

## Desertification in Africa, Asia and Australia: Human Impact or Climatic Variability?

Martin Williams

*Geographical and Environmental Studies; University of Adelaide, Adelaide, South Australia 5005, Australia*

**Abstract:** Desertification is currently defined as: 'land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities' (UNEP, 1992). This definition highlights how difficult it can be to distinguish between the relative influence of climatic variations and human activities when assessing the causes of desertification. Examples drawn from Africa, Asia and Australia show that land degradation in dry areas is often far more complex than is first apparent and that great care is needed when attributing probable causes. Sustainable land use in such regions is possible provided some fundamental prerequisites are accepted and implemented by the societies concerned.

**Key words:** Australia, China, climatic variations, deforestation, desertification, drought, dunes, dust, ENSO, Ethiopia, feedback mechanisms, Niger, overgrazing, reservoir sedimentation, Sahel, salinity, Sudan, sustainable land use.

This overview draws heavily upon earlier more detailed reviews by the author, especially Williams (2000, 2002, 2003) and the volume by Williams and Balling (1996). Since *Progress in Environmental Science* proved a sadly short-lived and therefore unread journal, I have used some of the material already published there (Williams, 2000), suitably condensed and updated.

Interactions between human societies and the environment, of which they are an integral part, are complex and hard to unravel. Separating cause from effect can be especially difficult when the effect may only become apparent many years after the initial cause. Nowhere is this dilemma more starkly evident than in the discourse relating to land degradation in the drier regions of the world. The continuing debate in Africa, Asia and Australia over the precise causes of such

land degradation or desertification is part of a global debate. For over thirty years there has been considerable discussion over the causes of desertification and over the most appropriate remedial or preventative measures to adopt (UNEP, 1992; Thomas and Middleton, 1994; Williams and Balling, 1996; Williams, 2000, 2002, 2003). Until quite recently the internationally accepted definition of desertification was: 'land degradation in arid, semi-arid and dry sub-humid areas resulting mainly from adverse human impact' (UNEP, 1992, vii, 8). The emphasis on 'adverse human impact' seriously underplayed the importance of climatic desiccation or prolonged droughts as significant contributors to dryland degradation. 'Land degradation' refers to a decline in the ability of the land to support life and is evident in terms of a decline in soil nutrients, a breakdown of soil structure or soil aggregate stability

Table 1. Some consequences of desertification (after Kassas, 1995; Williams and Balling, 1996)

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- Accelerated soil erosion by wind and water
  - Salt accumulation in surface horizons of soils
  - Decline in soil structural stability
  - Increase in surface crusting and surface runoff
  - Reduction in soil infiltration capacity and soil moisture storage
  - Replacement of forest or woodland by savanna grassland or scrub
  - Reduction in species diversity and plant biomass in ecosystems
  - Increase in flow variability of rivers and streams
  - Increase in salt content of previously fresh lakes, wetlands and rivers
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and a reduction in the ability of the soil to store and transmit water (Table 1).

The 1968-74 drought in the Sahel region of West Africa prompted a renewal of world interest in drought as a significant factor in environmental degradation in Africa and elsewhere. (The Sahel region lies between the Sahara desert and the West African forest). The role of climatic variability was clearly recognized at the Conference on Environment and Development held in Rio de Janeiro in June 1992. Desertification was redefined as: 'land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities' (UNCED, 1992). This compromise definition might appear too vague to be of practical use, but it does leave open the question of causes, and therefore of the most appropriate mitigation and rehabilitation strategies to adopt in dealing with desertification (Williams and Balling, 1996, chapter 9).

One enduring debate concerns the nature of the interactions between climate, humans and desertification (Tucker and Nicholson,

1999; Verschuren *et al.*, 2000). As often happens, the debate has unfortunately become polarized (Williams, 2002; Zeng, 2003). One school of thought advocates no role for human activities as agents of drought; the other maintains that overgrazing could alter surface albedo sufficiently to reduce summer precipitation and accentuate or prolong drought. There is certainly very good evidence that Saharan dust transport across the Atlantic increases in the year following below average Sahel rain (Prospero and Lamb, 2003). There is equally compelling evidence that sea surface temperatures around Africa control Sahel rainfall at scales ranging from interannual to interdecadal (Giannini *et al.*, 2003). However, what has now been demonstrated for the first time is that feedback mechanisms involving human activities do influence the natural land-atmosphere interactions in such a way as to amplify rainfall anomalies in the Sahel (Giannini *et al.*, 2003; Zeng, 2003).

The purpose of this article is to explore a variety of human and non-human causal factors that may lead to actual or apparent land degradation, using selected examples

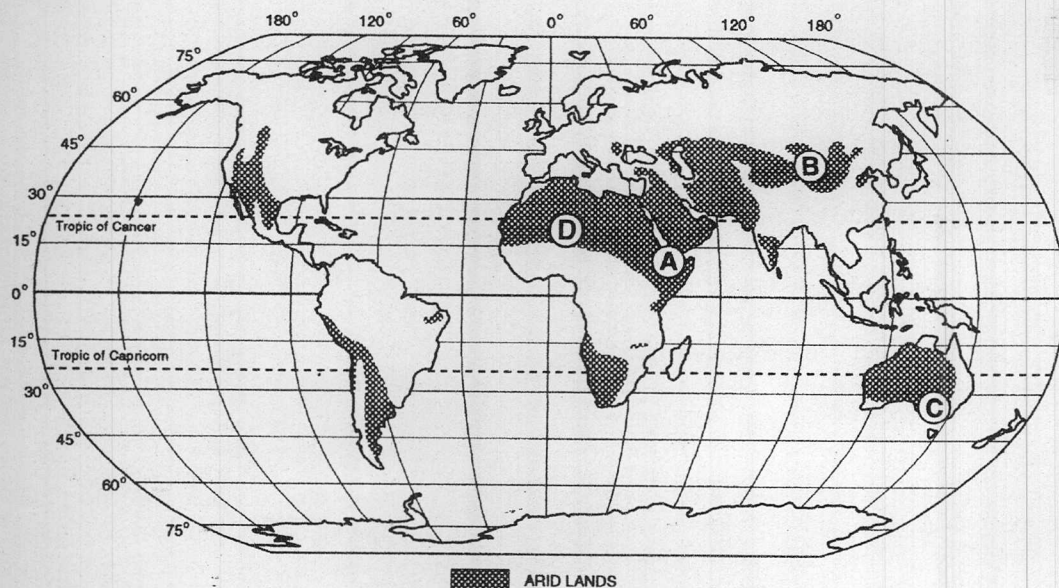


Fig. 1. Distribution of arid and semi-arid regions of the world, with location of four of the case studies. A is the Ethiopian highlands; B is the Alashan plateau, Inner Mongolia Autonomous Region, China; C is the Murray-Darling basin, Australia; D is the Wadi Azouak area in Niger.

drawn from Africa, Asia and Australia (Fig. 1). The examples chosen are all ones with which the author is directly familiar, and so may suffer from being unduly restricted in time and space. The opening discussion of gully erosion in parts of Africa and Australia shows that certain instances of accelerated erosion apparently triggered by human mismanagement may have little to do with human actions. In contrast, the clearing of native vegetation in parts of northern China, southern Australia and upland Ethiopia can be clearly slated to human action and has had adverse repercussions well beyond the immediate area affected, some of them decades later and only belatedly recognized. Certain prerequisites for achieving sustainable land

use are defined in the closing section of this article.

### Gully Erosion: Human Impact or Natural Variability?

#### *Gully erosion in southern Australia*

Accelerated soil erosion is evident throughout the semi-arid regions of south-eastern Australia and is common in the 70% of Australia considered dry (Morton *et al.*, 1995). This erosion often takes the form of narrow, steep-sided and actively extending gullies. The impact of overgrazing is widely blamed as the primary cause of such erosion and much of the blame is often placed on overstocking by the first European settlers to occupy the drier

parts of New South Wales, Victoria and South Australia over a century ago. Many rangeland scientists feel that the causes are so intuitively obvious that the inception of gully needs no further investigation. However, there are other possible causal factors to be considered, including changes in the seasonal incidence and intensity of rainfall, and changes in local geomorphic thresholds brought about by prior denudational and depositional events (Prosser *et al.*, 1994; Wasson *et al.*, 1998). The issue is one of choosing appropriate criteria to allow the impact of climatic and other natural environmental variables to be clearly distinguished from the influence of historic changes in land use (Graf, 1987; Bull, 1997). In seeking to elucidate cause and effect, the issue of timing is critical. Does the inferred acceleration in soil erosion coincide with local land use change and how well dated are the two phenomena? Furthermore, since correlation does not necessarily imply causality, is there a functional relationship between posited cause and inferred effect?

A number of fundamental questions need to be asked when attempting to evaluate the relative influence of human activities and climatic variations on land degradation in semi-arid southeastern Australia. For example, to what extent is the gully erosion evident in many parts of semi-arid South Australia and adjacent parts of New South Wales and Victoria a consequence of land use change, overgrazing and clearing of native vegetation? What is the role of long-term desiccation and possible seasonal changes in rainfall amount and intensity (Kraus, 1954; Nicholls and Lavery, 1992; Suppiah and Hennessy, 1998; Power *et*

*al.*, 1999) associated with the passage out of the Little Ice Age (AD1270-1850)? What is the impact of recurrent droughts and floods linked to El Niño Southern Oscillation (ENSO) events? (Whetton *et al.*, 1990, 1993, 1996; Whetton and Rutherford, 1994; Cai *et al.*, 2001)? Is there evidence of past changes in the incidence of ENSO events (Moy *et al.*, 2002) and is the magnitude and frequency of such events liable to change in the near future as global warming increases?

In order to resolve the issue of when, how and why the gullies were initiated, it is first necessary to date the inception of gully erosion using appropriate dating methods to find the age of the youngest sediments incised by modern gullies in the study area. In many parts of arid southern Australia a series of valley fill deposits indicate recurrent erosion and deposition during the last 30,000 years. However, the timing of the present phase of vertical channel incision is not yet known. The second task is therefore to determine the environmental conditions under which the now incised valley-fill deposits accumulated, using evidence from sediments, soils, microfossils and geochemistry. For example, the most widespread valley-fill deposits in the central Flinders Ranges of South Australia appear to have accumulated under a cooler and less seasonal climate that ended fairly abruptly with renewed torrential erosion and incision some 15,000 years ago (Williams *et al.*, 2001). It would be useful to know if the youngest and as yet undated valley fill in this and other now semi-arid areas also accumulated during cooler and perhaps wetter conditions associated with the Little Ice Age. If this

proves to be the case, then the present phase of channel incision may relate more to changes in plant cover and climatic regime associated with the global increase in temperature that followed the close of the Little Ice Age than to humanly induced changes in land use.

The third task is to investigate all available archives relating to historic and, if need be, prehistoric changes in land use evident in increased charcoal concentrations in the youngest sediments exposed in channel bank sections. The ubiquitous abandoned homesteads to the north of Goyder's Line in South Australia bear eloquent witness to past efforts to cultivate cereal crops well beyond the present-day limits of wheat production in South Australia. G.W. Goyder (1826-1898) was the government surveyor who, in the late 19th century, mapped out a notional line in South Australia, north of which rainfall diminished rapidly, rendering the area unfit for farming, particularly wheat cultivation.

In one detailed study of erosion and sedimentation in the semi-arid central west of New South Wales, Williams *et al.* (1991) mapped and dated a number of gullies that seemed to reflect the impact of European settlement. The gullies were incised into red sandy slope mantles ranging in age from at least 5500 years BP to about 640 years BP. Inception of the gullies predated the arrival of Europeans and their sheep by several centuries, but the original channels were broad and shallow, in contrast to the present-day channels that are deep and narrow. Accurate reconstruction of past and present gully cross-sections (Fig. 2) revealed a major change in channel

morphology over the past hundred years. The authors noted that the presently active phase of gully erosion was initiated during the life of still living pine and eucalypt trees 'at a time when their root systems already extended up to 9 m laterally' (Williams *et al.*, 1991, p. 280). They considered that while the current phase of gully erosion seemed to be associated with the late 19th century arrival of sheep, other causal factors were also relevant. These factors included changes in drought frequency and the seasonal incidence of rainfall, as well as changes in fire regime associated with European settlement (Braithwaite, 1991). This example illustrates something of the multi-causal and complex origins of historic gully erosion in semi-arid Australia. The next example deals with an entirely different set of causal factors.

#### *Gully erosion in the Ethiopian highlands*

Gully erosion is very visible in Ethiopia but there is a dearth of research to indicate when the different gully systems developed and whether they are still active. Since active gully erosion can lead to loss of productive farmland, it is useful to know whether the erosion was triggered by human or non-human causes. As in Australia, overgrazing, trampling by herds of cattle, sheep or goats, and removal of trees for fuel and building are often held responsible for accelerated erosion in Ethiopia. Non-human causes in Ethiopia may be climatic, tectonic or volcanic. The example that follows is one of tectonically induced gully erosion, but was initially blamed upon local charcoal burners.

Spectacular gullies are incised into fine-grained sediments that line the floor

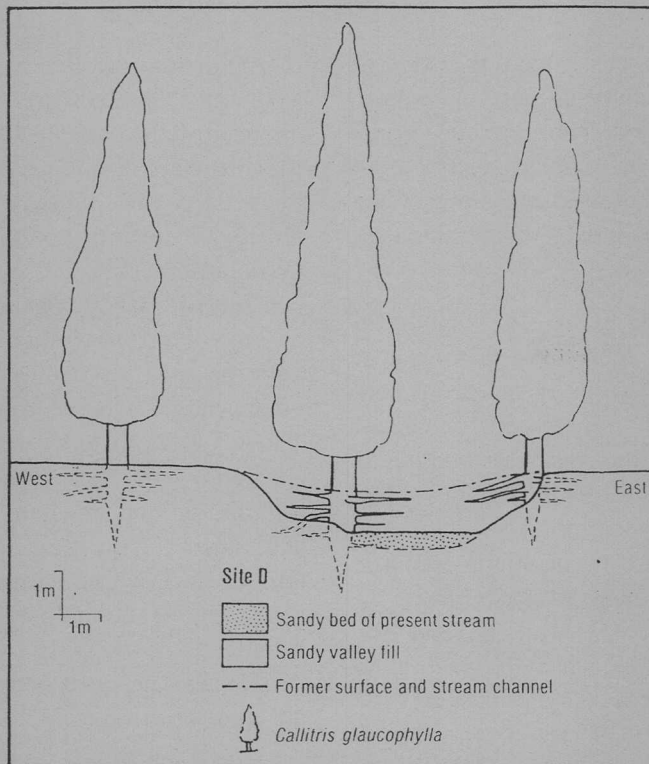


Fig. 2. Cross-section through a gully in west central New South Wales, Australia, showing present-day and former channel cross-section. (Source: Williams et al., 1991).

of one of the volcanic calderas at K'one in the Ethiopian Rift. K'one lies 60 km NE of the small town of Nazret and about mid-way between the towns of Wolenchiti and Metahara at  $8^{\circ}50'N$ ,  $39^{\circ}43'E$ . The 600-800 mm annual rainfall falls mainly during June to August. A welded tuff of probable Middle Pleistocene age covers the floor of the caldera in which the gullies occur. Up to 15 m of horizontally stratified clays and silts and a basal layer of airfall pumice overlie the welded tuff. The clays and silts contain numerous Middle and Late Stone Age flaking floors that range in age from over 150,000 to about 8,000 years ago. The welded tuff is cut by two narrow

and fresh-looking tensional fissures, one of them at least 36 m deep. Diversion of surface flow into these fissures initiated erosion of the overlying sediments. When did this erosion begin?

The gullies must post-date the youngest horizontal sediments into which they are cut. No cut-and-fill structures or buried prehistoric gullies were found, suggesting that the present episode of gully erosion is unique relative to the depositional history of this area. The second youngest unit has yielded radiocarbon ages between 14,700 and 6,800 years before present. The onset of gully erosion, and the opening of the

fissures that diverted surface runoff below ground, must be younger than these ages. The present geodetically monitored rate of rift dilation is  $5 \text{ mm yr}^{-1}$  (Williams *et al.*, in press). If we assume that the K'one fissures also widened at this rate, we obtain a maximum age of 300 to 500 years for the opening of the fissures. The fissures very plausibly formed during seismic activity associated with the 1820 AD volcanic eruption at Fantale volcano further east (Harris, 1844). There is therefore no valid reason to implicate the charcoal burners for the tectonically induced gully erosion at K'one. Many of the gully walls have attained a stable  $30$  to  $35^\circ$  angle of repose, consistent with a long history of gully extension and eventual stabilisation. In such circumstances, soil conservation measures are irrelevant. Tuan (1966) made a similar point nearly forty years ago in relation to naturally induced New Mexican gullies.

#### *Gully erosion in the Sahel zone of Niger*

The third example of gully erosion deals with erosion of normally stable and vegetated dunes as a result of an extreme climatic event. Vegetated and stable dunes are characteristic of the southern borders of the Sahara and extend more or less unbroken from the Atlantic to the Nile (Grove and Warren, 1968; Talbot, 1980; Nichol, 1999). In common with their counterparts in the Rajasthan desert of India and the sand deserts of northern China, the sandy soils of these now vegetated African dunes have trapped fine clay and silt particles derived from many millennia of dust storms and so are valued for cereal cultivation. A number of the dunes are

dissected and gullied. Is such dissection evidence of land degradation caused mainly by overgrazing and inappropriate methods of cultivation, or is it part of a suite of geomorphic processes characteristic of these particular savanna environments?

During the 1974-75 dry season, Talbot and Williams (1978, 1979) carried out a survey on foot and by camel of the Wadi Azouak basin in central Niger. This account revisits that work. They discovered a series of very recently formed sandy alluvial fans located on the lower slopes of fixed dunes near Janjari village between Tahoua and Abalak, midway along the road from Niamey to Agades. Older fan sediments were exposed in the banks of the entrenched channels upstream of the intersection point on the most recent fan. Buried soils showed that previously active fans had eventually become vegetated and stable (Fig. 3).

Exceptionally intense rainfall early in the preceding wet season, confined to an area about 10 to 15 km radius, had triggered very high rates of runoff from the sparsely vegetated surface of the fixed dunes at Janjari. This caused channel entrenchment above the fan apices and fan sedimentation below. The youngest buried soil predated a fireplace dated to  $335 \pm 60$  years B.P. (N-2129). The soil was regionally widespread and may have formed during a slightly wetter interval evident throughout the Sahel zone dated to about 150 to 350 years before present (Talbot and Williams, 1979). The bank sections showed that episodic dune dissection, fan accumulation, soil formation and fan stabilization had been typical of the last few thousand years.

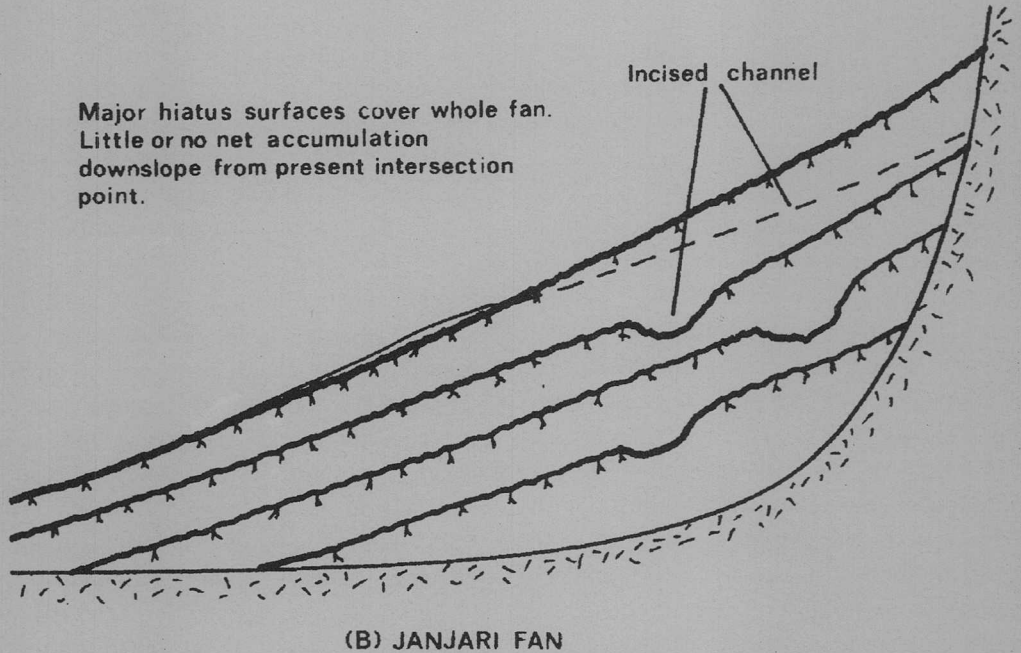


Fig. 3. Diagrammatic cross-section through a Janjari fan. The solid line denotes a former surface with a weakly developed soil and indicates intervals of little or no sediment accumulation on the fan (Source: Talbot and Williams, 1979).

The conclusion drawn from this work was that the 1974 phase of dissection was no greater in scale than previous phases and that there was good reason to believe that recovery would once again be possible (Talbot and Williams, 1979). A similar inference is probably equally true for other parts of the Sahel, assuming that they have not been too severely overgrazed and depleted of their protective plant cover. Comparable examples of dissected dunes extend from Mauritania to the Sudan and appear to be characteristic of a geographically restricted climatic zone, with high mean annual temperatures, a highly seasonal rainfall regime, and a mean annual rainfall of 200 to 400 mm (Talbot and Williams, 1979).

### Direct and Indirect Impacts of Vegetation Clearance

#### *Impact of vegetation clearance in Inner Mongolia*

Land degradation in semi-arid northern China has been a matter of national concern for over half a century (Zhu *et al.*, 1992; Fullen and Mitchell, 1994; Williams, 1997a; Ci, 1998; Zhao, 1999). One chapter in China's Agenda 21 (1994) deals with possible solutions to desertification. Recent articles in 'Beijing Review' reinforce this concern (Jiang, 1997; Kou, 1998). The silting up of the Huang Ho (Yellow River) is a graphic response to accelerated erosion in the Loess Plateau where rates of soil

and nutrient loss remain very high (Douglas, 1989; Liu, 1999; Fu *et al.*, 2000). One region where desertification is of current concern, in part because of the present influx of sand into the adjacent Yellow River, is Inner Mongolia Autonomous Region (Nianfeng *et al.*, 1999), especially the Alashan area in the northwest of the region.

The Alashan region of Inner Mongolia in northern China is one of the driest regions in China and covers an area of about 270,000 km<sup>2</sup>. Rainfall declines from about 300 mm in the east to less than 50 mm in the west (Yang, 1991). Mountains occupy roughly 10,000 km<sup>2</sup> of the area and are flanked by gently sloping sand and gravel alluvial plains or *gobi*. These cover about 91,000 km<sup>2</sup> of Alashan. In the northeast, west and southeast of Alashan there are three major active dunefields that cover a total area of about 81,000 km<sup>2</sup>. Fixed and semi-active dunefields cover about 90,000 km<sup>2</sup> and are the areas most vulnerable to desertification. Areas were estimated from the 1:4 million map of Sand Desert Landforms of China (1971) and checked against the 1:500,000 Geomorphological Map of Badain Jaran Desert and its surrounding areas (1998).

Until the 1950s many of these low dunefields and sandsheets were covered in a relatively dense cover of shrubs, trees and grasses. Since then the human population has doubled and livestock numbers have tripled (Professor Xiao Honglang, pers. comm., 1999). There have been a number of severe droughts, including the exceptionally severe 1989 drought. Many localities in the extreme west of

Right Banner were suffering from inadequate rainfall during the three years prior to August 1999. (The exceptionally heavy rains of 5 and 6 August, 1999 coincided with my visit to this area and were considered the best rains of the past ten years, bringing the three year drought to an end). The precipitation record is too short to show whether or not there has been a long-term decline in rainfall. Greatly increased stock numbers, the influx of immigrants from Gansu Province and from Ningxia Autonomous Region to the south, and the occurrence of sporadic but severe droughts over large tracts of Alashan have resulted in widespread and locally severe desertification and associated ecological deterioration. Official local estimates in 1999 suggested that some 30,000 km<sup>2</sup> of land are now severely degraded and that the rate of desertification was increasing by about 1,000 km<sup>2</sup> each year (Li Aixin, pers. comm., 1999). In the absence of accurate soil and vegetation maps for the area, it is not possible to confirm or refute these estimates. They are probably reasonable order of magnitude estimates.

The perceptions of Mongolian herders and Han Chinese land managers differ as to the severity of land degradation in other parts of Inner Mongolia (Williams, 1997b), but in Alashan there was widespread concern among all the people I talked to over the perceived increase in sand and dust storms and the decline in quality of pasture. Accelerated soil erosion by wind and water has certainly increased since the 1950s. Former agricultural settlements immediately west of the Helan Shan ranges have been abandoned and the fine-grained alluvial soils are extensively gullied. In places, a single

tree is all that remains of the 1950s riparian woodland. In the sand deserts north and west of these mountains, removal of the plant cover of previously vegetated and stable dunes through overgrazing by goats and sheep has reactivated many of the dunes. Monitored rates of dune advance range from more than  $10 \text{ m yr}^{-1}$  near the Yellow River to less than  $1 \text{ m yr}^{-1}$  further inland. The dunes along an 80 km long stretch of the left bank of the Yellow River opposite the industrial city of Wuhai are currently advancing from the northwest at rates of up to  $10 \text{ m yr}^{-1}$ . An estimated 80 million  $\text{m}^3$  of sand is being blown into the river each year in this sector. Major re-afforestation of the active dunes is proposed for this sector, and a useful start has been made at the Shu Gui Desert Control Station, although problems with salt and with insect pests are killing many trees.

Douglas (1989) reviewed the impact of land degradation on the sediment load of the Yellow River in the late 1980s. In 1988, the Yellow River had a mean annual sediment yield of  $1010 \text{ t km}^{-2} \text{ yr}^{-1}$  and a total mean annual runoff of  $3.26 \text{ km}^3$  in the 716 km long reach between Longyangxia and Hekouzhen. In the 1353 km reach from Lanzhou to Hekouzhen, the sediment yield was  $202 \text{ t km}^{-2} \text{ yr}^{-1}$  for a mean annual runoff of  $65 \text{ km}^3$ . Since that time the influx of blown sand into the river has increased dramatically, as has upstream abstraction of water for irrigation. The result was highly visible in the summer of 1999 as mid-channel bars, so that many parts of the channel have become very shallow, greatly reducing navigability on the river to all but very shallow draught vessels. Control of desertification along the

Yellow River is an important element of China's national plans to combat desertification (China's Agenda 21, 1994: 189).

#### *Impact of vegetation clearance in southern Australia*

In many parts of the semi-arid world, salt accumulation in soils is associated with insufficient leaching of the soil from infiltrating rainwater. In the southern third of Australia the reverse is paradoxically true. As a result of clearing the native vegetation, too much water is percolating down into the subsoil and too little is being used by existing plants. The long-term effects of clearing the deep-rooted eucalyptus trees were seldom realized. Strzelecki (1845) was an early and perceptive exception, warning in surprisingly modern terms against the adverse effects of clearing and burning upon soil erosion, infiltration capacity and soil structure. But even he had no inkling of the processes involved of what is now termed dryland salinity. In particular, there was almost no recognition of the role played by the native flora as natural groundwater pumps and as effective agents for maintaining groundwater tables below the level of shallow rooted pasture grasses and cereal crops.

The first Australians practiced a successful hunter-gatherer lifestyle for over fifty thousand years. With the arrival of Anglo-Celtic settlers two hundred years ago came small herds of hard-hoofed domestic sheep and cows that proliferated and spread. Applying the agricultural practices of their European homeland, these immigrants set about clearing the woods and forests of

southern Australia for crops and pasture. The outcome was stark. Half the original woodland and forest that grew 200 years ago has now gone from Australia. The repercussions have been dramatic, and the process continues. In the ten years before 1993, Australia cleared an average of 500,000 ha of woodland and scrub, equivalent to two football pitches a minute. In 1990 Australia cleared 650,000 ha, or 'more than half the area cleared in the Amazon Basin' (Anderson, 1995:12).

One unforeseen consequence of the widespread tree clearing only became apparent many years later (Macumber, 1991). The deep-rooted eucalyptus trees acted as natural groundwater pumps and kept the local water table well below the rooting depths of wheat, barley, improved pasture and other crops widely grown in the southern third of the continent. Groundwater recharge under native vegetation is 1 to 2 mm yr<sup>-1</sup>. Under wheat cultivation it is 40 to 120 mm yr<sup>-1</sup> (CSIRO Land and Water, 1999). Once cleared, the groundwater levels rose, slowly but inexorably, bringing dissolved salts to the surface.

This process has resulted in a huge loss of productive agricultural land in many parts of southern Australia. In Western Australia, the area of saline land in 1994 was 1.6 million hectares or about a tenth of the cleared agricultural land in that State. In 1992 over 200,000 hectares of the Murray-Darling basin was in the grip of dryland salinity. Five years ago, the figures for South Australia and Victoria were over 400,000 ha and 150,000 ha, respectively (Commonwealth of Australia, 1996). The

losses in terms of agricultural production amount to over A\$500 million each year, so that considerable effort is now being devoted to arresting the process and preventing further damage.

Rising groundwater brings 5 m t of dissolved salt to the surface of the Murray basin each year, with 2 m t flowing down the river and 3 m t remaining on the land and preventing farming. In October 1999, the Murray-Darling Basin Ministerial Committee published its 'Salinity audit of the Murray-Darling Basin'. A key contribution to the salinity audit was the 1999 CSIRO Land and Water report on 'Effectiveness of current farming systems in the control of dryland salinity'. The audit showed that the economic damage due to salinity had been grossly underestimated. More than 2.5 million ha of former agricultural land in Australia are now unusable because of dryland salinity. The cost to the Australian economy is nearly one billion Australian dollars a year, or triple previous estimates. If the current trends continue unchecked, in 50 years some 15 million ha will be affected by salt. At least 80 towns and cities in regional areas are presently threatened by salt. 20% of South Australia's surface water is too salty for human consumption. Western Australia is losing the use of an area the size of a football field every hour due to salinity and its biodiversity is under threat, with hundreds of species unique to the State in danger (Australian State of the Environment Committee, 2001).

In many cases, mitigation will be a complex and very long-term process (Clarke *et al.*, 1998), and may require widespread

adoption of salt tolerant plants as well as judicious planting of deep-rooted perennials, especially along aquifer recharge sites identified through remote sensing and ground control. Dryland salinity in Australia is a classic example of a creeping environmental problem comparable to the progressive desiccation of the Aral Sea (Glantz, 1999).

### **Impact of Vegetation Clearance in the Ethiopian Highlands**

Ethiopia is endowed with deep fertile volcanic soils, a range of microclimates and diverse ecosystems. It could be one of the most successful agricultural nations in Africa. However, prolonged clearing of forest in the steeply sloping uplands areas has left the soil exposed to the high intensity seasonal rains. Even within the Simien Mountains National Park, for example, the area of natural forest declined from 56% to 22% of the Park area within 40 years (Hurni, 1999). Clive Nicol, the first game warden appointed by the former Imperial Ethiopian Government to manage the Park, provided a vivid description of the process of deforestation in the earliest years of the Park's existence:

"Everywhere the ground was strewn with hot ash, smoking debris, charred stumps, and partially burned tree trunks... I could hardly believe that a few men, with simple, blunt iron axes had felled so many huge trees. Cedar, olive, hagenia, Podocarpus, euphorbia, and many others" (Nicol, 1971: 262).

Traditional farming methods recognized that soil losses during cultivation were high and so allowed many years of fallow for

soils to recuperate. Mean annual rates of soil loss today amount to about  $40 \text{ t ha}^{-1}$  ( $2 \text{ mm yr}^{-1}$ ) on mountain slopes, but attain rates of over  $300 \text{ t ha}^{-1}$  ( $15 \text{ mm yr}^{-1}$ ) during cultivation years, or some 5 to 10 times more than in non-mountainous areas (Hurni, 1999). The increasing demand for land has meant a reduction in fallow to virtually zero and an expansion of the area under cultivation. In one region in Gojjam Province the area cultivated rose from 40% in 1957 to 77% in 1995, while natural forest land decreased from 27 to 0.3% (Hurni, 1999).

These rates of accelerated soil erosion can be compared with long-term denudation rates. The mean rate of geological erosion over the past 23.5 ma was  $0.01 \text{ mm yr}^{-1}$  in the Ethiopian headwaters of the Blue Nile (Williams and Williams, 1980). The rate of erosion in the Blue Nile headwaters during the 70 years before completion of the Aswan High Dam was 0.12 to 0.24  $\text{mm yr}^{-1}$ . In the 1970s annual soil loss from parts of the Ethiopian plateau was roughly 0.4 to 1.0  $\text{mm yr}^{-1}$ . What we are witnessing is an increase in the rate of soil loss by two orders of magnitude, a rate that is much faster than corresponding rates of soil formation.

Removal of forest in the seasonally wet tropical uplands of Ethiopia has changed the local hydrological balance, resulting in reduced infiltration, increased runoff and increased soil loss. The downstream effects are equally significant and in this instance are not confined to Ethiopia. The Roseires dam was built close to the Ethiopian border to store Blue Nile water for irrigation use in central Sudan. By 1996, the capacity

of the Roseires reservoir had been reduced by almost 60% by the influx of sediment from the Ethiopian uplands and that at Khashm el Girba on the Atbara, by 40% (Swain, 1997). (The Atbara rises in the Ethiopian uplands, close to the sources of the Blue Nile). It thus appears that deforestation in the headwaters of the Blue Nile and Atbara rivers during the past forty years has triggered a wave of accelerated soil loss from cultivated land and has led to siltation of reservoirs many hundreds of kilometres downstream.

However, a number of workers have questioned the notion of recent, progressive and linear deforestation in the Ethiopian uplands (Leach and Mearns, 1996). Certain regions have been treeless for centuries (McCann, 1999). Others have experienced recurrent intervals of clearing and forest regrowth linked to sporadic military conquests and social upheavals during the past three centuries, with forest having now totally replaced land cleared and cultivated as recently as fifty years ago (*op. cit.*, 93 to 104).

A similar conclusion emerges in relation to land degradation (Hoben, 1996). Elias and Scoones (1999) considered whether soil fertility was declining in the Wolayta region of southern Ethiopia. Using a combination of field level evaluation of soil nutrient balances, archival data and personal interviews with farmers, they concluded that soil fertility decline was true of some localities, for certain farmers, over certain periods, but was far from universal. Scoones (1997) had reached a similar conclusion during his earlier fieldwork in Zimbabwe that led him to

reject over-generalized assessments of environmental change and resource use.

### Discussion

Irrigation in the Sudan depends upon a guaranteed supply of water from the Ethiopian Highlands via the Abbai/Blue Nile and Tekazze/Atbara rivers. Reservoirs in the Sudan are silting up rapidly as a result of sediment brought in from the Ethiopian uplands, aggravating existing land degradation within the Sudan (Ayoub, 1999). Deforestation and accelerated soil loss from cultivated land in the Ethiopian highlands have been held responsible for these rapid rates of sedimentation. Although there is much truth in this assessment (Hurni, 1999), the reality is also more complex. Some parts of the Ethiopian uplands draining towards the Sudan have more forest today than they did fifty years ago, and soil fertility and soil depth are actually increasing in some places as a direct result of human management. Equally, some sites in the Ethiopian Rift that display striking evidence of badland erosion have nothing to do with human impact. For example, the gullies in one locality (K'one) are in fact stable and were most probably initiated by an earthquake several thousand years ago.

Nevertheless, the problem of declining crop yields and periodic famine is real and remains so to this day. In order to achieve a more sustainable form of agriculture, the local farmers need to be actively involved in soil and water conservation measures and a program of long-term re-afforestation of steeplands and interfluvies initiated as a matter of urgency (Hurni, 1999). However, as Hobin (1996) has warned, willing and committed local

community involvement is a prerequisite for any effective long-term solution to desertification. Heavy-handed, top-down, high technology solutions are seldom effective for long.

The role of other forms of non-human catastrophic events is also evident in the pattern of cyclic erosion of fixed dunes in the Sahel zone of Niger (Talbot and Williams, 1979). Contrary to expectation, the cycles of gully erosion and alluvial fan deposition along the flanks of the fixed dunes are unrelated to human activities and are caused by severe and very localized cloudbursts which occur during otherwise prolonged regional droughts. The incidence of such events is extremely rare but the effects persist for many hundreds of years. Restoration of the bare dunes and gullies has occurred in the past as part of this rare but cyclic erosion and deposition of the dune flanks. Hence, restoration of degraded dunes seems equally likely to occur in the future, setting natural limits to processes some have regarded as causing irreversible land degradation.

In the Alashan region of Inner Mongolia in northern China, overgrazing during the last 30 to 40 years has re-activated previously vegetated and stable dunes, resulting in a massive influx of sand being blown into the adjacent middle reaches of the Yellow River each year. The key issue is to minimize grazing pressure and not to exceed the carrying capacity of the vegetated dunefields. Dune stabilization using the straw mulch chequer-board technique now widely used in northern China (Zhu *et al.*, 1992) combined with forest shelter-belt planting is both feasible

and desirable in areas of potentially high agricultural and economic productivity or major strategic and environmental importance such as close to the Yellow River and along the main railway line.

Clearing of the deep-rooted eucalyptus trees from extensive regions of southern Australia since the onset of European settlement some 200 years ago has caused local and regional water-tables to rise, bringing dissolved salts to the surface, resulting in widespread salinity. Control and prevention of dryland salinity in Australia will require a combination of short- and long-term measures. These would include surface and subsurface land drainage and diversion of salt water to holding ponds and evaporation basins for commercial salt extraction. In addition, tree planting of trees and other deep-rooted perennial crops along the catchment interfluves and aquifer recharge zones is essential. Farmers should be encouraged to make greater use of halophytes for fodder. Finally, there needs to be greater development and use of salt tolerant crops, including trees for commercial use other than for timber.

Although the social, economic and political context of each of the examples discussed is very different, four themes are nevertheless common to all. First, in each case, indiscriminate destruction of the native vegetation has resulted in severe and widespread land degradation. Second, the consequences of this degradation resulted in severe repercussions well beyond the immediate area suffering from desertification. Third, the initial causes of the desertification go back in time for decades or scores of years. Fourth, the onset of degradation was gradual and the

resulting loss of productive land was at first almost imperceptible except to a few prescient and acute observers.

### **Prerequisites for Achieving Sustainable Land Use**

In the light of the examples discussed earlier, the question that arises is how we can better manage land use in dry areas so as to be sustainable. The laws of thermodynamics suggest some answers. First, we should not systematically remove materials from any natural system at a rate faster than the capacity of the system to replace them (Robèrt, 1992; Molly Olson, pers. comm., 1997). Soil loss at rates in excess of soil replenishment illustrates this contention. Second, we should not systematically add materials to a natural system at a rate faster than the capacity of that system to absorb and recycle those materials. Chemical pollution of our air, land and water is well known, with excess salinity – a pressing issue in dry areas. In regard to vegetation clearance we need to remind ourselves that solar energy, acting via photosynthesis, is the only source of a net increase in primary productivity on this earth. All else is simply applying energy into recycling earth materials into other forms of matter. A final prerequisite, based on simple human justice, is that there should be fair and efficient access to natural resources by all people of the globe. Put in terms directly applicable to desertification, local community involvement is a prerequisite for any effective long-term solution to desertification. The local communities need to be aware of the benefits for them and to have a full role in the design and implementation of the anti-

desertification measures. Finally, appropriate forms of environmental education must go hand in glove with measures to reduce poverty and ensure food security among the poorest communities. Maurice Strong's opening remarks to the Earth Summit in Rio de Janeiro should not be forgotten (UNCED, 1992).

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