

Desertification: Research Imperatives

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Abstract: This paper elaborates on the need for five major research imperatives relating to desertification. These are (a) disentangling the respective role of human activities and climatic fluctuations as causes of land degradation; (b) clarifying the causes of drought; (c) evaluating possible impacts of future climate change on desertification; (d) assessing ecological attributes and processes within different arid regions; and (e) identifying processes of 'natural desertification'.

Key words: Desertification, land degradation, climate change, drought.

Desertification was re-defined at the 'Earth Summit' United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992. The new definition specified that desertification was 'land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities' (UNCED, 1992; UNEP, 1997). The previous UN definition, still in use in the first edition of the UNEP sponsored 'World Atlas of Desertification' (UNEP, 1992), but revised in the second edition (UNEP, 1997), proposed that desertification was 'land degradation in arid, semi-arid and dry sub-humid areas resulting *mainly* from adverse human impact (UNEP, 1992, vii, *my italics*). The use of the adverb *mainly* begs the question as to the relative role of climate and humans as causal factors of desertification. Solving this conundrum remains a major research imperative (Williams and Balling, 1996; Pickup, 1996, 1998; Williams, 2002a; Dube and Pickup, 2001; Dube, 1998, 2008).

Although the Desertification Convention was duly signed by 87 nations in Paris on October 14 and 15, 1994 (Williams, 2002b), land degradation remains serious in the semi-arid and dry sub-humid margins of all our tropical and mid-latitude deserts. The full title of this convention is the 'United Nations Convention to Combat Desertification in those Countries experiencing Serious Drought and/or Desertification, particularly in Africa'. I have examined in some detail elsewhere the reasons for including 'climatic variations' in the revised definition and for the focus upon Africa (Williams, 1994, 1995a, 1995b, 2000, 2002a, 2004; Williams and Balling,

1995, 1996). The two are linked. The prolonged and widespread drought that began in 1968 along the southern margins of the Sahara in the Sahel region of West Africa and spread to over twenty African countries along a 5000 km wide transect from Mauretania in the west to Somalia and Ethiopia in the east was the catalyst. Understanding what causes such droughts is a further research imperative (Prospero and Lamb, 2003). Allied to this is the thorny question of how current changes in global climate might affect the incidence of future droughts (IPCC, 2007a).

Two other matters pertaining to research into the causes and consequences of desertification have also begun to receive attention in recent years. One is the realisation that we need a better understanding of the ecology of each of the world's arid regions, since their response to human impacts and droughts will differ from region to region (Pickup, 1998; IPCC, 2007b; Morton *et al.*, 2011). A management strategy that might work in one arid area may not be of much use in another arid area where the ecological processes are radically different (Williams, 2000, 2004; IPCC, 2007c). The second matter is best described as 'natural desertification' and has been observed in areas as far apart as Inner Mongolia in semi-arid northern China and in the Negev Desert of southern Israel (Avni, 2005; Avni *et al.*, 2006, 2010).

The aim of this overview paper is to elaborate on the need for the five major research imperatives alluded to above, namely, the humans versus climate conundrum, the causes of drought, possible impacts of future climate change on desertification, the ecological identities of arid lands, and finally,

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some hitherto unsuspected processes of 'natural desertification'. Space precludes an encyclopaedic approach to these topics, so that selective use is made of a few case studies to illustrate more general principles.

Human Activities and Climatic Fluctuations

A tricky problem in many degraded rangelands is how to separate out the effects of climatic fluctuations such as drought from those of overgrazing and indirect human modification of the vegetation communities. One useful approach to this complex issue, tested in both Australia and Botswana, is to monitor changes in land cover along selected transects starting near the main watering points where overgrazing pressure is likely to be the greatest, and to see whether plant recovery following the end of a drought returns to the same condition as in areas deemed least degraded (Pickup, 1998; Dube and Pickup, 2001). In an effort to assess plant cover across six types of terrain common in semi-arid SE Botswana, Dube (1998) used different wave bands of SPOT and Landsat imagery, but found that the variance in vegetation within a given landscape exceeded the variance in vegetation cover between different landscapes. She later developed a more precise method of estimating plant cover, in this instance woody plant density in communal and leasehold land tenure systems in semi-arid NW Botswana, using aerial photographs and a carefully devised set of protocols (Dube, 2008). These studies show the difficulties involved in gauging changes in plant cover, and also highlight the importance of taking into account differences in spatial scale. We turn now to the question of drought and plant cover.

A still unresolved problem in detecting a climatic influence upon desertification concerns the high degree of variability in the annual plant cover along the desert margins. Tucker *et al.* (1991) used remote sensing data for the period 1980-1990 in an attempt to plot the expansion and contraction of the Sahara Desert during that decade and found that there was such a high degree of variation in plant cover relative to both longitude and latitude that they were forced to conclude that ten years were too few for any meaningful trend to be discernible. Nicholson *et al.* (1990) had the previous year sought to use the Normalized Difference Vegetation Index (NDVI)

to evaluate the response to rainfall in the Sahel and East Africa. They discovered that there was a linear correlation between NDVI and mean precipitation. Tucker and Nicholson (1999) revisited this problem nearly a decade later, and claimed that the longer period of observation did enable them to detect significant trends in the response of plant cover to decadal variations in rainfall. This type of research is needed in all desert margin systems, since the response of the NDVI to annual rainfall may well vary from region to region, depending upon the different soil types and plant associations.

Causes of Drought

One cause of drought in the drier parts of the seasonally wet tropics is annual variation in the summer monsoon. These fluctuations are in part controlled by the relative temperature differences between land and sea in early summer. In the case of Asia these fluctuations are also linked to variations in the strength of the winter anticyclone over Siberia, which controls the strength of the winter monsoon and the extent of snow cover over central Asia (Diaz and Markgraf, 1992; Wang, 2006). Another major cause of inter-annual variation stems from changes in sea surface temperatures over the equatorial Pacific Ocean and adjacent Indian Ocean associated with the Southern Oscillation. Sir Gilbert Walker first recognised and defined the Southern Oscillation when he was seeking more effective ways of predicting Indian summer rainfall (Walker, 1924). The Southern Oscillation is a measure of the surface atmospheric pressure differences between the western and eastern limbs of the equatorial Pacific. Walker (1924) observed that when the pressure off the coast of Peru is below average, that at Jakarta is above average, and vice-versa. The difference is expressed as an index termed the Southern Oscillation Index (SOI), which is generally taken as the pressure difference between Tahiti in the central equatorial Pacific and Darwin in tropical northern Australia (Glantz *et al.*, 1991; Allen *et al.*, 1996; Diaz and Markgraf, 1992, 2000).

The relationships calculated by Walker (1924) have stood the test of time (Diaz and Markgraf, 1992) although they were at first criticized. When the SOI is strongly negative, droughts tend to be common in certain parts of the world and are often synchronous in regions as far apart as the

Ethiopian highlands, peninsular India, eastern China, northern Thailand, Java, NE Brazil and eastern Australia. Conversely, during years when the SOI is strongly positive, major floods are common and usually synchronous in these same regions. Peruvian fishermen have long recognized that around December in certain years the normally cold and nutrient-rich waters offshore are replaced by a tongue of warmer water and the Anchovy fisheries fail. They term these years El Niño years, and we now have a reasonably accurate record of such events spanning the last five hundred years (Diaz and Markgraf, 1992; 2000; Allen *et al.*, 1996; Whetton *et al.*, 1990; 1992; 1996; Whetton and Rutherford, 1994). Years when the waters off Peru are colder than average are termed anti-El Niño years or, more simply, La Niña years. The phrase El Niño-Southern Oscillation (or ENSO) event is a concise way of indicating a year marked by an El Niño event and a negative SOI. The two phenomena are closely related, but are not synonymous, since one refers to surface atmospheric pressure (Southern Oscillation) and the other to sea surface temperature anomalies (El Niño events).

Comparison of the five hundred year record of wet and dry years in China (Anon., 1981) and the corresponding flood record of the Nile with the updated El Niño record from Peru revealed some previously unsuspected correlations. Whetton *et al.* (1990) carried out time series analysis of rainfall and river flow in India, wet or dry years in China and corresponding values of the SOI. These authors were the first to show that in eastern China during the period 1870-1979 analyzed by them, years of strongly negative SOI coincided with a poor monsoon and below average crop yields.

In much of the peninsular India since at least the year 1871, years of severe drought are generally (but not invariably) years of strongly negative SOI. There is also good evidence that since the 1970s the links between Indian monsoonal rainfall and ENSO events have weakened (IPCC, 2007a, b), perhaps reflecting changes in the Indian Ocean Dipole (Ashok *et al.*, 2001), or perhaps reflecting the influence of warmer sea surface temperatures in the northern Indian Ocean and the Arabian Sea.

In a number of areas bordering deserts, including southern and eastern Africa, NE Brazil, New Mexico, eastern and northern

Australia, central India, and NE China, the incidence of wet and dry years is strongly influenced by the incidence of ENSO events. Many of the rivers in these areas are sensitive to small changes in rainfall, and ENSO events will amplify their already highly variable flow regimes. The sensitive hydrological response of desert rivers to global sea surface temperature anomalies is an integral part of global environmental change, and is likely to remain so in the future.

Using tree ring data from over three hundred sites across Asia, Cook *et al.* (2010) have established a very precise chronology of very severe droughts and monsoon failure in that region. Four of the worst droughts were those of 1638-1641, 1756-1768, 1790 and 1792-1796, and 1876-1877. There are two matters of particular interest concerning the timing of these droughts. The first is that these severe droughts seem to be synchronous with droughts of similar magnitude in the drier regions of N America (Wahl and Morrill, 2010). The second is that each of these drought intervals coincides with times when the volcanic dust veil index (DVI) was high in the northern middle and high latitudes (Lamb, 1970).

Less well documented is the impact of eruptions upon sea surface temperatures and upon sea level fluctuations (Cazenave, 2005), with the ocean cooling persisting in some cases for decades (Gleckler *et al.*, 2006). In this context, it is interesting to note that Trenberth and Dai (2007) recorded several decades of drought in SE Asia following the June 1991 Pinatubo eruption. They attributed the drought to a regional weakening of the hydrological cycle caused by cooling engendered by the eruption. A growing body of evidence also now suggests a causal relationship between historic eruptions and El Niño events, resulting in sea surface temperature anomalies of near global extent (Adams *et al.*, 2003; de Silva, 2003). Droughts are strongly controlled by changes in sea surface temperature (Lamb and Pepler, 1992; Williams and Balling, 1996), so that another possible mechanism for prolonging the initial reduction in precipitation following an eruption (Parker *et al.*, 1996; Trenberth and Dai, 2007) is cooling of the ocean surface, which can last for many decades following the initial eruption (Gleckler *et al.*, 2006).

Possible Impacts of Future Climate Change

Several important conclusions can be drawn from the work summarised in the previous section. First, the correlations between different localities, although statistically significant, do not account for all of the year-to-year variation in the strength of the summer monsoon, but do account for a modestly important part of the inter-annual rainfall variability. Second, at periodic intervals, for reasons we still do not understand, the spatial pattern of variation changes quite abruptly, so that two localities that were previously in phase suddenly cease to be so. A corollary to this is that future changes in the links between floods, droughts and ENSO events are to be expected and may offer surprises. Both of these conclusions accord with the views expressed throughout the three latest IPCC reports (IPCC, 2007a, b, c).

An important recent study by Power and Smith (2007), published after the three IPCC reports (IPCC, 2007a, b, c), has revealed that during 1977-2006, average values of the June-December SOI were the lowest on record, indicating a weakening of the Walker Circulation. At the same time, mean sea-level atmospheric pressure at Darwin was the highest recorded, equatorial surface wind-stresses were at their weakest, and tropical sea surface temperatures were the highest on record. They concluded that we need to take global warming into account in defining new ENSO indices, and in assessing and using statistical correlations between ENSO events and climatic variations across the globe.

Those areas now most vulnerable to inter-annual climatic variability will continue to be the arid and semi-arid areas, but the seasonally wet tropics and the dry sub-humid regions that now receive 1500-750 mm of rain a year will become increasingly sensitive to future changes in temperature, evaporation and precipitation.

The impact of future global warming upon El Niño-Southern Oscillation (ENSO) events remains unclear, although there are signs that previously stable patterns of correlation between ENSO and floods or droughts in the Asia-Pacific region may be changing. It is also not yet clear whether the increase in carbon particles in the lower atmosphere arising from biomass burning and use of fossil fuels is leading to increasing

desiccation of northern China and increasing flooding in the south (Menon *et al.*, 2002).

At present, the past offers us some valuable guidance as to which regions of the world are most influenced by ENSO, and this is unlikely to change very significantly in the future. Indeed, the IPCC noted that they were not able to predict likely future changes in the magnitude and frequency of ENSO events and were unable to discern any significant change in the pattern of such events in space and time since observational records became available (IPCC, 2007a).

Ecology of Arid Lands

Over twenty years ago, Stafford Smith and Morton (1990) attempted to synthesize the main ecological attributes of the Australian arid zone. Two decades later, Morton *et al.* (2011) revisited this topic, and proposed a new framework for the ecology of arid Australia, in which they put forward 14 testable propositions, summarized below.

- (a) Rainfall is especially unpredictable in Australia's arid zone**.
- (b) Big rains structure ecosystems*.
- (c) An infertile, well-sorted landscape*.
- (d) Soil moisture shapes the spectrum of plant life-history strategies*.
- (e) Fertility controls digestibility.
- (f) Carbohydrate is plentiful**.
- (g) Fire is a powerful influence**.
- (h) On poorer soils herbivorous and detritivorous consumers are constrained both by indigestibility and irregularity of production*.
- (i) On more fertile soils herbivorous and detritivorous consumers are constrained principally by irregularity of production.
- (j) Consumers of plant exudates are prominent**.
- (k) Assemblages of higher-order consumers reflect infertility and irregularity of production*.
- (l) Some consumers exhibit dramatic opportunism in response to irregularity of production*.

- (m) Consumer assemblages display underpinning stability within their dynamism.
- (n) Long-standing feedbacks between humans and environmental structure and function.

No asterisk means that these features are commonly observed in most deserts. One asterisk means commonly observed in all deserts, but expressed in a characteristic manner in Australia. Two asterisks means rarely seen in other deserts to the same degree. Hence, only four of the propositions are deemed to be universal in all arid lands, namely, (e), (i), (m) and (n). Four are considered different in the Australian arid zone to all other deserts, namely, (a), (f), (g) and (j). The remaining six, namely, (b), (c), (d), (h), (k) and (l) are all considered to have a characteristic expression within the Australian arid zone.

If these fourteen propositions are broadly correct, it follows that no single set of management strategies can be applied to all arid areas. Fundamentally, desertification is about loss of plant and animal productivity, so that efforts to deal with desertification must be fully adapted to local conditions (Williams *et al.*, 1995; Pickup, 1998), an obvious point, but one that is all too often ignored or forgotten.

Natural Desertification

Gully erosion is often considered one of the more obvious signs of accelerated soil loss brought about by human mismanagement. However, in a number of instances the gullies were already active along the valley floors well before humans had occupied those valleys. For example, Avni and his co-workers monitored a number of gullied valleys in the semi-arid Chifeng region of Inner Mongolia (northern China) and in the Negev Highlands of southern Israel (Avni, 2005; Avni *et al.*, 2006; 2010). They found that initial deposition of wind-blown desert dust (loess) across the hills and valley sides between about 70000 and 15000 year ago was followed by erosion and re-deposition of the valley side loess mantles and their subsequent accumulation in alluvial fans and valley-fills. A change in rainfall intensity and a reduction in dust influx some 15000 year ago triggered a change from reworked loess accumulation along the valley floors to vertical erosion and gully incision. Thereafter the gully network extended up-valley through a combination of

headwall erosion and some lateral erosion from bank collapse, leading to a loss of potentially valuable soil for cultivation and plant cover for grazing. The key factor here was the progressive exposure of bedrock surfaces along the valley sides and the ensuing increase in runoff and its capture by the expanding gully system.

In one instance in the Negev, two valleys of similar size and geology were compared, since one had been farmed in medieval times over a thousand years ago and the other had not (Avni *et al.*, 2006). The stone terraces constructed by the early Byzantine farmers in the cultivated valley had helped to trap several metres of colluvial-alluvial loess and gravel, and where these structures had survived undamaged, those parts of the valley were still cultivated by the local Beduin herders.

The methodology used in these carefully devised studies is relatively straightforward and could profitably be applied more widely. The first step is to date the valley fills using a combination of radiocarbon and luminescence dating methods allied to detailed mapping and logging of the main landforms and stratigraphic units. This allows the timing of the change from a regime dominated by loess and alluvial loess deposition to one of erosion to be determined reasonably accurately and compared with the archaeological evidence of human settlement in the region. A further by-product of this approach is that it allows rates of sedimentation to be determined for different intervals of time, together with quantitative estimates of the rates of gully headwall retreat.

The conclusion from each of the three studies is that land degradation caused by gully erosion is indeed contributing to desertification, but was not in any way brought about by human actions. On the contrary, well designed and properly maintained soil and water conservation measures helped to arrest the process in part of one valley for over a thousand years, indicating that human actions can be both beneficial and enduring.

Recommendations in Regard to Desertification

In order to place this work into its historical context, I conclude by summarising the ten recommendations proposed by Williams and Balling and accepted by the Expert Panel on

Desertification at the November 1993 meeting convened by WMO and UNEP (Williams, 1995; Williams and Balling, 1995; 1996, pp. 217-219).

Adoption of uniform criteria and methods to assess desertification

Recognising the variable quality of the data relating to the extent, severity and trends of desertification processes in different parts of the world, we recommend that greater urgency be given to the adoption of uniform criteria and methodologies to assess and delineate dryland degradation.

Establishment of regional training centres to monitor dryland degradation

Further to the need for uniform assessment and mapping of degraded drylands, we recommend that an integral part of capacity-building in these areas should be to strengthen existing regional facilities and establish international training centres at regional levels, for imparting training and for implementing regional programmes to assess the status and extent of dryland degradation.

Identification of sources and sinks of dryland carbon

An important factor relating to interactions between desertification and climate concerns the role of dryland soils and plant communities as sources or sinks of organic and inorganic carbon. We recommend that greater efforts be made to quantify the biogeochemical cycling of dryland carbon using a combination of field monitoring and applicable geophysical models.

Identification of sources and sinks of aerosols and trace gases in drylands

Drylands represent important sources of trace gases, dust and other particulates associated with a variety of human activities, including devgetation and biomass burning. We recommend that substantial effort be devoted to evaluating dryland sources and sinks of various particles and trace gases. Such baseline data are essential in evaluating the potential impact on climate of dryland rehabilitation projects.

Evaluation of dryland rehabilitation projects

The long-term sustainability of many apparently successful dryland rehabilitation

projects is often poorly understood. We recommend that a cost-benefit appraisal of successful projects include long-term ecologically sustainable principles, rather than short-term and purely economic criteria.

Enhancement of regional climate monitoring networks

Given the paucity of primary meteorological, agro-meteorological and hydrological data for many dryland areas, we recommend that national and regional climate monitoring networks be strengthened and expanded in all dryland regions, and that the important role of existing regional drought-monitoring centres be recognised through appropriate funding arrangements.

Coupling of numerical modelling studies with empirical field measurements

Our understanding of the climate impact of human activities in drylands has often been based predominantly on separate numerical model sensitivity studies and empirical measurements made in field experiments. We recommend that research programmes be encouraged which combine these two approaches. Sensitivity studies can become more realistic simulation efforts, given realistic inputs regarding surface characteristics and fluxes, atmospheric composition, and other meteorological and climatological information. Combining the two approaches should yield more information on the processes which govern climate response to human activities in drylands.

Assessment of biogeophysical models of Sahelian drought

Interactions between devegetation, albedo changes and Sahelian rainfall have been a focus of scientific enquiry since the publication of Charney's biogeophysical feedback hypothesis in 1975 (Charney *et al.*, 1975). However, many of the conclusions remain equivocal. We therefore recommend that numerical simulation using realistic values of albedo, surface roughness and plant cover be used specifically to test the possible impact of changes in dryland surface cover on local and regional climates in the Sahel as well as elsewhere.

Application of seasonal forecasting in dryland management

Given the recent advances in using ocean-basin and global sea-surface temperature anomalies to predict seasonal precipitation, river flow, crop yield and possible disease outbreaks in specific dryland areas, we recommend that greater efforts be encouraged to exchange information between different dryland forecasting centres as to the appropriate methodologies for using forecast information to enhance regional dryland management.

Provision of natural resources information to local communities

Recognising the power of integrated remote sensing, Geographical Information Systems and other systems in cataloguing and evaluating natural resources data from drylands, we recommend that greater efforts be made to provide information in an accessible and usable form to local farming and pastoral communities. The regional centres discussed in previous recommendations would be appropriate vehicles for providing such information to local communities.

Given the lack of discernible progress over the past two decades in implementing these recommendations, especially in much of Africa, central Asia and South America, it is hard to resist the conclusion that these recommendations and research imperatives remain as valid today as they were when first enunciated in November 1993. Among the reasons for this lack of progress is a lack of political will, rigid land use laws, social instability and unrest, war, famine, and lack of infrastructure, social capital and trained personnel in many of the poorer dryland nations.

Conclusions

Nearly twenty years have elapsed since 87 countries signed the Desertification Convention in Paris on 14-15th October 1994. A year earlier, in November 1993, Williams and Balling presented a report on 'Interactions of Desertification and Climate' to the intergovernmental committee responsible for negotiating the convention on desertification at a meeting in Geneva convened by WMO and UNEP (Williams and Balling, 1995; 1996). This report contained ten recommendations, five of which were specific

research imperatives. The UN negotiating committee unanimously endorsed each one. These recommendations remain as valid today as they were when first proposed.

During the past decade it has become increasingly clear that there are five key research imperatives relating to desertification. These are (a) disentangling the respective role of human activities and climatic fluctuations as causes of land degradation; (b) clarifying the causes of drought; (c) evaluating possible impacts of future climate change on desertification; (d) assessing ecological attributes and processes within different of arid regions; and (e) identifying processes of 'natural desertification'. The first two research imperatives are perennial issues and have been the subject of past research, but the last three have received less attention than they deserve.

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