model appears to have been the pattern familiar throughout northwestern Mexico among non-Indians, one characteristic of what has been labelled Norteño culture. This is a situation in which "ranching" is a single family enterprise and consists of farming small fields, raising chickens, goats or pigs, chopping and selling mesquite for fuel, and owning some cows, usually fewer than a dozen, and some horses. Such "ranchers" are, in fact, often expert cowboys, and they also sell their cowboy skills to the owners of large ranches for whom cattle comprise an industry rather than a means of simple subsistence.

After the 1870s, with Anglo-American and large hacienda models to emulate, a very few Papago families acquired extensive herds of cattle and proceeded to raise them and market them in the manner of non-Indians. The result was that by 1959 it was estimated that "something over 50 percent" of all Papago families had livestock, but that fewer than 5 percent of Papago people living on the three reservations owned about 80 percent of the cattle. As Metzler (1960 IV: 6) notes, "The figures distinguish roughly between the cattlemen and the families that just have cattle."

In short, the cattle "industry" on the Papago Reservation actually exists in two quite different, if interlocked, forms. One of these can be construed as an extension or subsistence; the other can be construed as a profit-and-surplus enterprise, a "business" in the non-Indian sense of that term.

As expressed by a range management specialist working for the Bureau of Indian Affairs, in the former pattern:

> ...to a Papago a cow may represent a walking check book...[I]f a man needs a hundred dollars for his family, or a fiesta, a funeral, or a marriage, or for whatever purpose, he literally goes and cashes one cow, or perhaps two or three cows,...whatever his needs are. He doesn't keep money in the bank. His bank's walking out on that reservation, and therefore, as...he needs cash, he goes out and sells. But the selling procedure is in itself unique, and in itself poses a problem for the Papagos because

> today they probably have a 5¢ spread in total income per pound that they get by the method of the trader's buying individual stock, one to thirty, perhaps, at a time...[T]he trader cannot afford to go down... with a bobtail truck and pick up livestock at this rate and pay the maximum market price for those cattle. But the Papago is the one that's hurting or suffering as the result of this system. Now they sell cattle over the scale. There are no public auctions where you can get the best price. But it's brought about the dual problem of the system of traders being on the reservation and making individual purchases and also the extended credit. Obviously these traders extend credit to these people, which many of them prefer. But at the same time the total income of the people is certainly reduced per...hundredweight by this system (Whitfield, 1970: 49-50).

An important ingredient in the relationship between the small cattle owner and the cattle buyer is that many Papagos have established long-term acquaintances with particular buyers, and their dealings transcend purely commercial considerations. There are social overtones to the relationship, and the buyer is one to whom a Papago might be able to turn in time of need or crisis. This is embodied in the notion of the willingness of the buyer to "extend credit," but the credit is more than strictly economic.

In 1968, Papagos belonging to the Gu Achi Stockmen's Association listed the pressures on small cattle owners which make them decline the chance to sell their cattle at a few large sales and thereby derive a greater profit. Bauer (1971, 89) lists these in order of most general occurrence:

> a) Selling cattle for money, as when they [Papagos] return from cotton camps, or just before they go to Magdalena [for an October religious fiesta], or in hard times.
> b) Exchange of cattle with someone for beans, etc. That's been going on for a long time.
> c) For church feasts, saints' days, weddings, other fiestas. Catholic families have pictures of their saints. On the day of their saint, these people organize the fiesta and butcher cattle for the meals. But it's also a community fiesta, so some people will make donations of meat to help out.

Not only Papago social organization and economy, but Papago values have been in contradiction to Western-type economic development. According to Metzler (1960):

> Anglo values emphasize individual initiative, responsibility, aggressiveness, and getting ahead. Papago ideals are cooperation, harmony, and doing your part.... This type of moral code created an individual who was highly subordinate and submissive.... Any desire to get ahead was outside his realm of thinking. This type of moral code created a society in which cooperation and sharing were the key values. Individual or family advancement was sinful, as it tended toward inequality and lack of unity.... This culture produced friendly, cooperative human beings, but had no goals in the way of material progress.... The whiteman, who simply assumes that the Papago can adopt his way of life is ignoring the depth of the Papago system of life.
>
> (The superintendent [John Artichoker, 1968] summed up these contradictions of Papago and Western values by commenting, "Their priorities are backwards.")

Although we agree with the quotation from Metzler in a general way, it needs to be emphasized that just as aggressiveness is not altogether an unqualified Western value, neither do Papago people lack individual initiative, responsibility, and the individual desire to "get ahead." Papagos are no more or less responsible than anyone else and certainly they possess individual initiative in the same proportion as do members of any society. It is instead that the cultural definitions of these concepts differ such that Papagos traditionally are perhaps less willing to "get ahead" if it involves doing so at the expense of one's kinsmen or fellow villagers. Extended families such as Papagos have and the familial obligations which go with them, not to mention the cultural constraints imposed on anyone living in small, face-to-face communities, almost always have a leavening influence on individual initiative. This is not to say, however, that initiative is lacking.

Contrasted with the priorities of the small cattlemen and their "backwards" mores are those of the large cattlemen, those for whom raising cattle is a commercial enterprise. A few of these Papago "cattle barons" live in ranch houses surrounded by all the auxiliary buildings and other appurtenances one would expect to find on a large Sonora or Texas ranch. There are garages, sheds, private wells and water tanks, new automobiles and pickup trucks, and, in some cases, private chapels and smaller homes in which the adult children of the head of the family live. One observer has written of them:

> Some men, misers, have hundreds of cattle. They are criticized for receiving more help than they give at roundups by statistically-inclined and less wealthy cowboys. They are not roundup bosses....The cattle misers have stayed aloof from the present institutions [which enable one to become powerful by being generous]. They have a great deal of money on the hoof. Such men have existed since about 1900 .... They are said to be buried with lard cans full of their unspent silver dollars. We can regard them as [aberrants] outside the generosity system...therefore outside the consumption system....Lard buckets of silver dollars are proofs that their deceased owner didn't get anywhere in Papago society (Bahr, 1964: 5).

One of the immediate effects of the adoption of cattle by Papagos during the late nineteenth century was large-scale overgrazing and consequent destruction of topsoil via gullying, washing, and eroding. It has been estimated that by 1914 there were between 30,000 and 50,000 head of cattle and from 8,000-10,000 horses in the Papago country, and that in 1919, by which time the large Papago Indian Reservation had been established, some 30,000 head of each. This resulted in attempts on the part of the Indian service to bring about a reduction in the numbers of Papago stock, so that in 1930 each Papago family was in theory limited to ownership of 100 cattle and 50 horses. Drought and dourine took a further hand so that 27,000 cattle and 18,000 horses on the Papago range in 1939 became 13,000 cattle and 7,000 horses by 1950. By 1960 the numbers of cattle had climbed back to 15,000, and in 1967 there may have been as many as 18,000 cattle and 3,000 horses. These numbers exist in the face of a 1944 Bureau of Indian Affairs' estimate that the maximum carrying capacity of the range is 11,000 head of cattle and 1,000 horses (Bauer, 1971: 89).

In 1935 the Papago Reservation was divided into eleven separate grazing districts, nine of them on the big reservation and one each for the San Xavier and Gila Bend reservations. Although previous to this there had been six ill-defined but commonly understood grazing areas on the Papago Reservation proper (Jones, 1969: 202-235), the new boundaries and three new districts approximated Papago notions of areas belong to related villages, possibly in keeping with pre-cattle hunting-and-farming areas. There was also a crude correlation between Papago dialect areas and the grazing districts, except that Totoguani speakers found themselves in the Schuk Toak and Baboquivari districts; the Ge Aji speakers were divided between the Gu Achi and Sells districts; the Kuk (Ko-lohdi) speakers were divided into the Chukut Kuk and Pisinimo districts; the Huhhu'ula speakers not on the Gila Bend Reservation were included in the Hickiwan District with speakers of Gigimai, even as Huhuwosh and Gigimai share the Gu Vo District.

Each livestock district is fenced and the cattle within them, with rare exceptions, are run in common. Individual Papagos have their own brands which can be passed to one's inheritor. In the absence of a formal livestock association, coalitions of villages go together to handle a particular range, to take care of the roundup, branding, and preparation for sales. Each household with cattle on the range is expected to provide a cowboy to help in the roundup. If the family owning cattle is not represented in the roundup, it runs the risk of losing calves to the brand of someone else or of having the mavericks turned over to the Papago Tribal Herd. Each coalition of villages selects a cattle boss, often a man who owns a lot of cattle. Each night out during the roundup the cowboys meet and discuss with the cattle boss the preceding day's work and make plans with him for future work. The cattle boss is not necessarily a "cattle baron," and in at least one instance in recent times this person in the district was also in charge of Indian religious observances and Christian fiestas (Bahr, 1964: 4-5; Jones, 1969: 208-210; Whitfield, 1970: 48-49).

In 1935 the Bureau of Indian Affairs brought in stock from New Mexico to be issued for slaughter, but they were so thin they were turned out onto the reservation for fattening. The twelve animals which survived became the nucleus of the Papago Tribal Herd, used by the Bureau of Indian Affairs as a kind of school for Papago cattlemen, demonstrating range management principles and modern ranching procedures through its facilities. The Tribal Herd also supplies registered bulls on a rental program to other Papago livestock owners. The Papago Agency of the Bureau of Indian Affairs created a Livestock Board composed mainly of prominent Papago cattlemen who owned large herds and assigned them the task of overseeing operations of the Tribal Ranch. Although the Livestock Board was a part of Papago Tribal operations, there is evidence to suggest that the Tribal Ranch was in fact run and controlled by the Land Operations division of the Papago BIA Agency. In any event, in 1956 the Agency turned the Tribal Herd over to the Papago Tribe; in 1962 the Tribe requested additional technical support and supervision of the Tribal Herd operation from the Agency; in 1966 the Tribe re-assumed responsibility in full for the herd; and since 1966 the Tribal Herd and Ranch have been handled by the Papago Tribal Herd Manager.

The reasons for these fluctuations in responsibility for the Tribal Herd have been discussed by Bauer (1971: 91-93). He notes that the BIA made a successful economic enterprise of the ranch, but when Papagos assumed its control in 1956 there were no Papago cowboys who had been trained specifically to take over the jobs which had been done by BIA personnel. The Livestock Board "fell apart," and by 1962 the Tribe could no longer afford to run the Tribal Herd out of its own meager resources, hence the call to the BIA for help. What looked like help in 1962, by 1966 looked to Tribal officials like "planning, supervision, and repossession," so the Tribe reduced the role of the BIA in the Tribal Ranch operation. The Tribe hired its own Tribal Herd Manager, a non-Indian, to oversee management of the Tribal Ranch.

Beginning in 1935 the BIA tried to encourage Papagos to form district livestock associations as a means of coping with problems related to overgrazing, marketing, and related matters. For years most Papagos viewed such encouragement as the BIA's attempt to force Papagos into a stock reduction program, something they had always staunchly and bitterly resisted. Beginning with San Xavier in 1953, however, district land codes and cattle associations came into existence in several places.

In 1955 total gross receipts from sale of Papago cattle were estimated to have been about $634,000. In 1959 they ran as high as $750,000, and in 1967 were estimated to account for about $846,000 of Papagos' on-reservation income, some 31 percent of the total from all sources. Recalling that a very few families own most of the cattle, this means that great wealth is concentrated in the hands of a relatively small number of people. It is not surprising that many such wealthy Papago cattlemen have been prominent in Papago tribal politics and have exerted considerable influence on tribal affairs. There is no reservation-wide grazing ordinance; there are no reservation grazing fees. There is a flat 3 percent sales tax on all animals sold on the reservation, the money accruing to the Papago Tribe. Livestock associations, such as they are, collect a small fee in their own areas for operational costs.

In 1969 a well-publicized drought was responsible for the deaths of about 1,200 head of Papago cattle. The BIA was able to expend approximately $200,000 to supply hay, other feed, and veterinary supplies to alleviate the situation. Some tribal and BIA employees were paid overtime wages for working in the emergency helping to haul water and feed; others worked long extra hours at no extra pay, and hard feelings were engendered. At least one large cattle-raising family refused all proffered Federal or Tribal help and elected to handle the drought situation in its own way. Others accepted whatever help they could get regardless of the size of their herds or of their relative wealth.

It was obvious that the small cattle owner was more seriously hurt as a result of the drought than the large owner. If a person owns a thousand head of cattle and loses half, he is still fairly wealthy. But if a man owns five animals and loses two, he is left even more poverty stricken than he was to start with. On the Papago Reservation, moreover, most Federal or outside efforts aimed at improving the range and stock benefit the wealthy more than they do the poor.

Little did Father Kino know when he brought these tame, controllable four-legged Old World beasts from Mexico to the Pimería he was sowing the seeds of an elite class of wealthy Papago cattlemen; of grazing districts and village-coalition cattle bosses; of a Papago Tribal Herd, Ranch and Livestock Board; of cattlemen's associations; and BIA supervision of various aspects of the cattle industry. But the legacy has remained, and the raising of livestock and its many sociological, psychological and political implications continue to exert a powerful influence over the lives of the desert people of the Papago Indian Reservation.

So has another legacy remained: the threat to a fragile land, one which may be stripped beyond its ability to regain a bygone productive capacity. There are still good years among the bad years, but the direction of the curve would appear to be downhill over the long term. And it is the short-term ends which most often set in motion the long-term, disastrous consequences.

Not that the situation need remain this way. The problem is ultimately a human one. Until now Papagos have lacked the organization to adjust the sizes of their herds to match the cyclically-changing carrying capacity of the range. If given the incentive, however, Papago cattlemen, both large and small, can change the status quo. And I believe if they are made aware of the long-range effects of too many four-footed beasts on too sparse a land, such as has happened in other deserts of the world, they will find a way to save their heritage.

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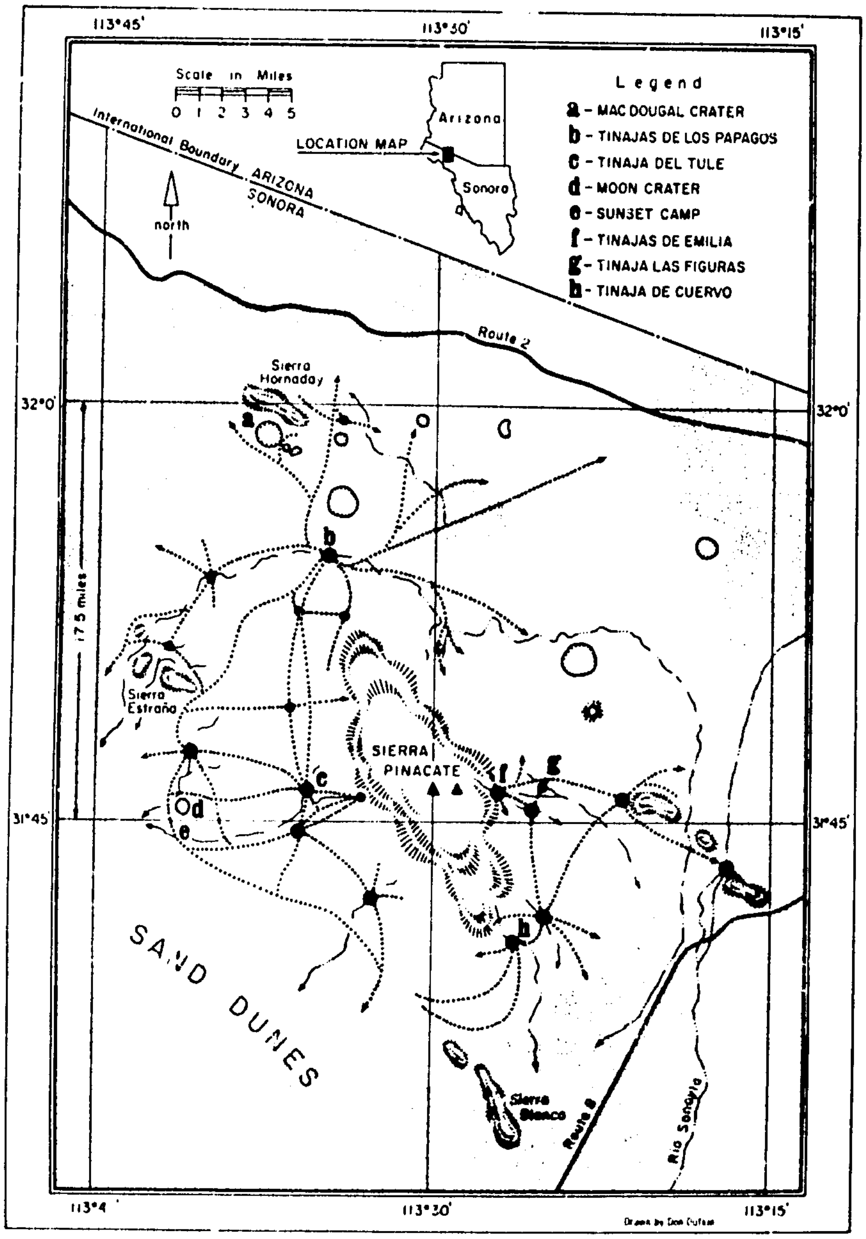

Fig. 1: Some of the major trails and water holes of Pinacate

January 29, 1976

CHANGING CLIMATE IN THE SIERRA PINACATE OF SONORA, MEXICO

by

Julian D. Hayden*

When I first began an archaeological survey of the Sierra Pinacate in 1958, I expected to be engaged for perhaps four or five years in recovering evidence of Indian occupation there before campers and collectors destroyed these patterns forever. I did not realize then that the Sierra was an absolutely unique study area in the North American deserts, one where all the imperishable remains of man have been preserved in direct relationship to the land surfaces of the mountain. This preservation applies to tin cans as well as to the earliest stone tools. Further, since the desert around the Sierra is essentially waterless, with waterholes few and far between, rain-filled rock tanks of the Pinacate have been centers of human life since the first Indians arrived in the desert. So now, eighteen years later - not four or five - I am still at work, still involved, still learning.

Over the years, observations and deductions have been made concerning the effects of changing climate on the desert landscape and the men who depended on it for subsistence. Perhaps the accompanying illustrations will help explain the bases for some of these deductions.

* Research Associate, Arizona State Museum, Tucson

-Official U.S. Navy Photo

Fig. 2: U.S. Navy Viking rocket photograph taken at a height of 125 miles looking northwest:

a. Pinacate
b. Adair Bay
c. Colorado River Delta
d. Salton Sea
e. Pacific Ocean
f. Gila River

-Dick Laidley Photo

Fig. 3: Aerial view across Pinacate from 35,000 feet, looking west. From top center to bottom center are: Adair Bay, the dunes, Sierra Pinacate peaks, Crater Elegante, and Cerro Colorado. This is an isolated volcanic region of some 600 square miles, surrounded by the Gulf dunes and flanked by granitic ranges typical of this desert.

For a study of the geomorphology of the area, see William B. Bull (1974): Playa processes in the volcanic craters of the Sierra Pinacate, Sonora, Mexico. In A. P. Schick, D. H. Yaalon, and A. Yair, eds., Geomorphic Processes in Arid Environments, Proceedings of the Jerusalem-Elat Symposium, vol. I, p. 117-129. Zeit. f. Geomorphologie, n.f., Supplementbände 20. -Ed.

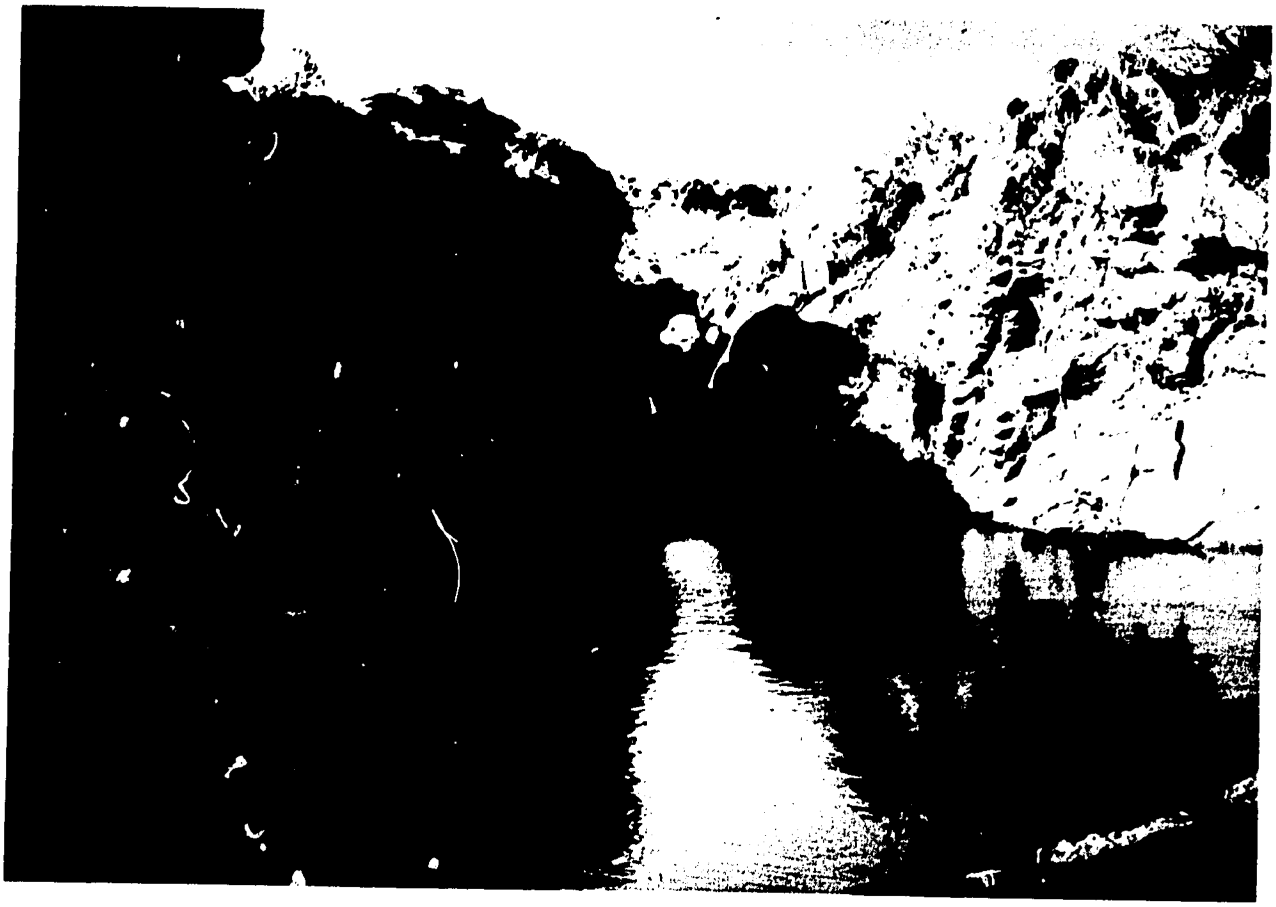

Fig. 4: Tule Tank, full. Water is found in basins scoured in arroyo floors which cut the lava flows. Indian trails link the waterholes and extend toward the sands in all directions.

Fig. 5: Tule Tank, dry. Burro in the foreground died of thirst.

Because of the drought during recent times, the Sierra is surely an area where no man can live off the land. But there have been a few wet years during the last eighteen which have provided a glimpse of the comparative lushness of the Sierra during Pluvial times.

Even now grasses and seed-bearing plants revive during such periods, and rodents multiply greatly. During the Pluvial, and before, until some ten thousand years ago, there were horses, camels, dire wolves, tapirs, and very probably mammoths drinking at these water-holes. Now bighorn sheep, antelope, and deer move in when conditions are favorable, and even man himself could live very well with some effort, as long as the circumstances permitted.

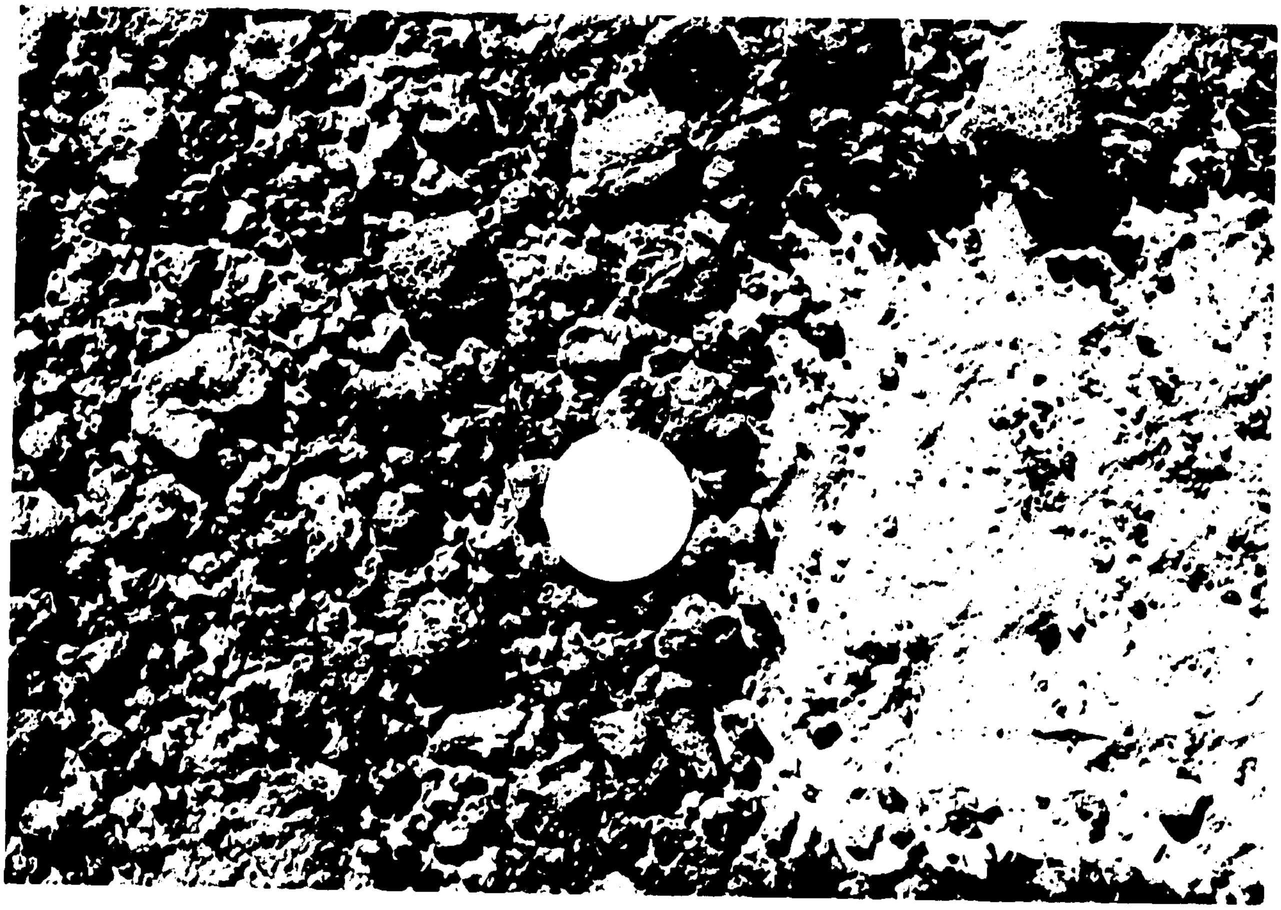

Fig. 6: Pavement mosaic, Tinaja Maria. Elements removed at right to expose sand layer just under mosaic.

The soil in the Pinacate is remarkably fertile, needing only water. Composed entirely of loess, or sand blown in from the dunes, it contains no metals other than those derived by solution from basalts of the lava fields. Windblown sand has been deposited on the cinder-covered lava flows and has packed the spaces between the cinders. Acting as a windbreak, vegetation has sprung up to trap more loess. There is an appreciable depth of soil deposit, especially in depressions and broad basins. Rodents have churned this loess, bringing up cinders from below. This activity has a direct bearing on the formation of desert pavement, a most significant aspect of the Pinacate landscape.

Desert pavements, so common in our deserts, usually are nearly level, composed of a mosaic of large and small stones tightly wedged together, resting on soil. It is fragile; if cut or broken, the scar will last as long as the pavement lasts.

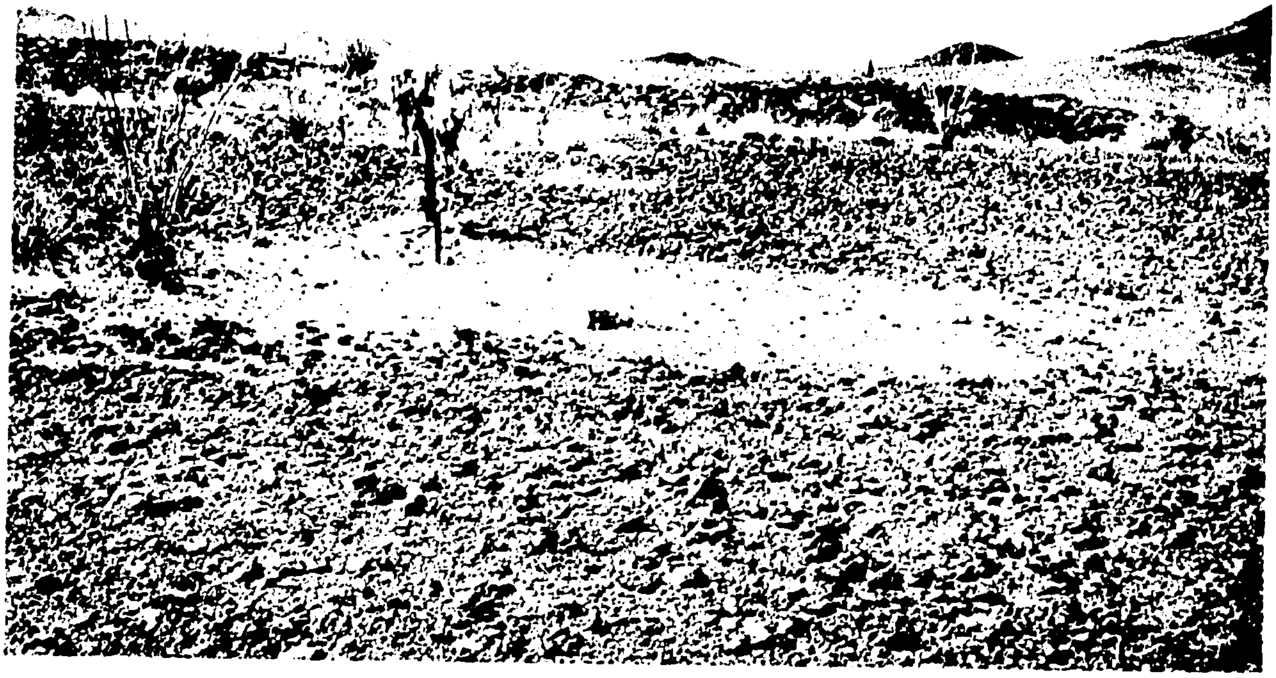

Fig. 7: Vegetative islands, Kino Crater

Just under the mosaic, the soil is locked tightly by a layer of evaporite deposits — carbonates and soil salts that are sterile and almost waterproof. In the Pinacate and very likely elsewhere pavements are formed during dry periods. Plants die, rodents leave, and soil is blown away leaving behind the cinders to form the pavement. Islands of vegetation survive, to expand, perhaps, during the next wet episode, as rodents return and loosen the soil creating conditions that allow seedlings to germinate. These islands never completely revegetate because the evaporite layer is saline and tightly sealed, making it difficult for seedlings to take root.

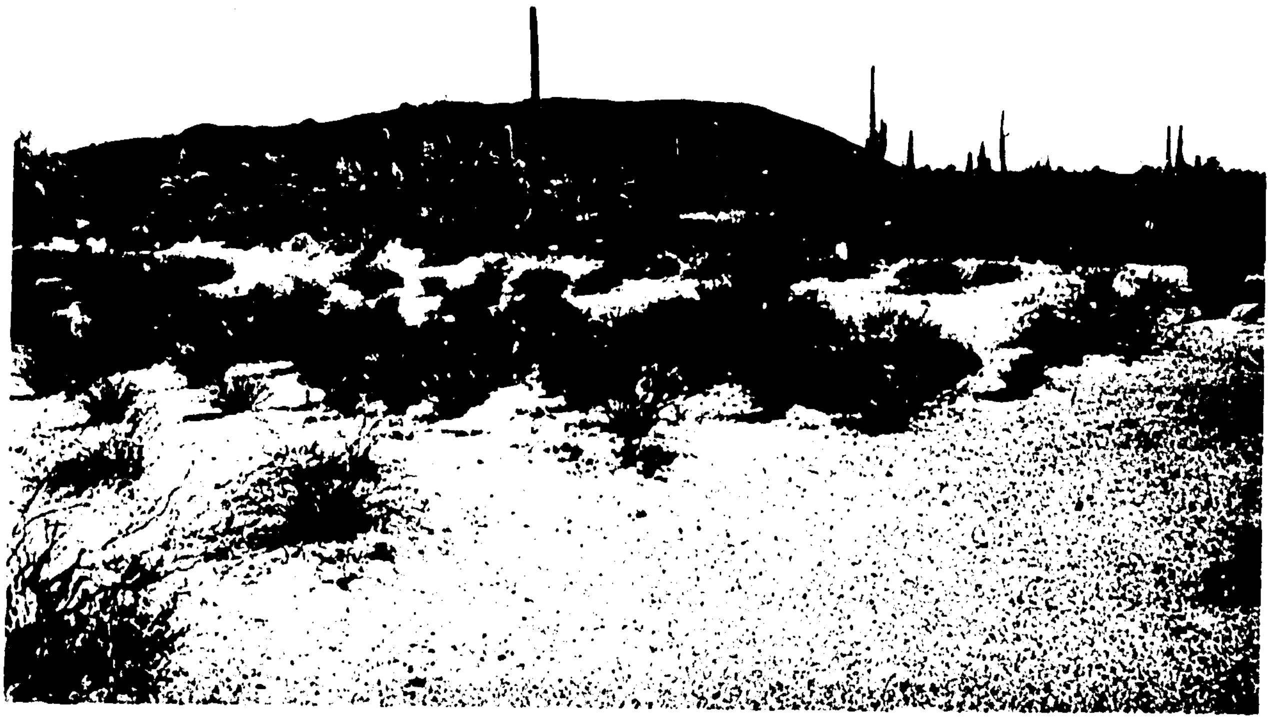

Fig. 8: Here pavement is encroaching upon loess which is in a deflation process.

The pavement forming process is almost imperceptible but nevertheless continuous, during dry times. Occasional rains crust the soil and the curled mud crusts fray at the edges. Blowing branches, running lizards, and other phenomena wear the crusts down. Dust devils and constant winds move the soil away and lower the surface, resulting in pavement formation.

Fig. 9: This stone chopper of the last Pluvial rests on pavement.

Early in my work I noted that man's stone tools of the last five thousand years lay on pavements and were only slightly oxidized, if at all. They bore no desert varnish, that dark glossy coating so noticeable on our desert pavements. Stone tools of the Pluvial, dating before nine thousand years ago, were either resting on or embedded in pavements. In either case, these tools bore a thin coat of varnish like that of the pavements. It appeared logical, then to assume that the embedded tools had been in the soil before surface deflation, and that the varnish had formed during the Altithermal or dry period, between five and nine thousand years ago. These tools on the pavement must be younger than the pavement.

Further, the mosaic elements of certain pavements bore a very heavy varnish which looked for all the world like a once liquid plastic coating. Stone tools of an earlier typology were projecting through these pavements. These tools bore the same heavy varnish as the mosaic elements.

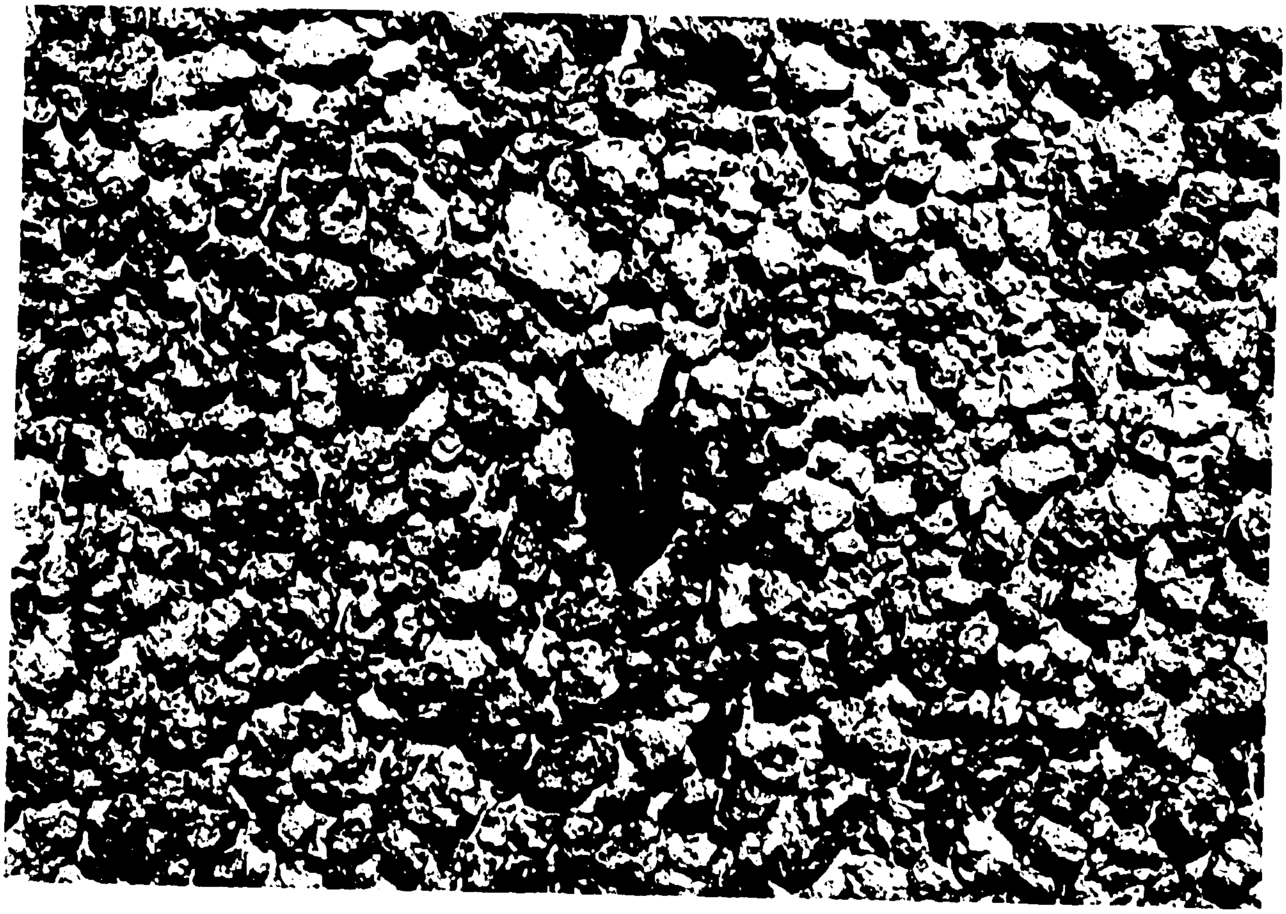

Fig. 10: This varnished stone chopper of the earlier Malpais Pluvial projects through pavement formed in a succeeding Altithermal.

Clearly, then, there had been an earlier Altithermal which I call the Malpais Altithermal. Indians had been living in the Sierra during a prior wet climatic period which I call the Malpais Pluvial.

The stone tools with thin varnish could be related to the occupation of Ventana Cave, seventy-five miles northeast of the Sierra, where such tools were found in a deposit with bones of extinct animals yielding C-14 ages of twelve and eleven thousand years, more or less. This was a drying time ending in the Altithermal which forced the abandonment of the cave, perhaps nine thousand years ago. The Pinacate was also abandoned at that time.

The question then became: when was the earlier Malpais Altithermal? We had help from several sources. Caliche on bones of a burial on the shore of an extinct lake in the Imperial Valley yielded an age of twenty-one thousand five hundred years. Heavy varnish on exposed burial cairn boulders was identical in appearance to that of the oldest Pinacate tools. Tools from both areas were similar. So, the Malpais Altithermal must have occurred after twenty-one thousand five hundred years ago. A limit could be set on the recent side. Travertine from a lake shore in the Pinacate's Crater Elegante dated at about seventeen thousand years ago. Obviously a lake and an Altithermal could not coexist.

I called Dr. Karlstrom at the Astro Lab in Flagstaff and told him my problem. I needed a dry period between twenty-one thousand and seventeen thousand years ago. He said a man had just left his office with a soil core from Walker Lake matching a core from the Plains of San Augustine in New Mexico which indicated a short and severe dry time at about nineteen thousand years ago. This was wonderful news. When he said I could quote him I was very happy.

We had, then, an occupation of Pinacate and the Imperial Valley during a wet time before nineteen thousand years ago. It is not known yet how much further back in time the occupation extends. From various lines of evidence I am willing to suggest thirty thousand or more years before the present.*

With the onset of the medi-thermal period, about five thousand years ago, heavy rains and flooding at Ventana Cave and elsewhere appear to have ended the long drought. The climate appears to have become much wetter than it has been since. This change in climate made it possible for a new people, the Amargosans, to move from the north into the uninhabited deserts. These people, who, I think, were the ancestors of the present-day Pima and Papago, may have settled as far south as Jalisco, in Mexico. Some moved into the Pinacate, reoccupied camps at all waterholes and reused old trails.

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* A detailed report on this pre-Altithermal occupation of the Pinacate will appear in the July 1976 issue of American Antiquity.

Fig. 11: Gyratory crusher in use with wooden pestle, processing mesquite pods.

Perhaps three to four thousand years ago the inhabitants of the Pinacate invented a new tool to process mesquite pods for food. This tool looks like a stone mortar with a small round hole in the bottom. A wooden pestle probably was gyrated in the utensil, reducing the pods to bits which could be ground to meal on the metate. There were large numbers of these gyratory crushers in the Sierra camps, so it seems probable that mesquite trees were plentiful and an important food source.

Fig. 12: Gyratory crushers at Tule Tank.

By about 1,200 A.D. these crushers were no longer in use. In fact, they were stacked up to form windbreaks during the last few centuries. It appears that mesquite were dying out during the climatic changes then taking place, changes marking the end of a long and dense occupation of the Pinacate, as the waterholes dried up and game presumably became scarcer. Population was greatly reduced. When Father Kino visited the Sierra in 1698, there were only a hundred or a hundred fifty Indians living there, eking out a bare subsistence.

Fig. 13: The top of this ironwood stump was once at ground level, but has been exposed because it is in a deflating area. Note the cattle trails breaking the soil crust.

In summary, the evidence seems clear that dry periods have forced human abandonment of the region at least twice since man's arrival, and bid fair to do so again. Mesquite forests are dying out in the Pinacate, waterholes are dry for years, other vegetation generally is disappearing, pavement areas are expanding, erosion is increasing — all the classic manifestations of desertification. None of these phenomena can be laid entirely to the impact of recently introduced cattle or to woodcutters. I believe that, on the evidence, man at present is only aggravating the inevitable and that climatic history repeats itself.

QUESTIONS and ANSWERS

Q. Sir, I was intrigued by the ironwood stump (Fig. 13) where you said that eighteen inches had been deflated from the area. I didn't notice any excessive pavement.

A. You didn't see pavement because the stump stands in an area where the soil is deep, so deep that cinders were not brought up by rodents. The tree burned down to ground level, perhaps in the last few hundred years, and erosion has since lowered the ground surface around it.

Fig. 14: Deep erosion and piping north of Kino Crater. This erosion is less than five years old.

Q. What was the time of the last volcanic activity in the Pinacate?

A. I don't know, but it was surely much longer ago than many people think. The eruption of the Cerro Colorado has been variously placed at one and three thousand years ago. Certainly there is no evidence that any of man's remains have been disturbed by volcanic activity.

Q. How long does it take for desert varnish to form?

A. It is hard to say. As I remarked before, no tool dropped since the last Altithermal, that is in the last five thousand years, bears any varnish. Varnish forms in an Altithermal period, but whether quickly or slowly I do not know. It is, by the way, a dehydrated colloid of silica, containing iron and manganese which give it the dark color. It is not soluble in rainwater, and apparently can be removed only by sandblasting, so that it is therefore essentially permanent. I am told that until varnish is duplicated in the laboratory, not much more can be said about its formation.

Q. How many years have you kept track of the rainfall? Is the whole mountain dry?

A. I haven't. Larry May* did for three years or so, but I have kept only notes of rains for about eighteen years, not of amounts. I can say, nevertheless, that except for spits of rain, none has fallen at one study site in the past three and a half years. To answer the second question, I should say no. Rains are unpredictable in time, quantity, and location. Figure 15 shows a pool formed by rain which came across the mountain in a mile-wide bankd, just a mile south of the study site.

Fig. 15: Rain pool south of Celaya Crater

*An ecologist with the U.S. National Park Service and a member of the team which prepared the master plan for the proposed Parque Natural del Pinacate for the Mexican Government.

January 22, 1976

DESERTIFICATION AND THE SALINITY PROBLEM IN AUSTRALIA

by

Ian Douglas*

Australia has witnessed both the degradation of marginal semiarid pastoral land and the successful improvement and agricultural use of areas once described as "desert" by pioneer European settlers. Perhaps two major physical factors are involved in the difficulties of managing semiarid lands in Australia: first, the complex legacies of past climatic oscillations between wetter and drier phases with consequent effects on the nature of soil and terrain, and second, the extreme variability of present day climate.

The Australian arid zone comprises a single vast expanse of land occupying all the central part of the continent and extending to the western and southern coasts. It is more than 3,200 km from east to west and 2,000 km from north to south. If the term "arid" is defined in the way suggested by Meigs (1953) as being a state "in which rainfall on a given piece of land is not adequate for crop production", then it must be noted that at the southern margin of the Australian arid zone, rainfall is concentrated in the cool winter months when evaporation is low and thus crops and sown pastures can extend to areas where the mean annual rainfall is as low as 250 mm. To the north of the arid zone, however, rainfall is restricted to the summer months when evaporation is high, and thus a mean annual rainfall of 630 to 750 mm is needed for crop growth. Usage of the word "desert" in Australia has differed from the scientific definition of aridity. Just as the seemingly impenetrable mass of vegetation of the tropical rain forest in humid northeast Queensland was termed "scrub" by the pioneers, so any area of poor vegetation, apparently useless for either crops or stock, was termed "desert". Thus the area of the Ninety Mile Plain in the southeast of South Australia is in fact a westward extension of the Big Desert of Victoria. The northwest of the Eyre Peninsula of South Australia was described by the explorer E. J. Eyre as "a perfect desert, very scrubby and stony, with much prickly grass growing upon the sand ridges, which alternated with the hard lime-

*Professor of Geography and Head of Department, University of New England, Armidale, New South Wales

stone flats" (Twidale and Smith, 1971). Both these areas have dunes of Quaternary age which are now fixed by vegetation. Both "deserts" have become areas of crop production as a result of a series of technological changes, particularly in terms of water supply and improvements to soil fertility through the application of trace elements (Hoffman, 1967; Twidale and Smith, 1971).

The Quaternary dune systems of these transformed "deserts" illustrate the role of historical geomorphic and pedologic hangovers in Australia's desertification problems. Just as the semiarid zone is marked by relics of former more arid phases, so the arid zone has large relict fluvial systems which are occasionally reactivated by such events as the 1974 floods which changed many parts of the interior into temporary inland seas surrounded by rapidly growing grasses and wildflowers. Conditions after such events have always tempted settlers farther inland, while drought conditions coinciding with economic conditions unfavorable for agriculture have forced back the settlement frontier.

The succession of Quaternary climatic oscillations has created land surfaces and plant associations which are naturally unstable under present conditions. Much of the continent's surface dates from the widespread peneplanation and deep weathering of Tertiary times, with some lateritic profiles exceeding 60 m in depth. Present-day soils in these areas reflect the degree of later modification and stripping of the Tertiary surface and subsequent erosional depositional history.

At one extreme are the extensive low tablelands of the stable Great Plateau, which comprises much of the western two-thirds of the continent, and the widely-distributed smaller plateau of the eastern highlands. Such landscapes are dominated by relict lateritic soils, either the podzolic form with its prominent horizon of ironstone nodules or massive laterite, or the red and yellow earthy forms, either sandy or clayey, with varying pisolitic, cellular or massive laterite. At the other extreme are such landscapes as the undulating "downs" of central western Queensland - a modern erosion surface covered by moderately fertile self-mulching grey and brown clays formed from underlying fresh Cretaceous sediments following complete stripping of the old weathered profile. Between these extremes are large areas of soils formed _in situ_ on the deeper horizons of the weathered profile exposed by truncation, and on lower plains of redistributed weathered detritus, or on mixtures of these materials and fresh parent rock.

Among more recent influences on arid zone soils are oceanic and relict salts and periodic phenomena of erosion and deposition (Butler, 1959). Soils thus often consist of several layers, each of which was the topsoil at some time in the past, but was later buried by aeolian deposition. Among the peculiar profiles thus produced are the soils with up to one meter of calcareous clay which has been blown over the leached and acid kaolinitic clay of an old eroded laterite (Bettenay, 1962).

Vegetation patterns in the arid zone are complex. Communities are simple structurally; the layers are short-grass forb, tussock or hummock grass, low shrub, tall shrub-low tree. Within each layer one or a few species tend to comprise most of the biomass at each site. Species and layer communities (synusiae) react independently to environmental conditions and their distribution overlaps. Arid shrubland and grassland are poor floristically, the number of species being only a few thousand, a high proportion of which are endemic (Perry, 1970).

The present character of the arid zone is the result of interaction between this legacy from the past and the present spatially and temporally variable precipitation regimes. The notion of water as the limiting resource in Australia is so clearly perceived and drummed home that food producers can be said to have a drought complex (Wadham, Wilson and Wood, 1964).

Perhaps it is well to think of Australia as an area of some 4 million square kilometers of arid and semiarid land, with a discontinuous fringe of more or less watered land (McCay, 1972). Even this picture fails to convey the harsh truth that almost every locality in Australia sometimes has too much water and sometimes too little.

Much of the summer rainfall in the arid zone comes from convectional storms which may yield rain over an area of 25-40 km^2. In any year an area may receive several downpours from overlapping storms whereas a nearby area may receive few or none (Perry, 1970). The variability of rainfall and the even greater variability of river flow is well appreciated by those who have to manage water supplies, but fails to enter public consciousness save when an extreme event occurs, such as the isolation of Alice Springs by the 1974 floods. Droughts have led to pressures for flood mitigation dams. The Mallee water system was a sequel to the 1900-1903 drought, the Murray Irrigation Authority was a sequel to the Royal Commission following the 1914-1915 drought (Heathcote, 1967) just as the Hunter River Conservation Trust and the Glenbawn Dam on the upper Hunter were results of the 1955 floods. For every irrigated hectare in Australia 3.4 megaliters of water are stored compared with 1.5 megaliters in the USA and 0.85 megaliters in India.

Perhaps the fluctuating water resource ought to be seen as a challenge to adapt farming practices to non-annual regimes. Much flood spillage down the great inland channel systems is unused. The flood flows along the Thompson, Diamantina, Barcoo, and Cooper's Creek towards Lake Eyre greatly increase available stock feed. The period between 1890 and 1946 here saw five floods with flows exceeding 5 million megaliters, eight with flows of 2.5 to 5 million megaliters, and 13 with flows of 1.2 to 2.5 million megaliters (Nimmo, 1947). Although a significant correlation indicates that the volume of the annual flood is the dominant factor determining the number of cattle fattened in the channel country, much more could be done if animals could be moved in and out of the area quickly and if pasture plant seeds which will lie dormant and only germinate when floods come could be bred. Today the larger cattle raising companies have developed a chain of stations from the beef cattle breeding grounds of the Northern Territory, extending southwards to the main fattening stations in the Channel Country and beyond. In part, this system of cattle movement, in which the Channel Country is used primarily as a fattening rather than a breeding area, reduces the likelihood of large numbers of stock being marooned in the district as a result of one of the frequent droughts (Allen, 1968).

Even though such management schemes and the beef roads linking remote inland areas to railheads have helped adjust grazing to the temporal and spatial availability of water and fodder resources, there is no hope of drought or flood-proofing Australia. Much of the desertification of Australia has arisen through attempts to cope with drought and flood hazards and taking risks with regard to the promise offered by a succession of relatively wet years on the fringes of the arid zone.

The Impact of Animals on the Arid Environment

Much use of grazing lands has been exploitative. The pattern is a rapid rise in animal numbers generally following settlement, followed by a spectacular, sudden crash generally associated with drought and then recovery to a fairly steady level of about a third of peak figures (Perry, 1970). Fluctuating stock numbers are associated with changes in pastoral leases and thus with land management.

From the start of colonization in South Australia, policy decisions were made to ensure the destruction of the shrub-steppe plant communities. The first lessees were required, upon pain of forfeiture, to stock runs within three months with not less than eight sheep per km^2 and to increase this to 40 sheep per km^2 within five years (Crowcroft, 1972). The present-day obligatory stocking rate, maintained to prevent speculation in leases, is two sheep per km^2.

Vegetation degradation due to increased animal populations, including native and introduced wild species such as the rabbit and feral livestock (McKnight, 1975) since European settlement are evident in western New South Wales and in northwest Australia, so that fodder availability is now the limiting factor to an increase in stock numbers.

In drier areas the effects of animals on their environment are slower but more lasting and conspicuous. Some species decrease, others increase, while still others invade. In some localities, deep-rooted perennial grasses killed by overgrazing are replaced by native short-lived annuals or by spiny unpalatable shrubs. Experiments at Koonamore Station in northeastern South Australia have shown that the deep-rooted bluebush (Kochia) and the shallow-rooted saltbush (Atriplex) often appear to be in dynamic equilibrium. Major changes in dominance occur over long time periods, depending on soil and weather (Carrodus and Specht, 1965). The bluebush occurs where soil is wetted to a depth of five cm or more by normal rainfall, while the saltbush seeds better during drought, absorbing moisture from the air when humidity exceeds 85 percent, as often happens at night.

After sheep have been excluded from the Koonamore Reserve for six years, areas trampled by sheep were still devoid of vegetation. Few new saltbush plants appeared and the bluebush had only partially recovered. There had been no flowering, and no reseeding had been possible from outside because trampling and wind erosion had removed the surface soil. In one hectare quadrate, one rabbit had destroyed 18 one-year-old mulgas (Acacia aneura) in a single night, indicating how effectively rabbits restrict tree regrowth.

Elsewhere on Koonamore, light grazing 1.5 to 3 km from water produced increases in the number of bushes. Moderate grazing up to 1.5 km from water led to a significant increase in the number of dead and defoliated plants, but also in the number of healthy and vigorous plants. Removal of dead bushes and pruning of vigorous plants by grazing animals stimulates development of healthy lateral shoots. Heavy grazing around watering points, however, produced severe damage; all living saltbushes were removed, followed by the removal of the dead plants through trampling. In such localities plant debris and topsoil were blown away, leaving a sterile waste (Osborn, Wood and Paltridge, 1932).

Regeneration experiments on soft scalds were conducted near Condobolin, New South Wales. After animals had been excluded for nine years islands of vegetation were well developed and apparently stabilized by perennials, but the total percentage of cover was relatively small. In two transects each 150 meters long through the plot the mean percentage of cover was estimated at 11.2 percent (Beadle, 1948a). The perennial diamond saltbush (Atriplex semibaccatun) which germinates in cracks in scalds as soon as free water disappears from the scald surface was particularly important in the recolonization process.

Similar evidence of vegetation degradation and the difficulties of regeneration is seen throughout the spinifex, saltbush, and mulga communities of New South Wales and Western Australia. The general sequence of events is thought to be: depletion of perennial grasses by overgrazing followed by wind erosion, reduction in surface litter, increased runoff and decreased water penetration producing high soil temperatures leading to a more arid habitat. This process of desertification results in an environment unfavorable for plant establishment, and, as Beadle (1948b) found in New South Wales, one which is extremely difficult to revegetate even with plowing, seeding and applications of water.

Pasture Land Use Problems

The management of semiarid and arid land in pastoral areas has long been of concern to state soil conservation authorities, who, in a quiet but practical way have done about as much to increase knowledge and techniques of conservation as the more widely known Commonwealth Scientific and Industrial Research Organization (CSIRO). The CSIRO Regional Surveys published in the Land Research Series include examinations of many parts of arid and semiarid Australia. In the Alice Springs area Perry (1962) noted zones of grazing intensity with consequent vegetation conditions around watering points similar to those described in South Australia. Commenting on large bare areas occurring some distance from watering points, Perry wrote that it is difficult to assess how much is normal and how much is induced by grazing. Often such bare areas become covered with grasses and wildflowers in favorable seasons, thus the effects of environmental fluctuations must be known before the impacts of grazing may be evaluated. But he points out that "the ecological approach to range management has received little attention in Australia and none in northern Australia".

Perry's summary (1962) of the situation of the pastoral industry in central Australia is worth noting: 1) large areas of the usable country are under utilized because they are too far from water, 2) insufficient knowledge of pasture deterioration is available to indicate how much country is affected or how seriously; the direction of the present trend is unknown but if it is determined that it is southward, how it can be reversed; and, a hopeful note, indications are that pastures are in good condition compared to similar rainfall areas of Africa and Asia that are subject to much more intensive use and misuse, and 3) legislation to control stocking exists but no methods have been formulated to determine correct rates consistent with maximum returns and the maintenance of productivity.

In Western Australia, too, problems of range management have been emphasized (Nunn and Suijdendorp, 1954; Suijdendorp, 1955; Nunn, 1960; Wilcox, 1960a, b, 1963), noting trends towards deterioration and degradation in the pastures of the Wiluna-Meekatharra area with pressures of subclimax vegetation in some areas, the removal of perennial vegetation and soil erosion or sealing of soil surface in others. In almost every part of the area there has been an increase in the density of unpalatable shrubs and herbs.

Deterioration of pasture lands in Western Australia need not be ascribed solely to overgrazing. More probably it is due to a combination of drought, animals, and current grazing practices. Wilcox (1963) advocated a change in range management with recognition of the requirements of the pasture species for survival, along with propagation to ensure increased production and range improvement.

The Soil Conservation Authority of Victoria has produced a land reports series using land systems techniques similar to those employed by CSIRO. Northwestern Victoria relict dunes, particularly in the Big Desert and Berrook land systems, are extremely unstable when cleared. Native vegetation provides complete protection from wind except along the very crests of the highest jumbled dunes where there is some sand movement. Not a great deal of drift follows fires in the area because of the wind breaking effect of remaining shrubs and mallees stalks and because of the presence of a resistant surface seal created by raindrop impact combined with the binding effect of mosses and lichens (Rowan and Downes, 1963).

Before settlement is contemplated in these dune areas there should be a comprehensive series of pasture and grazing trials to determine if pasture can be economically and safely produced. Heavy applications of fertilizer, careful fencing and bore water supplies would be necessary. Costs would require a relatively high carrying capacity achieved only by most judicious range management. Generally, the few cleared Big Desert sands have become unmanageable with dunes drifting and lower sites supporting either regenerating scrub or weeds tolerant of low fertility. The condition of such terrain warns of the general instability that could occur if large settlements were developed.

In New South Wales the Soil Conservation Service sponsored Noel Beadle's classic study of the vegetation and pastures of western New South Wales (Beadle, 1948c) and a series of reports, trials and surveys (Condon, 1961a). Much of the severe erosion and serious pasture degeneration evident in western New South Wales can be traced back to the 1902 drought and before. Subsequent droughts have all accentuated the problem. Extremely heavy stocking took place between 1880 and 1900 when 15 million sheep grazed the western area compared with some six million since the accompanying rapid increase in rabbit population and the great drought of 1902 took heavy toll of pastures and soils in the region. Although conditions have improved since then with improved farm management, watering facilities and transport to move stock during drought, progressive deterioration will continue, especially during future droughts, unless advantage is taken of increased knowledge of soils, vegetation and range management (Condon, 1961b).

Western New South Wales is marked for its diversity of soil types and thus spatial variability of susceptibility to erosion and composition, quality, relative palatability and rapidity of response to rains of the pastures. The more highly erodible soil types invariably support sweeter pastures of higher quality and quicker response to rains than the more stable soils. Consequently, where both erodible and non-erodible soils occur in the same paddock, the former are subject to constant grazing pressure, while the latter may be relatively unstocked. Successful management of such situations involves separation or particular types of country by sub-division fencing, a practice often hard to justify on short-term economic criteria.

Drought periods produce some of the more dramatic features of desertification. Dust storms occur often in dry periods. Their severity is markedly affected by grazing management methods affecting vegetation. During a storm on 20th November 1944, the rate of dust deposition was estimated at 176.8 kg/ha (Blandford, 1948), while winds in February 1947 in the Harden area of central New South Wales stripped all surface soil from pastures, leaving grass and vegetation roots standing up to 75 mm above the hard, scoured subsoil (Taylor, 1948).

The interior of Queensland also experiences dust storms believed to be the combined result of severe drought, overstocking and excessive powdering of soil by passage of animals (Skerman, 1947). Whitehouse

(1947) notes the natural equilibrium between soils, vegetation, and climate in the Channel Country, pointing out that future utilization of these plains should be based on policies that do not disrupt the natural equilibria: "All care should be taken that, in stocking the region, the herbage is not permanently depleted and the soil loosened so that it may drift." Many of the trends towards desertification in the Queensland Channel Country, however, can be seen as the product of land speculation. Before 1900 pioneers usually were resident for only short periods before moving on to more favorable districts. Those who followd the pioneers were less concerned to make a quick profit and revealed a genuine desire to develop the area. An unusual succession of poor seasons at the end of the 19th century, aggravated by declining cattle prices, pests, and a statewide monetary crisis, led many pastoralists into indebtedness and eventual financial ruin. Since then pastoral management has become more stabilized and adjusted to policies of living with the environment, even though grazing practice remains largely one of management for animal production rather than management for maintenance of vegetation and pasture quality.

The last words on desertification in the arid and semiarid rangelands should come from Francis Ratcliffe's account (1963) of his travels between South Australia and the Queensland Channel Country in the early 1930s:

> "The inland pastoral country of Australia is a land of alternate feast and famine.... The inevitably recurring droughts are the weak links in the continuity of prosperous settlement in the Australian inland. In a severe drought, in order to keep themselves live, the stock have to eat and destroy, often beyond hope of recovery, those long-lived resistant plants on which the stability of the soil itself depends."

In a preface to the 1963 edition these comments on the 1930 situation were added:

> "Landholders have become more experienced and cautious in their handling of the dry country, and a good deal of scientific attention has been directed to its problems.... Whatever people may say or hope for, there is no sign as yet of what in the modern jargon would be termed as technical break-through that would assure the future of settlement in the semi-desert regions beyond reach of irrigation water." (Ratcliffe, 1963).

Impacts of Irrigation and Other Land Developments

The development of irrigation schemes led to much closer appraisal of the soils of the areas concerned and from these studies the ideas of the periodicity of soil development, the genesis of duplex soils and Butler's K-cycle concept were evolved (Butler, 1967). From these detailed investigations emerged the data for the Geomorphic Map of the Riverine Plain (Butler et al, 1973) which shows the extreme complexity of the aeolian and fluvial depositional landforms of the Murrumbidgee and Murray River plains. In a way, the map warns of the dangers of excessive generalization about land and soil management in the semiarid areas of Australia. Failure to recognize the character of a particular feature of an alluvial plain may lead to inefficient use of water resources in an irrigation area, or to severe erosion under dryland farming.

Dryland farming cultivation in parts of semiarid Australia has often been successful, but many examples of loss of soil productivity through destruction of native ecosystems exist. Economic factors have led to successive advances and retreats in wheat cultivation in semiarid areas (Camm, 1976; Dahlke, 1975). More recently a 1965-1975 boom in oilseed demand prompted farmers in northwestern Victoria and parts of the Western Australian wheat belt to grow oilseed crops. Their efforts met with failure because of the incidence of plant diseases not so prevalent in traditional oilseed growing areas. Once economic failure occurs, the care of the soil may fall off and conditions deteriorate. The threat of this abandonment of land management as a result of changed economic situations is always present. If it should occur at the same time as a drought, many fossil arid zone features, such as relict sand dunes, would be reactivated, become mobile and lead to desertification. This situation exists in the marginal dryland farming areas and is possibly the major threat of increased desertification in Australia.

The other major activity in the Australian interior, mining has had locally severe impacts on the environment. Natural vegetation is scarcely resilient enough anywhere in the arid zone to supply fuel and incidental requirements for mining operations. Where vegetation has been exploited results have been depressingly devastating as around Broken Hill in New South Wales (Morris, 1939). Mining waste disposal and erosion of abandoned mine workings produce local pockets of desertification.

Against these difficulties must be set the successful improvements in soil capability through the use of trace elements. In the Esperance region of Western Australia and the 90-mile plains of the South Australian-Victorian border, additions of trace elements have made cereal cultivation possible on soils which originally supported only natural vegetation with low productivity. In the 90-mile plains, copper and cobalt deficiencies were corrected and groundwater from the Mt. Gambier limestone was used to irrigate crops. Both these improvements and those of Esperance took place through the enterprise of an insurance company, the Australian Mutual Provident Society. Over 110,000 hectares were so developed.

Other examples of the transformation of marginal land into agriculturally productive areas could be cited, but in Australia the question as to whether such pioneering ventures should continue to be sponsored must be raised. Australia has more land in agricultural use than it needs at present levels of demand:

> "Whether Australia can utilize a high proportion of its existing sheep country for beef production or not, it is obvious that there is little point in opening up new land for agriculture or in storing additional water for irrigation. The cheapest means of producing beef is to graze cattle on pastures which are no longer required for sheep and wool production. As the market for beef is likely to be limited and the cattle needed to graze all of Australia's existing pastures are not available, the possible conversion of some land to forestry, nature reserves or for some recreational purposes should be considered" (Davidson, 1972, p. 211).

The consequences of this statement are likely to be abandonment of some pastures, amalgamation of rural properties into larger units and less expenditure on pasture improvement. Such factors could set the scene for further desertification if 1976 market trends continue into a succession of drought years.

The Salinity Problem in Australia

Changes in pasture conditions affect the mobility of chemical elements in the landscape and aggravate the problem of salt redistribution in Australia leading to desertification in many places across the continent. Practically all Australian inland waters, unlike those of other continents, are dominated by sodium chloride (Williams, 1967). Although much evidence suggests that a substantial proportion of these salts is derived from marine sources, whether primarily or secondarily (i.e. cyclic salts), the evidence is mainly circumstantial, and much more direct evidence is needed (Williams, 1976).

Precipitation accounts for much more of the salt in Australian rivers than it does in rivers elsewhere. In the western United States, the supply of chloride to rivers from precipitation is greatest in the wettest catchments close to the northwest coast (Van Denburgh and Feth, 1965). Even in these catchments, the chloride supplied by precipitation amounts to only 20 percent of the total chloride removed by rivers. In Finland, on the other hand, chloride supplied to the land surface from precipitation slightly exceeds that removed by rivers (Viro, 1953). In northeast Queensland, Australia, rainfall supplies 70 percent of the total chloride removed by the Millstream at Ravenshoe on the Atherton Tableland, but only 55 percent of the total chloride removed by the Wild River, a score of kilometers farther inland (Douglas, 1968). On the basis of the rainfall-runoff ratio, the estimated average concentration of chloride from precipitation in the waters of Strike-A-Light Creek on the Southern Tablelands of New South Wales would be 18 ppm, but the average measured concentration of only 14 ppm suggests a net accumulation of chloride in that catchment.

On the Southern Tablelands generally, where problems of salt accumulation are common (Wagner, 1957), relict salt has been a common limiting factor in pasture management (Van Dijk, 1969). High concentrations of chloride occur in small catchments, such as Yarralumla Creek near Canberra, where concentrations exceeding 300 ppm occur at low flows (Douglas, 1968).

The accumulation of chloride from precipitation may be greater than that of sodium which is released from the catchment surface while chloride is precipitated, perhaps in conjunction with calcium as gypsum, as is noted by McLaughlin (1966) in a discussion of the salinity of the lakes of the Victorian Mallee. An alternative explanation may be that an ion exchange occurs in the soil zone of the Southern Tablelands, calcium and magnesium being removed from the water and sodium added, thus creating an excess of sodium over chloride. Furthermore, a spatial variation in the accession of salts of marine origin is to be expected. At a given locality within 500 km of the coast, the chloride concentration in the rain is related to the distance from the ocean. The concentration can be estimated from the equation

$$\text{Chloride (m-equiv./liter} = \frac{0.99}{4\sqrt{d}} - 0.23$$

where d is the distance in km from the ocean in the direction most likely to contribute maximum oceanic salt (Hutton, 1976).

Downes (1961) pointed out that the salinity problem in the Tableland areas near the headwaters of the major inland, westward-flowing streams of eastern Australia is localized. Man's use of the land has altered the hydrologic cycle in such a way that salt has been redistributed into local concentrations. Brackish soil water kills vegetation, creating bare soil patches. Once the areas are denuded, evaporation becomes more effective and a continual buildup of salt occurs. Heavy rains produce sufficient runoff to wash some of this salt into streams and thus into the Murray drainage network.

Salt buildup in northward-flowing tributaries of the Murray in Victoria has been explained in terms of a different model (Webster, 1965). There is evidence to suggest that before the country was settled, streams were not as saline as they are now. It is believed that clearing, trampling of ground by stock, and destruction of certain natural grasses has changed the hydrological cycle (Marker, 1959). In areas like the Victorian basalt plains, highly saline groundwater has risen because of reduction in tree cover. Salt has been brought to the surface by capillary action and is subsequently washed off by rain. Careful management is needed in such areas, the Soil Conservation Authority of Victoria (1968) advising that this redistribution of salt need not cause trouble if there is adequate vegetation to use the slightly saline water. Because pastures in such situations become more attractive to stock, they are apt to be overgrazed, causing further salinity dangers. Such salinity hazards are indicated in regional land capability studies, for example in the assessment of the Willaura land system in the Grampians area of Victoria (Sibley, 1967).

The most westerly of the northward-flowing Willaura tributaries, the Loddon River, traverses an area affected by Quaternary aeolian activity, during the last phase of which evaporite salts, mainly gypsum, lime and halite, were incorporated into lunette sediments (Macumber, 1969). These salts are now being remobilized by surface and groundwater. Sodium chloride is carried from lunettes to the plains where it is added to salts from other sources, including those blown in by wind from depressions in lunette areas. The buildup of salt in the plain has been effected by irrigation which has raised the water table in places to within 1.5 meters of the surface, a level close enough to the surface to greatly increase soil salinity.

Throughout the tributaries of the Murray, instances of local salt accumulation may be found. Washing some of the salt from these areas has helped to make the salinity of the Murray one of Australia's major pollution problems (Australian Senate Select Committee, 1970). So real is the problem that citrus growers have installed sprinklers under trees instead of overhead to prevent leaf damage due to excessive salt.

Salinity in the Murray-Darling Irrigation Areas

Much of the water draining from the upland tributaries of the Murray passes into surface storages such as the Hume Resevoir before it enters the Murray Valley proper. The Murray Valley is divided into two distric' zones by a boundary running approximately north-south in the vicinity of Swan Hill. To the east in the Riverine Plains zone, the land is flat, the soils are generally fine-textured, and the natural drainage conditions are poor. The main irrigation enterprises are pasture and cereal growing. In the irrigation areas there are continual additions to the groundwater from channel seepage and farm irrigation water that percolates past the upper soil layers. This has caused the water table to rise under all of the irrigation areas. In many places it has risen to a level where it affects agricultural production, either by waterlogging of plant roots or by the transfer of salt into the root zone by capillary action.

To the west of Swan Hill, in the Mallee Zone, the soils are generally coarser-textured and easily drained. The irrigation areas support horticultural crops, mainly stone fruits, citrus, and vines. Irrigation water salinity has a significant influence on crop productivity particularly the stone fruits and citrus. Substantial losses have occurred in the past when river salinity levels have remained high for extended periods.

The major salinity problems in the Murray Valley are shallow watertables in the Riverine Plains Zone and high river salinities which occur at times in the Mallee Zone.

The two problems are interelated. In areas with shallow water tables, saline groundwater seeps into natural and constructed drainage systems and thence flows into the Murray, which is the ultimate drainage collector for the whole valley. Thus the shallow watertables in the Riverine

Plains Zone affect the salinity of the river water in the downstream Mallee Zone (Gutteridge, Haskins, and Davey, 1970).

Signs of surface salinization caused by shallow water tables in the Riverine Plains Zone first occurred in the Kerang region at the beginning of the 20th century. The Kerang region remains the only seriously affected area at present, but it is estimated that by the year 2000 almost three times the presently affected area will be under the hazard of salinity from high water tables (Gutteridge, Haskins and Davey, 1970).

Downstream in the Mallee Zone the salinity of the Murray River increases. Some of the increased salinity comes from saline springs and groundwater seepages from the bed and banks of the river, but an important source is the uncontrolled disposal of highly saline drainage water, from a number of irrigation schemes, sometimes containing up to 20,000 ppm total soluble salts.

This combination of factors has produced a definite trend towards greater salinity throughout the Murray, apart from the general downstream increase which is even more marked when river flow is low (Helliwell, 1963). Periods of low flow, as in 1965 and 1967-68, are thus crucial, particularly as tributaries like the Loddon are apt to bring in surges of highly saline ater which pass down the Murray system. Unfortunately storages needed to mitigate against low flows would provide opportunities for evaporation and increased salt concentration (Crabb, 1967).

In five of the ten years before 1968, the River Murray provided more than 40 percent of South Australia's water for domestic consumption. Far more, however, is used for irrigation, particularly of horticultural products, many of which are classed as "extremely sensitive" to total salinity (Allison, 1964). The estimated $A2.5 million per annum loss of horticultural production in South Australia as a result of saline irrigation water is not surprising, is probably an underestimate. To keep the quality of river flow acceptable to South Australian irrigators, dilution flows of up to 620 million m^3/yr have been required. Some is provided by natural peakflows, but with increased regulation of the river, more and more water will have to be reserved for dilution purposes unless the inflow of saline water is reduced. So severe is the problem that a proposal for a separate water supply channel above groundwater level greatly impressed the Senate Select Committee. Another alternative is to lead irrigation drainage water into stilling ponds or enclosed drainage areas where the water would stand until lost by evaporation, leaving an artificial salt lake. Such a solution would create local saline desert areas from which winds could eventually blow salt back into the atmosphere and aggravate the cyclic salt problem.

These salinity problems in the Murray Basin arise from the successive reuse of water as it passes downstream. Every agricultural water use causes evaporation and increases salt content. Thus as Langley (1967) has pointed out, the paradox is that while greatest benefit is acquired from multiple reuse of water, inferior water quality often restricts optimum use at the downstream end of the river basin.

Salinity Problems in Western Australia

In Western Australia, particularly in the interior areas receiving less than 500 mm of rain per year, soil salinity occurs naturally and has shown an increased incidence following clearing for dryland agriculture. In the Belka Valley, field and laboratory studies (Bettenay, Blackmore and Hingston, 1964) showed that salinity is associated with a three-component hydrologic system involving surface, soil, and aquifer waters. Amounts of water involved in surface runoff and soil water storage have increased since clearing. The third component, which has not been affected to any large degree by clearing, consists of a partly confined and continuous aquifer present in the clayey pallid zones which extend over most of the landscape. This aquifer has its major intakes adjoining rock dome outcrops, contains acid waters, and is the main repository for salt in the landscape. Salinity of overlying soils results where the aquifer intersects the surface, or where capillary contact occurs in the valley bottoms. Because of low gradients and low permeabilities water movement in the aquifer is very slow, so that salt increase following clearing of the Valley floors is attributed not so much to massive movements of water as to decreased usage by transpiration, and a consequent increased transmission of water and salt to the surface by capillary action from the naturally occurring bodies of water which exist in these situations.

An alternative hypothesis of increase in salinity due to lateral subsurface soil-water movement has been put forward by Conacher (1975a) on the basis of studies in the York-Mawson and Dalwallinu areas of Western Australia. Natural vegetation influences water movements through interception, transpiration, retention, and infiltration. Since most West Australian wheatbelt soils have sandy textures at or near the surface and increasingly finer textures with depth, it is considered that the greater part of water movements redistributed following vegetation clearance occurs as throughflow rather than overland flow or deep infiltration. Repeated plowing to the same depth may enhance the throughflow component by accentuating texture, and hence presumably the permeability. The throughflow zone may even rise closer to the surface. As throughflow passes through a larger volume of soil than either overland flow or vertical infiltration, it may mobilize much more salt than other water movements.

Throughflow becomes concentrated in percolines a short distance downslope (Bunting, 1961). The percolines lead to valley floors, where soil materials have accumulated from both upslope and upvalley. Here the throughflow movements with their relatively low concentrations of dissolved salts are checked. The spatial extent and temporal duration of water accumulation is now greater than before clearing. Seepages occur where relatively impermeable soil layers are close to the surface. In addition, capillary action and suction resulting from intense evaporation during the hot summer months bring soil-water to the surface and increase surface salt concentrations to toxic levels that kills the vegetation.

Most bare salt scalds (Plates 1 and 2) are at the heads of, or adjacent to, stream channels. Seepage from the scalds is drained downvalley; now characterised by high salt concentrations, the water contributes to downstream scalds whose water and salt imputs may be predominantly from upstream rather than upslope. Episodic floods may flush salts from valley bottom scalds; however, such floods contribute to scald waterlogging and many salt scalds have been identified by farmers as being initiated or expanding in areal extent after particularly wet seasons.

PLATE 1 Salting of bottom land along a small second stream near Mundaring, Western Australia (Photo by Ian Douglas)

While the two suggested causes of salinity are in conflict, it is possible that in some areas one process occurs and in other areas the other. Nevertheless the degree of salt mobilization following clearing is dramatic. In a comparison of the chloride budgets of forested and cleared catchments of Western Australia Peck and Hurle (1973) showed that inputs and outputs of salt from forested catchments more or less balanced, but in cleared catchments the output was always at least three times the input, and in one catchment 21 times greater.

The growth of mining and woodchopping in the Darling Ranges of Western Australia is a potential cause of greater stream salinity (Conacher 1975b). It is impossible to predict the extent of the increase, if any, caused by either of these developments. If forest cover is restored quickly, the mobilization of salt will be minimized, but should exploitation expand east into lower rainfall areas, the risk of further desertification through salt scalding will be increased, not to mention the impact of salinity on urban water supplies for Perth and country towns. Salinity near the most densely settled parts of Western Australia has thus become a crucial land use problem.

PLATE 2 Expanding salt scald leading to death of tree vegetation and stream erosion near Mundaring, Western Australia (Photo by Ian Douglas).

CONCLUSION

The much greater extent of the Australian arid zone in past dry periods has left a legacy of relict desert landforms and salt accumulations. Clearing and exploitation of land on present arid zone margins has altered the hydrologic cycle and conditions similar to those of past dry periods may be re-created. Stabilized, vegetated dunes may again become mobile, relict salt may be reconcentrated creating salt scalds and erosion may strip off surface soil leaving an environment unfavorable for seed germination. The costs of trends towards desertification are arising. In 1971 annual production loss due to salinity in Victoria was estimated at $A5 million. Costs in other states are probably approaching this order of magnitude.

The delicate balance between environmental and economic factors which determines the success or failure of Australian agriculture is also the equilibrium which will determine the extent of desertification. In 1967 Donald wrote that since 1945 the economic climate had favored investment in agriculture. Such investment had mitigated against the effects of the mid-1960s drought. Since 1970 economic conditions have generally been unfavorable for the pastoral industry but rainfalls often have been good. If both drought and economic instability came together, the resulting lack of investment in land management could see an increase in the rate of desertification in Australia.

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DESERT REPAIRED IN SOUTHEASTERN OREGON:

A CASE STUDY IN RANGE MANAGEMENT

by

Harold F. Heady*

and

James W. Bartolome**

This report briefly evaluates a large-scale rangeland rehabilitation program in the Vale, Oregon, District of the Bureau of Land Management (BLM). Our objectives are to make the lessons of this program generally available and to present a large practical example of successful repair of deteriorated rangeland. In the context of the United Nations Environment Programme on desertification it is a case study of anti- or de-desertification. Support for the study came from the U.S. Bureau of Land Management and the U.S. Forest Service.

Site Characteristics

The Vale District forms a rough rectangle approximately 100 kilometers east-west by 280 kilometers north-south in the southeastern corner of Oregon. The area is approximately 2.6 million hectares of which 75 percent is public land administered by BLM. Elevations range from 600 to 2400 meters. A rolling lava plateau, extensively dissected into canyons, dominates the land form. Most of the soils developed from basalt or rhyolite.

The district has 175-300 millimeters average annual precipitation with greater amounts on small areas of high elevation. It is a continental-type cold desert with winter precipitation and a short growing season ending when soil moisture becomes exhausted about mid-July. Little yearlong surface water exists in the district, except that contained in the Malheur and Owyhee Rivers and their major tributaries.

*Associate Dean and **Associate Specialist, College of Natural Resources, University of California, Berkeley

The vegetation on 90 percent or more of the district is dominated by big sagebrush (*Artemisia tridentata*). It associates with juniper (*Juniperus occidentalis*) at high elevations and with saltbush (*Atriplex* spp.) at low elevations. The major native grasses include mostly perennial bunchgrasses: bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), Sandberg's bluegrass (*Poa secunda*), and squirreltail (*Sitanion hystrix*).

Grazing History

Early trappers, Donald MacKenzie in 1818 and Peter Skene Ogden in 1824-1829, brought horses to the district; this was the beginning of about 150 years of livestock grazing. The Oregon Trail was opened across the northeast corner of the district in 1843, resulting in local overgrazing near Vale shortly afterwards. Following gold discovery in Jordan Creek in 1863, populations of people and livestock increased rapidly. Many thousands of cattle were trailed eastward from this region to the Great Plains between 1876 to 1882. Sheep reached their largest numbers in the 1920s and horses only a few years later. Overgrazing became widespread about 1880 and continued for more than 50 years. While most of us look back in horror at the destructive land use, we should keep in mind that land use decisions— by the Supreme Court, by Congress in passing the Homestead Laws, by the granting of alternate land sections for road building, and by a general attitude for "opening the West" — encouraged destructive use. The whole of the U.S. population should take its share of blame and now do its part in land rehabilitation. The first step toward repairing the vegetation and soil on the Public Domain lands came with passage of the Taylor Grazing Act in 1934, including regulations to control livestock numbers. The Vale District rehabilitation program, supported by Congressional appropriations, was a special effort between 1962 and 1973 to speed range recovery by use of all feasible techniques.

Changes in Ground Cover

Before we describe the program in detail, an additional description of vegetational conditions needs to be made. The original shrub cover, mostly sagebrush, probably was no more than 25 percent. Wildfires and competition with grasses prevented dense stands of sagebrush from developing. Native perennial grasses undoubtedly grew between the bushes and under them. Overgrazing first killed the grasses in the open, then, after fires removed the sagebrush, most of the remaining grasses were destroyed. Fortunately this process was not complete. Palatable forage species remained in places inaccessible to animals and on large areas where little or no drinking water existed. By 1900 and until 1920 the Vale District was characterized by large areas of bare soil and monocultures of sagebrush with little cover of other kinds of plants (Fig. 1).

The first trend toward re-establishment of cover was the unplanned invasion by cheatgrass (*Bromus tectorum*) about 1920. An arrival from Europe, it first became a common weed of roadsides and fields about 1915. Cheatgrass filled the interspaces between the sagebrush plants and reduced erosion, but it furnished little forage. This condition still persisted in 1962-1964 when a range survey was made of the Vale District. The cheatgrass also furnished a flash fuel which favored wildfires. Vegetation on burned areas became cheatgrass alone, without sagebrush. The survey determined that less than one percent of the District had excellent condition range in 1963.

Fig. 1: This thick stand of big sagebrush on the Vale District has considerable bare ground among the bushes.

The Rehabilitation Program

Several factors contributed to the establishment of the Vale rehabilitation program. The 1950s marked the end of major legal actions to delay changes in the management programs by Federal range users. The general public of the United States was beginning to emphasize conservation. Federal legislators responded to local needs in this particular district. The proposal, as written by BLM personnel, was realistic and immediately enlisted enthusiastic local support. The proposal passed through Congress in 1962, followed by an appropriation of $2 million for the first two years of rangeland rehabilitation. While the total proposed budget for seven years was $16.2 million, less than that was spent over a period of 11 years. We have not been able to separate the extra funds for the program from normal appropriations for the BLM District. Neither could the normal work and extra projects be separated. Therefore the cost of the Vale rehabilitation program alone is unknown but probably lies between $10 and $12 million.

Land treatment projects between 1962 and 1973 numbered 154. They included the following treatments and acreages:

	Number	Hectares in 1,000s
Plow and seed	68	66
Spray	55	116
Spray and seed	14	21
Wildfire rehabilitation	13	14
Seed only	2	2
Re-seed	2	1
Total	154	220

These projects range in size from 113 to over 8,000 hectares, averaging about 1,450 hectares. Projects covered less than 10 percent of the total district. Over 20,000 hectares were treated in several of the project years. Lessons learned during the first projects contributed to improved effectiveness in later projects. For example, spray formulas were improved, sites were chosen more selectively for treatments, wildlife habitats were given greater recognition, and test plot failures provided information that revised approaches to projects or even caused some of them to be cancelled.

Improved livestock management was a highly important part of this range rehabilitation program. Construction included more than 3,000 kilometers of fence, 28 deep wells with storage tanks and 713 kilometers of pipeline, 574 small reservoirs, 429 spring developments, 360 cattleguards, and over 800 kilometers of roads. All of these accomplishments were made effective in land management by detailed planning and revision of plans as the users required. Written management plans have been completed for 30 allotments and all the remaining land is grazed under seasonal plans less formally agreed to by permittees and BLM. Multiple use was a principle employed from the beginning, although the major user was the livestock industry. Let us summarize the benefits from this large and highly successful program.

Benefits of the Program

Estimates by BLM personnel and by us suggest that the grazing capacity for livestock has doubled. While this is not based upon survey and plot measurements, the real increase may be more or less than the estimate. Actual permitted stocking did not decrease early in the program nor has it increased greatly in recent years. This resulted in maintenance of ground cover and an accumulation of plant litter on the soil surface. Erosion from the district hardly exists. During close to three months of field surveying we found no gullies that did not show evidence of healing. Plants were growing in the gully bottoms and soil was accumulating there (Fig. 2).

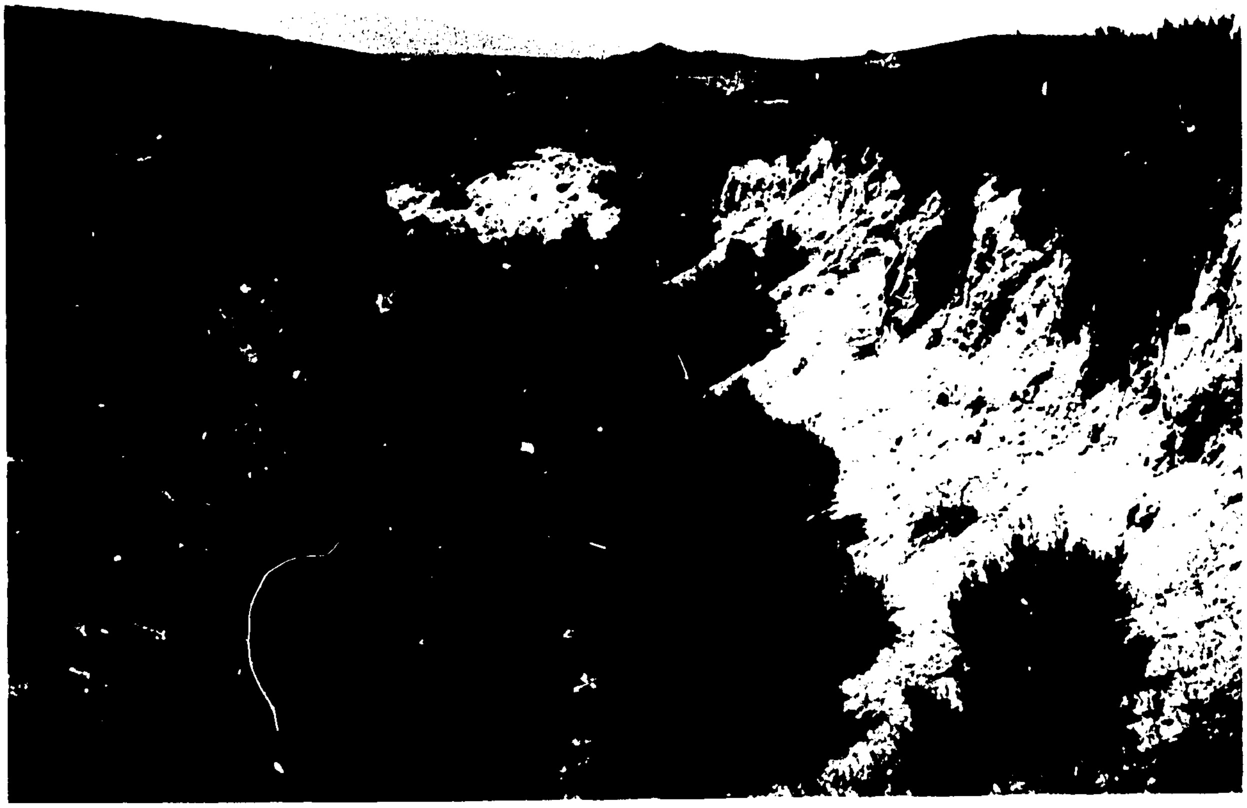

Fig. 2: Big sagebrush plants about 10 years old growing in a gully bottom and helping to stabilize it.

Crested wheatgrass (Agropyron cristatum and A. desertorum) stands vary greatly in density but few of them were complete, that is, with more than 3 plants per square yard, which reduced cheatgrass density. On plow-and-seed and on most of the spray-and-seed projects sagebrush is present today. Fire following spraying removes sagebrush completely. Criticism that large blocks of crested wheatgrass result in monocultures are unfounded in this district (Fig. 3).

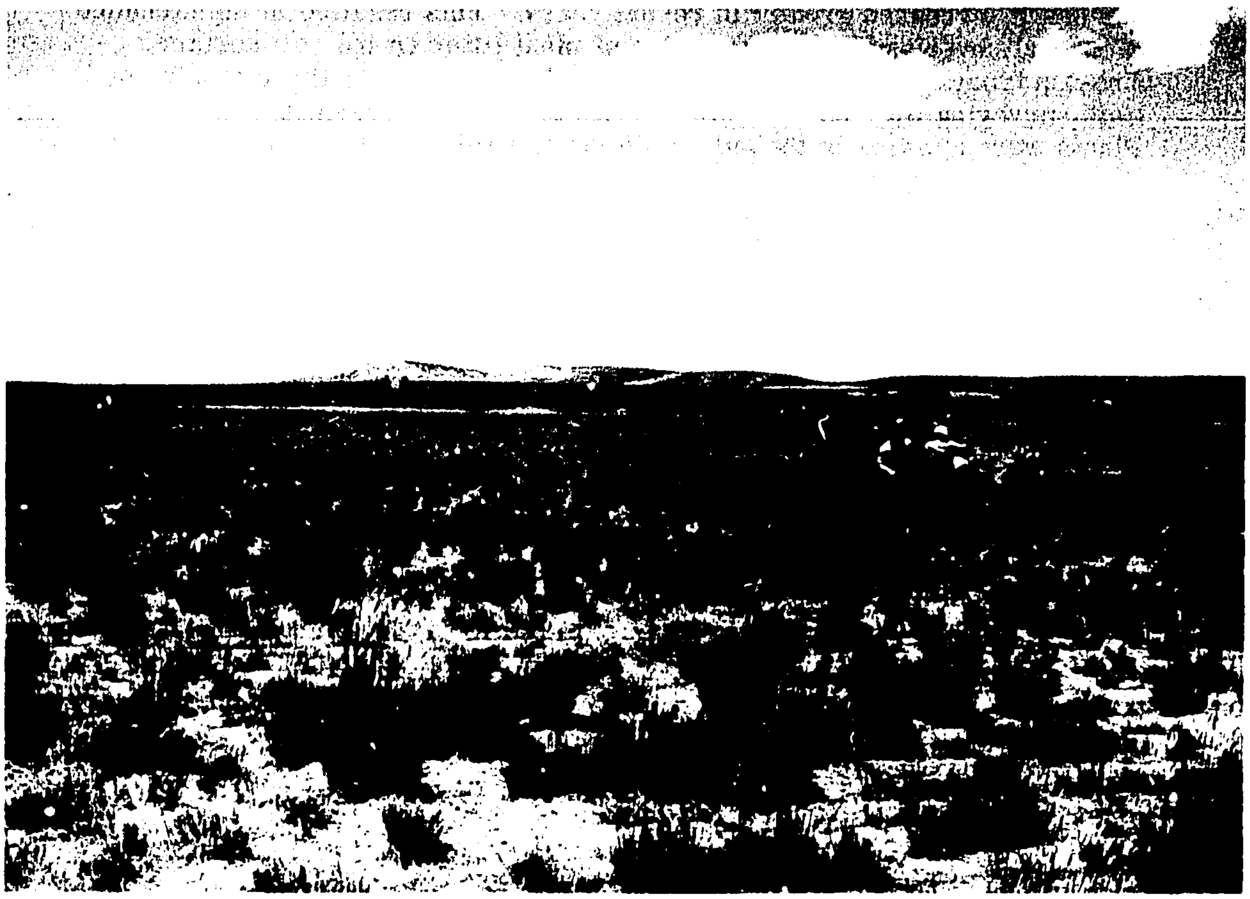

Fig. 3: Many small sagebrush plants grow in this grazed stand of crested wheatgrass.

The 111,000 hectares of sagebrush spraying opened the cover which permitted bluebunch wheatgrass and other native perennials to increase in density. As in the crested wheatgrass seedings the kill of brush was not complete. The additional grass in the project areas reduced the grazing pressure on untreated sites resulting in improved range condition. Thus, intensive manipulation of about 10 percent of the land area promoted favorable vegetational changes on the untreated 90 percent. A few areas near villages still need considerable vegetational repair. Perhaps as much as 50 percent of the sagebrush-grass range is in good or excellent condition and the trend on nearly all the land is toward better cover than now exists. We foresee that climax cover, both seeded to crested wheatgrass and untreated, will be less than 25 percent sagebrush and at least 75 percent perennial grasses without bare soil between the bushes (Fig. 4).

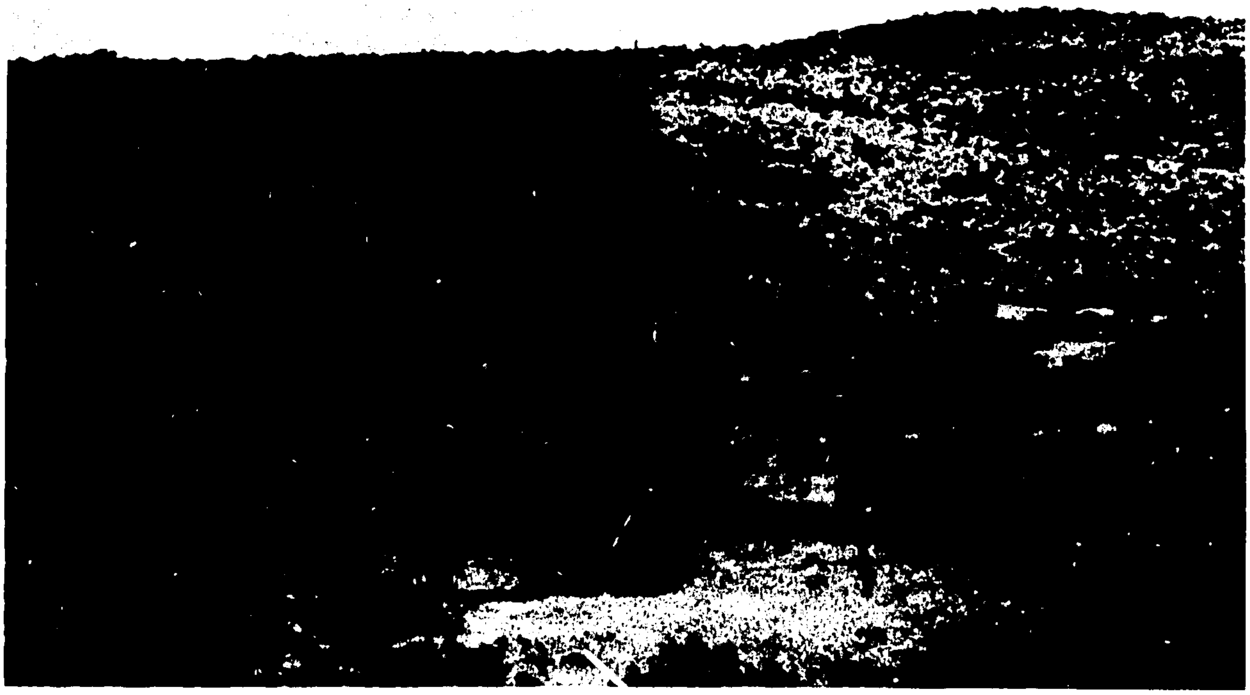

Fig. 4: To the left of the fence is a mixed stand of big sagebrush and rabbitbrush. Native bunch grasses dominate on the right where spraying has killed the brush and management has permitted range improvement.

Practices to favor wild animals have included 19,000 hectares of legume seeding, 800 hectares of browse seeding, deep reservoirs for fish, goose nesting sites, watering points protected from livestock grazing, fenced reservoirs, and special fence designs. Some 11 of the originally planned projects were eliminated because of probable damage to browse. One might argue by hindsight that too little has been done for wildlife in this project, but land management decisions and practices have increasingly considered wildlife throughout the life of the Vale program, in response to increasing public emphasis on wildlife.

Good data on wildlife numbers before the program started up and to the present do not exist for the Vale District. The early trappers and their parties found few large game animals and resorted to eating horsemeat on several occasions. Except for a decline in deer numbers, which

Fig. 5: A chukar partridge in excellent cover of big sagebrush, grasses, and forbs.

is similar to declines in many other deer herds in the western states, most local observers believe that wild species have increased or have been little affected by the range rehabilitation program. Perhaps the deer decline is not so great in the district as elsewhere as they still abound near meadows and hayfields. Less brush and more grass than in 1963 has favored antelope. Sage grouse numbers seem about the same and large areas support chukar partridge (Fig. 5). A stocking of 17 rocky mountain sheep in 1967 has increased to over 100 animals. Although significant increases in numbers of wildlife cannot be proved, neither can it be shown conclusively that numbers have decreased because of the program, except perhaps for the collared lizard which prefers sizable areas of bare ground.

Wild horses continually cause concern for their preservation and at the same time for protection of their habitats. The Vale District has about 2,500 head in 13 herds on 365,000 hectares. They continually expand beyond their designated areas, break fences, and cause erosion by trailing and pawing dust-bath areas. Their natural increase will soon result in overgrazed conditions. One herd, by annual counts, has increased at 21 to 24 percent per year for 4 years. Management of the horses and their habitats to prevent overgrazing is an unsolved problem within this district due to the present national social and political pressures to protect the herds (Fig. 6).

Fig. 6: Wild horses on the Vale, BLM District.

Many persons have asked: "Is the investment in this program worthwhile and will it pay?" This question cannot be answered with certainty because value judgments and evaluation of extra-market products are confusing factors. If the increased AUMs of grazing were valued at $1.51 each, the current price to permittees, the annual increased income would be about $300,000. At 5 percent interest, that amortizes to about $6 million, much less than the investment in the program. Other standards, such as a Federal AUM value at $3, as it is by private appraisers, or a different interest rate would improve the benefit/cost ratio, and show that increased forage for livestock will pay the whole bill for rehabilitation.

However, other values must be recognized. Landscape destruction from 1863 to 1934 was fostered by the social and economic forces of the time; therefore, the whole nation should assume a part of the rehabilitation cost. The Vale rehabilitation program has a national value. Campgrounds, roads to new sites used by rock hounds, use by hunters and off-road-vehicle travel, are benefits without fees. The construction of campgrounds, new roads, maps, cattleguards, and the like in the program facilitates these uses. A lower rate of erosion and sedimentation into the Owyhee Reservoir because of increased vegetational cover certainly is an unmeasured benefit to farmers on private land, which improves the benefit/cost ratio of the program. Continued and stable uses of the land bring outside money into the community, BLM's operating budget included, which may be transferred two or three times in the market place. All of these values, when added together, make the Vale rehabilitation program highly worthwhile, whether or not a specific set of calculations shows a dollar profit.

Summary

Several key ecological lessons in rangeland management have been strengthened during this program. They are given as a summary statement and as suggestions for other programs that might be contemplated.

1. Carefully appraised sites furnished a basis for selection of project areas and contributed to the success of the program. Experienced field men used common sense and principal indicators such as soil depth and vigor of plants to select project areas. They could not wait for the results of intensive surveys and their success shows that practical people can make practical decisions.

2. Mistakes in the first projects served as lessons to improve the later projects. The 2,4-D spray base was changed from diesel oil to water; the presence of remnant perennial grasses resulted in less plowing and seeding and more use of spraying as the program developed; and above all, contracts were monitored to insure compliance.

3. Native perennial bunchgrasses returned much more quickly than anyone suspected they would. After completion of a few projects, it became clear that the key forage plants were highly resilient. Given a chance, they responded by naturally seeding in the bare areas and by increased growth of each plant. This has been our experience in other places so we believe that nearly all of our depleted rangeland has high potential for improvement under reasonable livestock management. A desirable perennial grass on each 100 square meters is enough to warrant managerial care rather than expensive brush control and seeding.

4. This program resulted in less than 10 percent of the whole district being subjected to plowing, spraying, and fire. The favorable response of the untreated 90 percent suggests that the 10 percent was sufficient to result in range improvements over the whole district. The

values obtained are more than from just the treated land. The lesson is that expensive range practices need not be placed on all the land to obtain widespread range improvement.

5. Contrary to much popular belief, plowing, spraying, and seeding increased vegetational diversity rather than initiating a monoculture of crested wheatgrass. At the beginning of the program, the most complete single species stands were wide expanses of sagebrush with little understory vegetation. Plowing, spraying, and seeding did not kill all the sagebrush and left as many as one plant per 5 to 15 square meters. Many of the present sagebrush plants are seedlings younger than the control treatments. Only where wildfire followed other treatments did large grass monocultures develop and these were largely cheatgrass. We doubt that this occurred on more than 5 percent of the treated areas.

6. Stands of perennial grasses, either seeded or native, burn less readily than stands of cheatgrass. The perennials stay longer into the dry season and the fuel arrangement is less continuous than with cheatgrass.

7. Significant increases or decreases in any species of wildlife cannot be proved as being caused by the rehabilitation program. Feral horses increasingly cause land abuse and management problems. Much more data are needed on the ideal habitats of the wild species in order for the land manager to assist in managing their numbers.

8. Lastly, site and yearly climatic patterns result in no two projects giving the same responses. Beyond that, the vegetation on every site continues to change. Plant succession proceeds toward a climax of sagebrush and grass, perhaps on a 25-75 percent basis, but many variations characterize the progression. This vegetation is always changing in response to natural factors as well as those introduced by man. The manager must be careful to claim correctly what he did or did not do. The Vale rangeland rehabilitation project has speeded the restoration of a diverse sagebrush-grass vegetation over several million hectares in southeastern Oregon without greatly altering the expected climax conditions.

April 29, 1976

DESERTIFICATION SERIES RECAP:
WHAT HAVE WE LEARNED? WHERE DO WE GO FROM HERE?

by
Patricia Paylore*

When we began this series last November, I tried to set the stage for the experts to follow. I attempted to define the process, and although several succeeding speakers came up with their own definitions, I think in essence we all said the same thing, namely that it is a process of environmental change characterized by increasing aridity and intensification of distinct geomorphological processes, desiccation and increasing salinity of soils, and a manifest degradation of vegetative cover. I pointed out that the term implied a change, whether long-term in the geologic sense, or by man's intervention. I suggested that we take care to make the distinction between desertification, a long-established and complex process of the degradation of arid lands, and drought, an occasional but natural and recurrent phenomenon in arid areas that suddenly reveals the considerable extent of this degradation and exacerbates its effect. While there may seem to be no direct causal relationship between desertification and drought, there are indirect links between both factors as their mutual interactions tend to magnify their effects on man and on arid ecosystems.

After all I have heard during these several months, I am still of the opinion that as originally stated, the concept of desertification as one requiring us to establish that threshold of damage, from whatever cause, beyond which irreversibility sets in, is the most useful framework in which to summarize what we have learned:

... <u>Dregne</u>

placed his emphasis on his own definition of desertification as "the degradation of land and soil resources by man." He believes the overriding concern worldwide is that at the very time when populations are increasing, desertification is reducing the productivity of the land through poor management, either by willful exploitation of resources, or by overuse due to pressures for survival.

Nevertheless, he expressed optimism that most desertification of which he is aware is not yet irreversible. He described the circle of cause-and effect with its consequent impact on the societies affected:

- an increasing urban population as people flee the inevitable droughts
- food shortages
- economic development hampered because of a reduction of resource productivity

He was adamant in his belief that the basic underlying necessity for coping is a committed government, one determined to focus rehabilitation efforts on the most favorable regions, on already-irrigated lands, for instance; better care of land already in use, not new irrigation schemes to bring marginal lands into use that cannot be sustained.

We call it triage.

... Smiley

expressed the view that centers of climatic regions (such as steppes, prairies, and certainly deserts) remain essentially constant for long periods of "normal" time, but where the fringes of such areas interface with neighboring regions, a constant change takes place because of meteorological dynamics, and any given climatic region can wax or wane depending on the particular change taking place. But our impatience to improve on or outwit Nature has created several situations contributing to desertification:

- damming and diverting free water in streams
- pumping from underground to irrigate crops where evaporation is so great that from 70-90 percent of the water is lost back to the atmosphere, leaving behind
- the salts and other minerals that soon destroy soil fertility

We destroy sparse vegetation and disturb the crustal surface that took centuries or even millenia to develop, then curse the blowing sand and dust, laying under the cover, which is soon redistributed by the wind. Because Nature, too, contributes to the land degradation process, each area has its own particular environmental characteristics, and these must be known and understood in detail before there can be any man-made long-lasting solution to such problems.

... Idso

reviewed recent literature on the effect of atmospheric dust and surface albedo on desertification, then described some of his own studies of the effect of duststorms in the Phoenix, Arizona, area, finding that they did indeed increase the thermal radiation, and, in relation to the length of inversions that trapped the particulates near the surface, that the soil temperature was increased, with the albedo doubling as the soil dried. Loss of vegetation, too, from whatever cause, does increase the albedo, thus doubling the rate of possible transpiration.

... McGinnies

explored the concept of plant communities undergoing desertification as a result of such perturbations as grazing, fire, vegetation removal, cultivation, and erosion. The ecological processes involve interaction of species within the plant community related to changes in habitats mainly resulting from changes in moisture conditions. The end result is an altered environment in which soil depletion and erosion play a major role. The more mesic species give way to more xeric, which in turn may be further impoverished, and so the desert creeps outward from its original locale. Whenever man enters an environment, he exerts a controlling force on the effects of all other parameters, usually to the detriment of the ecosystem.

... Matlock

prefers the term "land degradation" to desertification, by which he means the result of reduction and ultimate removal of all vegetation, an increase in the rate of runoff and reduced infiltration of surface moisture, increasing soil erosion and loss of soil fertility, and finally, formation of mobile dunes and areas of desert pavement. He talked about:

- the effect of increased stream sediment flow on reservoirs, in irrigation canals, and in municipal and industrial waterworks
- the reduced direct recharge to groundwater aquifers
- the possibility that perennial streams become ephemeral
- the loss of vegetative cover from declining water tables

He made a plea for better planning to avoid many of these problems, for recognition of the limitations of our natural resources in arid lands, and a more rational use of limited water supplies.

... Simonett

discussed land use and agricultural applications of remote sensing for resource evaluation in developing regions, using LANDSAT data to illustrate the monitoring of dune migrations. He urged us to look far ahead as more sophisticated imagery now being developed can be used for cartographic and environmental uses, to minimize the lead time between observation of a phenomenon and action to halt or reverse it.

... Bull

spoke from the viewpoint of a geomorphologist, emphasizing by means of a very innovative and creative concept the feedback mechanisms and thresholds that tend to either promote or reduce desertification.

... Hayden

developed the first of our case studies, a close examination of the Pinacate region of northwestern Sonora, in support of his belief that the archaeological evidence indicates a long-term climatic change toward its present aspect.

... Fontana

took for granted the process of desertification in our own Papaguería, in the sense that we cannot deny the physical event resulting from overgrazing, drought, and range mis-management introduced by the early Spaniards and continued by late 19th century anglos. The present-day social and economic concomitants of that biological process on modern Papagos and what is left of their desertified homeland surely has its counterpart in many comparable areas of the arid world — from which we could learn some lessons, if we but would.

... <u>Douglas</u>

pointed out that in Australia, a continent of extreme variability of rainfall and streamflow, much desertization, as he prefers to call it, has been the consequence of attempts to cope with the hazards of this variability, and to risk or gamble on good years. This advance in good years of land under programmed range management or cultivation has witnessed successful improvements in the agricultural and pastoral uses of arid areas, but the retreat during drought years leaves behind the evidences of desertization.

He criticized many representatives of developed countries for their failure to help the developing arid countries as successfully as they might have because their concept of technology transfer often proves ineffective. He pled for greater realization that the recommended way may not be the best way, for recognition that often the problems of developing countries did not exist before they were drawn into the Western economic system, for acknowledgment that techniques to which adjustments had been made through centuries operated effectively without problems. And finally he urged greater efforts at bringing skilled and capable persons <u>from</u> those areas <u>to</u> the developed countries for exposure to a variety of experiences and opportunities to observe our technology in practice, then return home to make their own adjustments based on an understanding of cultural and political realities that too often escape us.

... <u>Heady</u>

brought the case studies and the series to a close on a somewhat upbeat note, by his demonstration of the Oregon case of a desert restored. His account of a long-term attempt by the BLM, at great expense he reminded us, to devise a program for a large area in the eastern Oregon cold desert had succeeded. Whether it was for the benefit of a few or should be examined for the education it can provide us as an example is for each of us to determine for himself. He felt that in terms of conservation and preservation, for wildlife, livestock, recreational use, and general environmental enhancement for the future, it was worth its cost. He was quick to point out that to be used as a prototype, we should take account of the mistakes he readily acknowledged had been made, as well as its successes.

So here now, at the end of these seminars, we can ask ourselves "What have we learned?" Perhaps it is only because I have been more closely identified with this phenomenon for so long a time on so many fronts, interacting with so many different experts in such a variety of situations that I for one can say in answer: "Nothing new."

What did we expect? What I expected and what I think we <u>did</u> achieve was a synthesis of what was already known, with some case studies of specific environments to illustrate that knowledge in capsule. We were reminded by speaker after speaker that increasing population pressure on marginal lands degrades the area and reduces its productivity; that sophisticated technology, dependent on an infrastructure beyond the economic or technical ability of an indigenous population to sustain, may not only not improve the situation but often worsens it; that the cycle of action-and-interaction is recognizable; and finally, that there is enough blame to go around:

- ignorance
- poverty
- unresponsive governments
- political obstacles
- international paralysis, and worst of all,
- too much talk and not enough action

So, where do we go from here? All the way from outer space to a dusty waterless dunam of scraggly millet in the Sahel, and the entire spectrum of knowledge and activity in between.

Do we benefit the one by greater expenditures on the other? Will more Skylabs help us understand the dynamics of upper-air circulation as it affects the intertropical convergence zone' Will weather modification outlive its sour reputation as a military weapon, t. benefit that farmer in the Sahel? Will the legalities of the creation of weather paralyze the whole science of environmental manipulation?

Will the remarks of the Director General of FAO in South America this spring, as reported in a UPI dispatch — that the swollen bloated bureaucracies of the great international organizations represent a poor return indeed on the billions invested in their architecture — will these foolhardy words, like our Bicentennial recollection of the shot that was, be heard around the world? Do these bureaucracies have a life of their own that cannot — or will not — be restructured to benefit those for whom they were created? Could the cost of maintaining just one of FAO's six buildings in Rome, including Mussolini's old palace, be diverted somehow to help that poor farmer in the Sahel, and by extension the millions of his fellow sufferers? Perhaps we may take heart from the subsequent action of FAO's governing council which endorsed a reform plan that calls for cutbacks in personnel, publications, and meetings [emphasis mine], and creation from savings in these areas of an $18.5 million fund for direct technical assistance to member nations, the first in FAO's history. Time will tell.

Will the United Nations' plan of action that will supposedly follow its Environmental Programme's 1977 Desertification Conference ever to executed? I sat in a penthouse meeting room at Boston's Sheraton Hotel last February with UNEP's Executive Director and heard him say angrily between clenched teeth that it must and it will, that we had talked long enough and that there must now be action. Someone attempted to interrupt him, and he burst out in annoyance, "No more talk ! Action, action, and action !"

So perhaps between him and the rashly outspoken FAO Director General we shall live to see these great international agencies do a turn-around. Dregne said he was optimistic, Matlock said he was optimistic, Simonett said he was optimistic.

But I am not optimistic.

To me, desertification is a real phenomenon, not the emotional topic that caused Matlock to prefer another term, but a process taking place continuously, measurably, relentlessly, incontestably. No matter how hard we try to define it to suit our own concepts of what is taking place, it persists in new and frightening ways. And if that is my emotional response to a physical and biological process, so be it.

Even provided we begin at once, in serious and dedicated ways on all levels everywhere, which obviously we are not, I do not believe that the several generations it will take to turn the population explosion around will give us the time we need.

CATASTROPHE is one solution to the impact of desertification on society, one that none of our speakers has offered. But it is a real one and it comes nearer each day the sun comes up
on the Sahel
the Rajasthan
the Dasht-i-Kavir
the Sechura
— or Papaguería

DISCUSSION

Q: I should like to hear you expound a little more on the solution that you indicated no one else had advanced, because I think that catastrophe again and again has been the solution for the past thousand or two years. Would you comment further?

Chair: Do you think we should just let it happen?

Reply: I think it is <u>going</u> to happen. I am not sure that if the whole world tried its utmost, it could be avoided, at lease somewhere. I think the maximum effort at this time will be no more than a delaying tactic that may save some. Let me join you on the side of not much optimism.

Chair: Do you agree with Dregne that rather than putting all our efforts on those areas that are really beyond help, we should concentrate rather on those areas where some amelioration is still possible?

Reply: Yes, I think that is the only rational workable solution to saving the greatest number in need.

Chair: Agreed. I have been outspokenly critical of government agencies for not being forceful enough in insisting that foreign countries receiving billions of aid from us should address the matter of overpopulation with seriousness and a degree of commitment lacking in many of the countries most affected.

Q. I should like to comment that we had better include consideration of the overall energy supply in any attempt to combat desertification, because just one look at the energy situation and we may be the <u>first</u> to go, and not the last !

Chair: I made a proposition about future use of deserts to the BBC with which I am beginning negotiations to produce a film on deserts of the future. I realize we cannot exclude everybody from desert areas by saying, for instance, "You can only come through once a year on a camel and see how beautiful the stars are at night," but for our projected film we have talked about the one thing we might tolerate in exploitation of deserts, namely the creation of the Meinels' solar farms, or some variation thereon, where such use could be an effective mechanism for the transmission of electrical power so generated, to areas outside the deserts proper. Would you agree that that might be an acceptable use of deserts?

Reply: I should think so. When one looks at the situation overall, there is no question that this is the ultimate solution, whether everyone likes it or not. Even though we may have as long as two hundred years before we come to the climax, long before that we are going to be in very serious trouble, no matter whether we are talking about coal or uranium or whatever. The end is just completely predictable.

Chair: And the political obstacles to be overcome when those in positions of power refuse to tell people what kind of life is ahead for us, that, like it or not, we shall be <u>obliged</u> to think small, draw in, scale down?

Reply: Problems are people problems, not technological problems.

Q: Let me comment here on "the system," here, abroad, anywhere. It seems to me that when responsible people get the feeling of inevitability, then all the hope of the less responsible is gone. I am almost worried to hear you all talking.

Chair: Perhaps we are just trying to frighten those responsible people to be more vigorous in their presentation of our global dilemmas and the uncomfortable decisions that will have to be made.

Reply: From the vantage point of history, I doubt it will work. Remember, even though the Bible says the world is going to come to an end, it has done no good. I am in agreement with you — don't misunderstand me — it's just that ... that ...

Chair: Ah, but we didn't know in those days how to bring it to an end, and now we do.

Q: As an outsider I wish to express my appreciation for this series. The impact has been startling, and your summation today, capped by your provocative theory of solution by catastrophe might have some publicity value. Perhaps the shock therapy would be more effective than more conventional presentations.

Chair: Well, let's see: Who would be mad at me ?

Q: We ought not to forget that the greatest degree of conservation through reduction of consumption must begin in the developed countries. We can't expect the LDCs who have nothing to give up part of nothing.

Chair: That's why Dregne was probably right when he said the first requisite is a committed government, one committed to advancing the level of living conditions, rather than cash crops and military hardware.

Reply: Well, desertification, though basically a biological problem, is exacerbated by intolerable population pressures. When I was in Chad some time back, it had so little money to run the government that they had to put an import tax on the grain imported for drought relief. These are hard facts most of us never have occasion to learn about, so perhaps we should be more tolerant of governments so desperate that they misplace what we believe should be their priorities.

Chair: And so we come back around, full circle. We really don't have the answers, do we?

Voice: But Mother Nature has !