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Desertification and climate change—the Australian perspective

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ABSTRACT: In Australia, desertification tends to be associated with land degradation in the rangelands. It results from unsustainable land use and the impact of European settlement, rather than changing climate. Desertification can, however, be exacerbated or triggered by climate variability. Some of the degradation occurred in the early stages of pastoral development but the problem has continued. The extent of degradation has proved difficult to assess but survey results show it varies in severity across the country. Grazed rangelands have been most severely affected but the problem extends outside the pastoral zone due to the impact of feral animals and changed fire regimes. Biodiversity has also been affected with extinctions occurring among small and medium-sized mammals. Climate change scenarios suggest shifts in rainfall patterns but the major impact will come through increased variability. Substantial shifts in rainfall have occurred over the last 100 yr with wetter periods generating unrealistic expectations about land use and drier periods triggering land degradation. However, pastoral management is focused on short term climatic variability since this is what dominates both production and income. Policy responses require that the whole issue of sustainable land use be addressed rather than climate issues alone.

KEY WORDS: Desertification · Land degradation · Australia · Climate change · Climate variability · Rangelands · Pastoralism · Biodiversity

1. INTRODUCTION

Desertification, like climate change and loss of biodiversity, is a global problem. However, its causes are complex, frequently local, and vary from one part of the world to another. The severity of impact also varies, with less-developed countries experiencing greater human misery than those with the resources to provide short and long term relief to affected populations. Desertification problems have therefore become inextricably linked with those of food security, poverty alleviation and lack of development in poor countries while in richer countries the emphasis is on environmental degradation, inappropriate land use, loss of biodiversity and rural restructuring. Desertification problems have also become linked with the long term droughts which have affected some parts of the world such as the African Sahel recently and were experienced in large parts of Australia in the 1890s, 1920s and 1960s.

This paper examines the issue of desertification in Australia, a developed country with a large arid and semi-arid zone whose principal land use is commercial pastoralism. While every nation is different, there are parallels between what is happening in Australia and events in parts of southern Africa, South America and the southwestern USA. All these areas were colonised by Europeans in the last few centuries and have large scale commercial grazing based on exotic animal species which is often export oriented. All face the cost-price squeeze affecting agriculture and all are associated with environmental degradation. There may therefore be common lessons to be drawn. Accordingly, the paper examines the extent and impact of desertification in Australia, explores the links with climate, and summarises the policy response. It also raises some of the key questions which have yet to be answered about the problem.

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2. THE DESERTIFICATION ISSUE

2.1. International perspective

According to the International Convention to Combat Desertification (CCD; United Nations 1994):

> 'Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities', with the arid, semi-arid and dry sub-humid zone defined as '...areas, other than polar and sub-polar regions, in which the ratio of annual precipitation to potential evapotranspiration falls within the range from 0.05 to 0.65.' Land degradation is described as: '...reduction or loss ... of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as:
> (i) soil erosion caused by wind and/or water;
> (ii) deterioration of the physical, chemical and biological or economic properties of soil; and
> (iii) long term loss of natural vegetation.'

The definition is unambiguous on the issues of what and where, but the question of why is not clearly answered. Put simply, this is because there are 2 polarised views on the causes of desertification (see Warren & Khogali 1992). At one extreme is the view that drought, which is normally a short term, natural fluctuation in climate, accelerates the long term rate of land degradation (Hill & Peter 1996). This implies that when long term reductions in rainfall occur, such as those which have affected parts of the African Sahel over the last 30 yr or so, the resultant degradation is a largely natural phenomenon and beyond the control of the nations experiencing it. At the other extreme is the view that traditional land use systems are often well adapted to periodic drought (e.g. Ellis et al. 1993). Desertification therefore tends to be human induced and arises because of pressure on land resources due to rising populations, unwise development policies and misuse of the land (e.g. Graetz 1996).

Both of these views are partially true but most desertification has multiple causes. The picture is further complicated by the as yet unsubstantiated view that, while the desertification process may be accelerated by the natural phenomenon of drought, some of the extreme droughts experienced recently in both the Sahel and other parts of the world may be a consequence of human-induced climatic change. Further complexity is added by the fact that vulnerability to drought increases as land resources become degraded and pressure on land often increases as population expands.

There is little doubt that desertification is a global problem but its complex nature means that there is no general solution. The CCD is therefore framed around the development of a set of national action plans supported by regional cooperation networks. It also emphasises bottom-up rather than top-down approaches to dealing with desertification based on local community action, much along the lines of Australia's Landcare Program (see below) which had a significant influence on the initial design of the CCD. So far, however, few additional funds have been mobilised, there is little truly effective action to report, and the CCD has captured less attention than the other international agreements arising out of the UN Conference on Environment and Development in 1992.

2.2. Australian perspective

In Australia, the term desertification has found little favour and land degradation is more widely used. The area prone to 'desertification' as opposed to land degradation in general is usually associated with the arid and semi-arid rangelands (Commonwealth of Australia 1995) although it would extend well into the croplands if the climatic definition in the CCD was used. There is little contention about the causes of rangeland degradation. It is clearly due to unsuitable land use or poor land management, although the triggering mechanism can be climate variability with both unusually wet and unusually dry conditions producing adverse changes in land condition (e.g. Wasson & Galloway 1986, Friedel et al. 1990). Feral animals have also played a role, especially the rabbit in the southern part of the continent.

The rangelands occupy 70 % of the Australian continent with about 60 % of that area being used for commercial pastoralism (Fig. 1). The remainder of the rangelands is too dry or infertile to support such activity. In 1991, the rangelands carried 6.7 million cattle and 24.5 million sheep (respectively 31 and 14 % of the national totals). Pastoralism is carried out on an extensive basis with individual paddocks varying in size from about 1500 ha in the southern sheep production areas to 500 km^2 or more in the cattle grazing areas of arid central Australia. Individual properties typically vary from 35 000 ha to 12 500 km^2 with 1 to 40 paddocks. Land tenure is mainly through restricted-purpose leasehold but varies from state to state, as do leasehold covenants. Management intensity varies from situations in which sheep are mustered and handled 2 to 3 times a year to cases in the remote areas of northern Australia where semi-feral cattle are tracked down and shipped out for slaughter once a year or less (Pickup & Stafford Smith 1993). Virtually no cropping is present except on an intermittent basis in favoured locations on the semi-arid fringe.

While there may be little contention about the causes of land degradation, there is still considerable argument about when the degradation occurred. Some claim that most of it happened in the early stages of pastoral development (e.g. Perry 1977, Curry & Hacker 1990, Palmer 1990) while others dismiss this as a 'convenient myth', providing justification for not addressing an ongoing problem (Pickup & Stafford Smith 1993). There is also argument about the potential for and timing of recovery from land degradation, with some claiming a major recovery in some parts of the country since the 1960s (e.g. Condon 1986, Hayes 1987, Palmer 1990) while others believe that the 'recovery' is no more than a response to an increase in rainfall of 10 to 30 % over several decades (e.g. Pickard 1993, Pickup et al. in press).

In summary, the situation is as follows. Prior to the arrival of Europeans, the rangelands were used by hunter-gatherers and grazed by native herbivores. From about 1850 onwards, European pastoralists displaced the native people and introduced sheep and cattle which were grazed around a limited number of natural waters, often in very large numbers by current standards (e.g. Landsberg et al. 1997). However, much of the country remained inaccessible to stock due to the absence of surface water except during wet periods. By the early twentieth century, there was severe land degradation around many of the natural waters and massive stock losses were occurring during droughts. For example, in New South Wales, sheep numbers reached 19 million in the 1890s, fell to 3.5 million in the drought of 1901-2, and never subsequently recovered, probably due to land degradation and resultant loss of stock carrying capacity (Newman & Condon 1969, Williams & Oxley 1979). A similar pattern of events occurred in South Australia but with heavy reliance on artesian bores as well as natural waters (Newman & Condon 1969). Pastoral development came later in Western Australia, with sheep numbers increasing from 1.6 to 4.8 million sheep between 1900 and 1930 and falling to 3 million in 1960, largely as a result of droughts and degradation. In central Australia, development occurred later with cattle numbers growing to a peak of 360 000 between 1900 and 1958, crashing to 120 000 in the 1960s drought and then rising to another peak during the record wet years of the 1970s, after which there was a decline (Newman & Condon 1969, Friedel et al. 1990). Here, however, the increase in animal numbers was accompanied by an expansion of the grazed area due to provision of artificial waters so the area escaped much of the severe localised early degradation experienced elsewhere.

After the initial catastrophic impacts, most pastoral development involved extension of the grazed area using artificial waters such as dams and bores, and the fencing of land into large paddocks. The result was a transition from localised but very intense land degradation to less intense and more intermittent degradation spread across a much wider area (Tolcher 1986). The opening up of more land to grazing has continued until the present day but accelerated after World War II when increased availability of earthmoving equipment made dam construction much easier. Indeed, in central Australia, 22 % of waterpoints marked on pastoral maps were first recorded in 1960 or later, which indicates just how recently some large areas have been exposed to regular commercial grazing. Another important development since World War II has been the expansion of the road network and improvements in road transport which allow rapid removal of stock from drought-affected areas. Prior to this, animals often could not be shifted, causing land degradation until death by starvation occurred. This still happens with feral animals such as horses and donkeys in northern Australia although shooting programs have reduced numbers.

Despite continuing improvements in farm productivity, declining terms of trade for the pastoral industry has placed increasing pressure on the economic viability of many of the 6000 rangeland grazing enterprises. Many

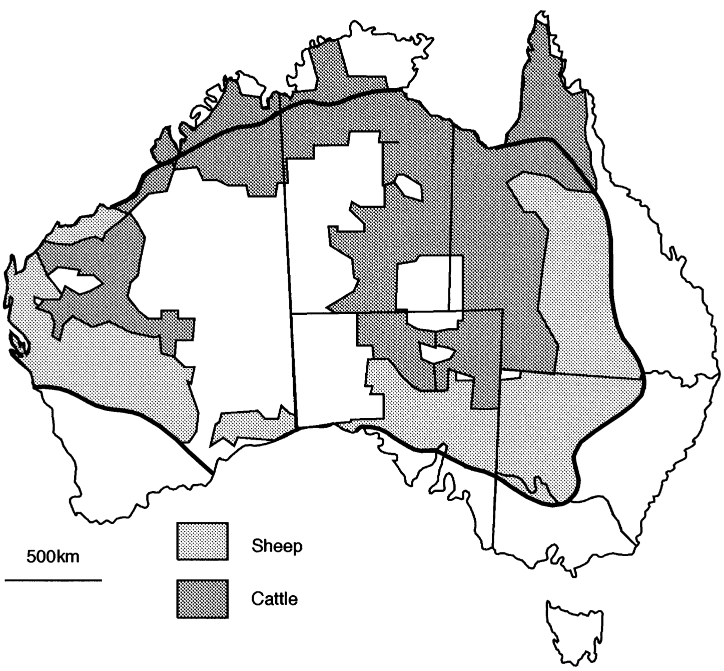

Fig. 1. Australia's rangelands showing sheep and cattle grazing areas. Thick solid line: limit of the arid and semi-arid zone usually associated with desertification. However, rangeland grazing extends beyond it into the humid tropics in the north. State boundaries are also shown

are too small or carry too large a debt to be economically viable and these problems have been exacerbated by the recent wool price collapse. These enterprises have increasingly less capacity to cope with drought and to carry out grazing in a sustainable manner. Substantial restructuring is now occurring in the rangelands through changes in ownership, government-encouraged property build-up (e.g. Williams 1995), enterprise diversification, and purchase of land through government-funded schemes for return to aboriginal traditional owners. Some areas have also been excised from pastoral leases or purchased for inclusion in conservation reserves.

3. DESERTIFICATION STATUS

3.1. Forms of land degradation

Rangeland degradation has a number of characteristic symptoms which may occur separately or together. They include:

- Soil erosion or soil degradation leading to loss of nutrients, chemical toxicity, and reduced ability to absorb and store moisture in plant available form.
- Adverse changes in herbage species composition which reduce the proportion of palatable forage in total plant biomass. These changes should be long term rather than short term for plant species composition fluctuates over time in response to grazing, fire and short term rainfall variation.
- Increases in the population of unpalatable native trees and shrubs due to reduced competition for moisture from herbage (which is now grazed) and from the exclusion of fire.

Most of these problems arise directly or indirectly from grazing but they are not confined to the commercial grazing areas for many areas not used for pastoralism are overgrazed by feral animals including rabbits, goats, horses, donkeys and camels (Newsome & Corbett 1977). These areas are also affected by changed fire regimes. There is relatively little clearing of native vegetation for conversion to pasture or cropland in the rangelands although this is a substantial problem in more humid areas. The proportion of country affected by dryland salinity is also much less than in the more humid areas, although it may be growing in areas which have experienced increases in rainfall in the last 30 to 40 yr.

Rangeland degradation is not a spatially uniform process and there are substantial off-site effects. Some landscape types are more prone to degradation than others because they have erodible soils, palatable pasture types which attract more grazing activity, or both (e.g. Bastin et al. 1993). Also, animal activity decreases with distance from water in most rangeland areas so, when grazing is centred on artificial waters, it produces a radial or star-shaped pattern of land degradation (e.g. Lange 1969, Pickup et al. 1994a). In the cattle grazing areas of central Australia, these patterns usually extend 4 to 6 km from water but where degradation is extensive, they may be detected as far out as 12 km. Sheep do not travel so far from water, especially where the salt or mineral content of fodder or water is high (see Landsberg et al. 1997 for summary), and most degradation patterns are restricted to within 3 to 5 km from water. Grazing-induced degradation often intensifies natural patterns of erosion and deposition in flat rangelands and these patterns may largely subsume simple radial effects. Degradation then appears as an erosion cell mosaic (Pickup 1991) made up of large areas of eroded bare ground feeding sediment and runoff into transfer zones of alternating erosion and deposition. These areas, in turn, feed material into densely vegetated sinks which are often choked with trees and woody shrubs.

The consequences of land degradation for production are largely unknown but pasture productivity losses of 50 to 80% are sometimes cited while production losses in monetary terms of 30 to 40% have been estimated for parts of Queensland and Western Australia (Pickup et al. 1994b). However, assessing production losses is difficult because the most serious effect of degradation in variable climates occurs through increased susceptibility to drought rather than simple loss of pasture production. For example, a modelling study by Pickup (1996) on a 576 km^2 paddock in central Australia representing one of the most degraded areas in the district shows that degradation reduces herbage consumption by cattle by between 9 and 13% overall. At the same time, the need for major destocking during drought increases from 2 to 5 times. The economic impact of such a change is substantial, with modelling studies suggesting a reduction in cash surpluses of between 21 and 63% depending on whether stocking rates are low, medium or high (Foran & Stafford Smith 1991). Effects such as these are usually blamed on drought rather than degradation so the impact of declining land condition tends to be underestimated.

3.2. Extent of land degradation

Information on the extent of land degradation in Australia has only become available recently and is still of limited accuracy in most cases. Information on whether the situation is getting worse, improving or remaining stable is largely non-existent because detection of land degradation with sufficient precision

Table 1. Areas (in thousands of km^2) and forms of degradation in Australia's arid zone. Source: Woods (1984). All values are approximate only

	Australia	New South Wales	Queensland	South Australia	Western Australia	Northern Territory
Area in use	3356	335	840	441	1114	626
Area affected by:						
Vegetation degradation and little erosion	950	32	234	173	372	139
Vegetation degradation and some erosion	467	150	80	120	61	56
Vegetation degradation and substantial erosion	284	110	50	56	39	29
Vegetation degradation and severe erosion	148	43	71	12	7.3	15
Dryland salinity	1.1	–	1.1	–	–	–

to determine change over time at the scale of a decade or so is fraught with difficulty. In the more arid areas of the continent huge variations in vegetation cover occur because growth is episodic and subject to substantial short term rainfall variability. In the areas where rainfall is more seasonal, there is still enough variability for trends in land condition to be masked. The rangelands are also highly variable spatially and contain the scars of past erosion events which predate European settlement but are easily confused with grazing-induced land degradation (Pickup 1991). The spatial variability, when coupled with variation through time, poses major problems for sampling and measurement. Thus, on-ground assessment techniques may give precise results but their high cost prevents use at a sufficient number of locations to cover the spatial variability (Bastin et al. 1993). The alternative is to use less precise techniques such as air-photo interpretation which give regional coverage but introduce too much subjectivity to allow detection of change in degradation. It is also rarely possible to carry out such assessments with sufficient frequency to filter out climatic variation (Pickup & Chewings 1996).

The first major survey of land degradation in Australian rangelands was carried out in the early 1970s (Department of Environment, Housing and Community Development 1978). The results were based on subjective assessment by Government land management agencies and are summarised in Table 1. Given the methodology, the data are of low accuracy and are not good enough to allow detection of trend. They do, however, provide an indication of the extent to which Australia is affected and show that the problem is national in scale.

A number of regional surveys have produced better information. Tothill & Gillies (1992) assessed the northern rangelands using a subjective rapid appraisal method based on discussion with expert groups. They adopted 3 condition classes: pastures in a sustainable condition, those which are deteriorating, and those which are degraded to the extent that earthworks or revegetation techniques are required for rehabilitation. The results were presented by pasture type and region (Fig. 2) with quantitative data for Queensland and the northern part of Western Australia and suggest a better picture than that presented in the national survey. Tothill & Gillies strongly endorse the need for more objective and quantitative methods if changes over time are to be monitored.

Several regional surveys have produced quantitative data. In Western Australia, a long term vegetation monitoring program based on small sites on pastoral leases has produced a record of change in plant species composition. Between 1983 and 1995, 7% of sites were found to have changed, with both improvement and decline in condition being noted, and most of the changes were attributed to climate (Duckett & Holm 1996). However, most sites were only measured twice and it remains difficult to separate the effects of climate variation from land degradation and to extrapo-

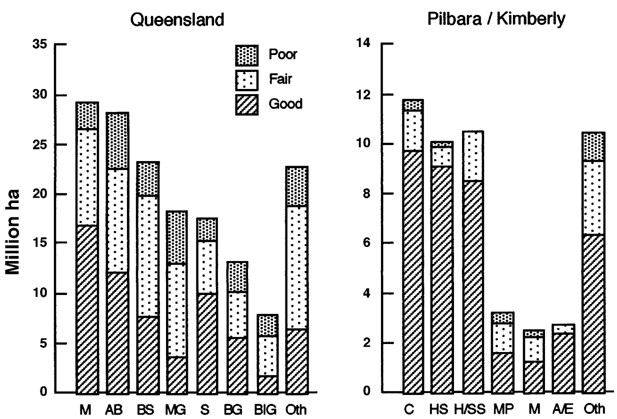

Fig. 2. Condition of grazing lands in northern Australia from Tothill & Gillies (1992). Pasture type codes for Queensland are: M, Mitchell grass; AB, *Aristida*/*Bothriochloa*; BS, black spear; MG, mulga; S, spinifex; BG, brigalow/gidgee; BlG, blue grass; Oth, other. Codes for Western Australia are: C, curly spinifex; HS, hard spinifex; H/SS, hard/soft spinifex; MP, Mitchell grass plains; M, mulga; A/E, *Acacia*/*Eremophila*

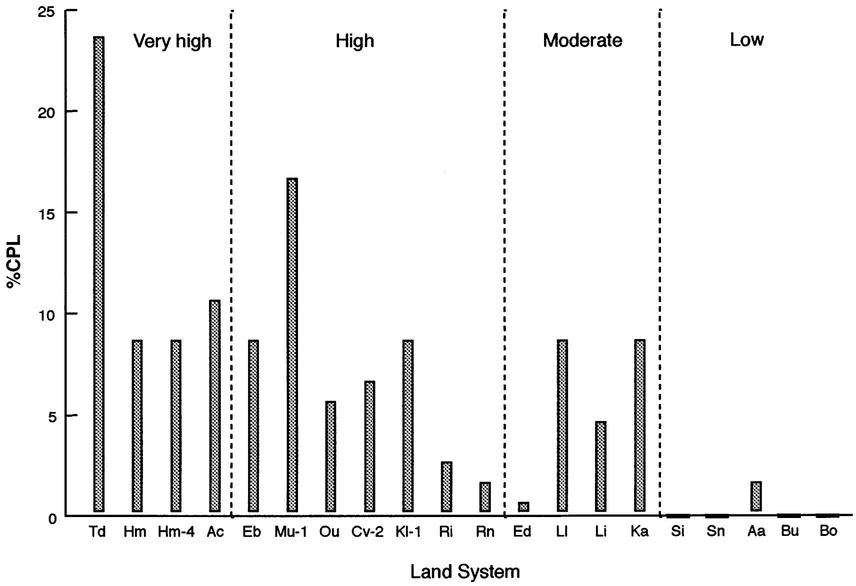

Fig. 3. Condition of central Australia grazing lands of low to very high pastoral value from Bastin et al. (1993). The %CPL variable on the *y*-axis refers to loss of ability to produce vegetation cover from rainfall as a result of degradation. Results are expressed as a percentage of total cover produced if the land system was grazed but undamaged. Land system (areas of relatively uniform geomorphology, soils and vegetation) codes are: Td, Todd; Hm, Hamilton; Hm-4, Hamilton Type 4; Ac, Alcoota; Eb, Ebenezer; Mu-1, Mueller Type 1; Ou, Outunya; Cv-2, Cavenagh Type 2; Kl-1, Kalamerta Type 1; Ri, Ringwood; Rn, Renner; Ed, Endinda; Ll, Lilla; Li, Lindavale; Ka, Karee; Si, Simpson; Sn, Singleton; Aa, Amadeus; Bu, Bushy Park; Bo, Boen

late from the point to the landscape given the sampling problems which occur with this approach. In New South Wales, a rangeland degradation survey was carried out as part of a state-wide effort using regularly spaced sample points on a 10 km by 10 km grid and recording the types of degradation within a 100 ha circle around each grid point (Graham et al. 1990). However, the results cannot be translated into total area of degradation, and information on the intensity of degradation at each point is not precise enough to demonstrate change.

A new approach based on the use of multi-temporal remotely sensed data from the Landsat satellite overcomes many of the problems of filtering out the impact of climate variability (Pickup et al. 1994a). This involves converting the data to an index of vegetation cover and examining the extent to which that cover varies with distance from water (a surrogate measure of grazing impact). Assessments are made after vegetation has responded to very large rainfalls, which removes the effect of temporary grazing impact on plant cover, and with reference to areas distant from water, which act as a benchmark. The method produces repeatable data and has been used in central Australia over regions with rainfalls varying between 150 and 450 mm yr^{-1}. Results for the southern part of the Northern Territory (Fig. 3) show that the severity of the problem varies but the areas most favoured for grazing are most severely affected. A recent variation on the technique (Pickup et al. in press) allows trend in land condition to be measured over periods of 10 to 15 yr but has yet to be applied on a large scale. However, initial results from central Australia suggest that over the last 10 to 15 yr, previously degraded areas have shown little further decline or improvement while some recently developed areas show decline in condition. There are also examples of improving condition where substantial reductions in stocking pressure have occurred.

3.3. Impact on biodiversity

Rangeland desertification has been accompanied by a loss of biodiversity as well as land condition (Table 2). However, species loss has also occurred in rangeland areas where there has been no domestic animal grazing (Curry & Hacker 1990). This makes it difficult to separate the impact of declining land condition on biodiversity from that of introduced predators and competitors, and changes in fire regime as the Aboriginal occupants were dispossessed and moved from their traditional lands.

Over the last 100 yr, 12 % of arid zone mammals have disappeared, representing 61 % of all mammal extinctions in Australia. The number of endangered mammal species is also disproportionately high in the arid zone. Morton (1990) suggests that a key factor in the demise of the mammals was their dependence on refuge habitats where the species survived during drought. These habitats were occupied by exotic predators, such as the feral cat and the fox, and competitors, including sheep, cattle and feral rabbits. There has also been a substantial impact on birds, with 8 % of arid zone species endangered, representing 59 % of endangered bird species in Australia (Woinarski & Braithwaite 1990, Garnett 1992, Reid & Fleming 1992). These authors attribute the decline in bird species to changes in habitat from grazing, clearing of vegetation and changes in fire regime.

Table 2. Extinct and endangered species in Australia's rangelands. Source: Pickup et al. (1994b)

Taxon	No. of species extinct in arid zone	Extinct arid zone species as a proportion of all extinct species (%)	Extinct arid zone species as a proportion of all arid zone species (%)	No. of endangered arid zone species (%)	Endangered arid zone species as a proportion of all endangered species (%)	Endangered arid zone species as a proportion of all arid zone species (%)
Flowering plants	6	7	0.4	8	3	0.4
Invertebrate animals	?	?	?	?	?	?
Fishes	0	0	0	0	0	0
Amphibians	0	0	0	0	0	0
Reptiles	0	0	0	0	0	0
Birds	0	0	0	19	59	8
Mammals	11	61	12	20	83	22

Some of the species loss and reductions in range have occurred in the grazed rangelands and can be related to land degradation and grazing impact. Landsberg et al. (1997) have tried to assess the extent of the problem by looking at species diversity along transects out from waterpoints in the chenopod and acacia rangelands, with distance from water as a surrogate measure of decreasing grazing impact. They found that 15 to 38 % of plant and animal species are at risk of substantial decline in the grazed areas, a similar number show signs of increase, and 36 to 75 % of species seem apparently unaffected. They regard this pattern to be of concern because most land lies within 10 km of water except in desert regions and the habitat available for the decreasing species (i.e. areas distant from water) is gradually disappearing. These figures may underestimate grazing impact on biodiversity because none of the transects examined were severely degraded. In the ungrazed rangelands, the impact of pastoralism on biodiversity has to be largely discounted so the extinctions have occurred for other reasons. In the spinifex grasslands, which are the most extensive rangeland vegetation type and cover 22 % of Australia, Aboriginal people manipulated vegetation patterns and animal populations by burning (Griffin 1984). This activity created a mosaic of vegetation in various stages of recovery since burning. The mosaic was fine grained close to waters and other inhabited areas and coarser further out, eventually merging with the very coarse wildfire-generated pattern in waterless, infertile areas. The fine-grained pattern disappeared as Aboriginal land use declined and most spinifex areas are now swept by large wildfires. The resultant change in patterning would have severely affected species with a limited range but requiring a diversity of habitats. This loss of habitat, coupled with the loss of drought refuges and increased predation, was probably enough to produce the extinctions (Pickup et al. 1994b).

4. LINKS WITH CLIMATE

4.1. Potential impact of climate change

While there are suggestions that desertification may be associated with climate change in other parts of the world, particularly through changes in ocean temperatures (e.g. Warren & Khogali 1992, Williams & Balling 1994), a simple linkage has not emerged in Australia. This may be because a relationship does not exist or the effect of climate change is relatively small compared with the impact of European settlement and changing land use in the rangelands. Also, Australian arid and semi-arid climates experience rainfall variability greater than that of comparable climates elsewhere in the world (Nicholls & Wong 1990). This variability makes it difficult to detect climate change given that few records extend beyond a century. It has also produced natural ecosystems which are highly resilient in their undisturbed state for there is plentiful evidence of major variation in climate throughout the Quaternary (e.g. Nanson & Tooth in press). The impact of European settlement on that resilience is largely unknown but it may have been so severe that much of what was vulnerable to climate change has already been affected or destroyed and what is left is relatively robust. Alternatively, it may have increased the effects of climate variability by putting less-affected ecosystems under greater stress. Establishing a relationship between climate change, climate variability and desertification is therefore unlikely to be easy.

Regional climate change scenarios have been issued for the Australian rangelands (Climate Impact Group 1992, 1994) but are subject to major uncertainties. In particular, little is known about changes to tropical cyclone patterns and to the El Niño-Southern Oscillation (ENSO) phenomenon, both of which have a major influence on rainfall patterns over much of Australia (e.g. Kane 1997). Several impact scenarios have also been developed (Graetz et al. 1988, Stafford Smith et al. 1994) postulating changes to land use in response to shifts in the pattern of vegetation cover and rainfall regime.

Stafford Smith et al. (1994) began from the standpoint that both variability and unpredictability will increase. There will be a shift towards summer rainfall, which will have its main effect on the currently winter-rainfall-dominated areas of southern Australia, and a small increase in total precipitation in most areas, which will be offset by the increase in evaporation associated with higher temperatures. Individual rainfall events will be larger and more frequent with a 3-fold reduction in the return period of 100 yr events being forecast, and there will be longer dry periods between rainfall events. Intra-annual variability will increase but the impact on ENSO-dominated inter-annual variability remains uncertain. This makes the impact on land degradation difficult to predict for there does seem to be a relationship between major shifts in inter-annual variability and landscape processes (see below).

Specific impacts of climate change which have implications for land use and land degradation include changes to hydrological patterns, plant species composition and plant productivity (Stafford Smith et al. 1994). There may be greater risk of flooding and erosion due to greater runoff. However, wet periods tend to promote revegetation and reduced erosion of the land surface while favouring channel erosion (Wasson & Galloway 1986, Pickup 1991). Enhanced runoff redistribution may occur, intensifying vegetation patterning and erosion cell mosaic structures in degraded areas (e.g. Stafford Smith & Pickup 1990). There may also be an increase in dryland salinity. Major changes in vegetation composition will come through shifts in rainfall pattern and increased runoff redistribution and will favour establishment of woody vegetation and encroachment of unpalatable woody shrubs in many areas. Plant production will be influenced by the CO_2 fertilisation effect and may increase by 10 to 30% in fertile sites in more mesic areas. In arid areas, the effects will be minimal because of moisture and nutrient limitations. The impact on land use will depend more on economic issues than climate but, based on climate alone, Graetz et al. (1988) postulate shifts in the rangeland-cropland boundary, a decline in the sheep grazing related to decline in fodder quality, and the expansion of cattle into what are currently drier parts of northern Australia.

Changes to terrestrial processes arising from climatic change will also generate feedbacks. However, European settlement has already had profound impacts in these areas. Biomass burning is an important source of trace gas emissions and atmospheric aerosols and it has been estimated that globally, dryland fires produce 10% of gross emissions from all sources (Williams 1995). In arid and semi-arid Australia, fire frequency greatly increases after wet periods (Griffin & Friedel 1985) so increased rainfall variability and more wet periods could increase emissions. At the same time, fire frequency has been reduced over time as traditional burning practices by Aboriginal people have largely ceased in most areas, as herbage fuel has been reduced by grazing, and as pastoralists have excluded fire as a land management practice. Changes in albedo also may occur and there are certainly increases due to reduced vegetation cover arising from land degradation and grazing in many areas. At the same time, there have been increases in tree and shrub cover relating to increased run-on in some areas, exclusion of fire and recent higher rainfalls, so the overall impact is difficult to assess.

4.2. Role of climate variability

So far, there have been no clear demonstrations of continuously increasing variability from meteorological records in Australia. There are, however, well-documented examples of shifts in rainfall over periods of several decades which may or may not be a consequence of greenhouse gas emissions (e.g. Nicholls & Lavery 1992). These fluctuations have had a considerable biological impact (e.g. McKeon et al. 1991) and may well show how Australian ecosystems will experience and respond to future climate change. They have also had a major impact on Australian attitudes to land settlement with excessive expectations of what is normal rainfall developing during wet periods (e.g. Heathcote 1987). The result has been unsustainable expansion of cropping into previously drier areas, pastoral developments with individual holdings too small to be economically viable, and unrealistic perceptions of drought risk from the pastoral industry. Many of these developments were sponsored or encouraged by government and supported by indirect subsidy or excessively generous drought assistance when drier conditions returned. The result has often been land degradation and economic misery producing an ongoing need for property restructuring and changes in land use (e.g. Young 1985).

The impact of rainfall variability is largely felt through changes in the pattern of plant growth since this provides fodder for grazing. An example of that impact is shown in Fig. 4 which illustrates how herbage cover in central Australia might have changed over the last 120 yr. At the broad scale, there are 3 long periods of below-average growth resulting from dry periods starting in the late 1890s, the late 1920s and

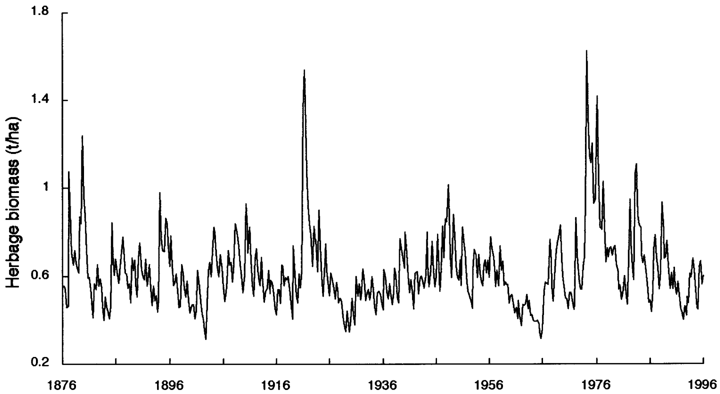

Fig. 4. Herbage biomass for a 576 km^2 area of calcareous shrubby grassland and mulga country near Alice Springs in central Australia modelled using the techniques of Pickup (1996). Note the high variability and the presence of long periods of above and below average growth

the early 1960s, and 2 exceptional growth pulses, one during 1920–21 and the other during 1973–75. These pulses resulted from rainfalls 3 times greater than the annual average (260 mm) sustained over 1 to 2 yr periods. However, most vegetation cover change occurs with greater frequency and in response to smaller rainfall events in which 50 to 150 % of the annual average falls in a period of a few days to several months. Periods in which these events are closely spaced in time or lacking create a series of minor growth periods and droughts which are superimposed on the longer term changes. Most pastoral management operates at this time scale since high frequency variability dominates both production and income. Inter-decadal variability usually remains unrecognised.

It is interesting to compare the behaviour of degraded and undegraded areas to see how the impact of degradation compares with that of rainfall variability. Fig. 5 shows how herbage cover varies over time in highly degraded areas of a calcareous shrubby grassland in central Australia and compares that behaviour with what happens when the landscape is in its undegraded state. The response of degraded and undegraded areas to rainfall variability is similar but that of the degraded area is much more damped and herbage cover is substantially reduced. However, not all degraded areas show such an extreme loss of condition and Pickup (1996) estimates that, in overall terms, the loss of herbage production is about 35 % on this particular landscape. Elsewhere in central Australia, it is much less.

The major growth pulses in the early 1920s and 1970s did not just affect herbage biomass production. They also had a substantial impact on the vegetation structure of central Australia. Anecdotal evidence, air photographs and some observations (Foran et al. 1982, Friedel 1985, Griffin & Friedel 1985, Cunningham 1996) indicate that major recruitment of tree and woody shrub species occurred. The resultant explosion of woody weeds affected large areas and reduced pastoral productivity. It was also exacerbated by grazing in some areas (e.g. Pickup et al. 1994a) although the dominant cause was climatic. The large growth pulses also established herbage on areas where it had previously been lost due to grazing or during drought (Friedel 1984, Purvis 1986). The pattern of erosion may have changed with soil being lost from catchment surfaces and accumulating in drainage systems during dry periods whereas these surfaces revegetated during wet periods and channel erosion became the dominant process.

While it is difficult to identify trends from the rainfall record, there is other evidence that extreme events have increased. Reconstruction of ancient flood sequences from sediment deposits in the gorge of the Finke River in central Australia shows that of the 8 largest flood events in the last 800 yr, 4 have occurred since 1967 (Pickup 1991). Such clustering of events may be coincidental but it could also be an indicator of climate change.

The relationship between climatic variability and desertification is complex and poorly understood, partly because it is compounded by the impact of land

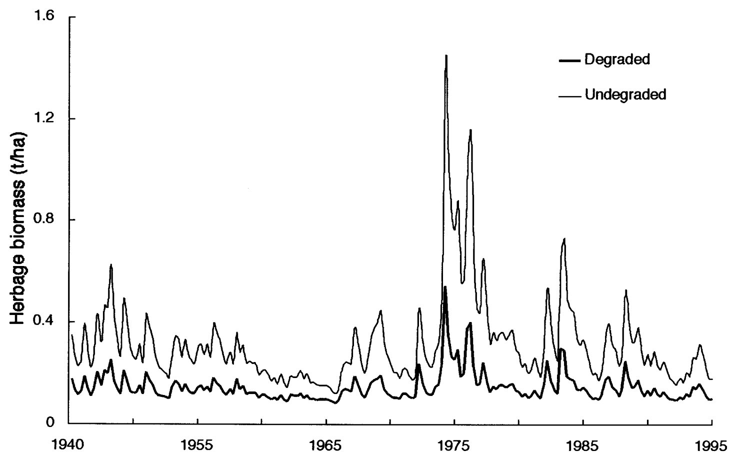

Fig. 5. Herbage biomass for degraded and undegraded areas of the calcareous shrubby grassland used in Fig. 4 modelled over a 55 yr period using the techniques of Pickup (1996). Note the damping effect of land degradation

use. It is sometimes argued that drought triggers degradation by reducing plant cover below the level already imposed by grazing so soil losses due to both wind and water erosion are higher (e.g. Warren & Khogali 1992). Also, grazing activities immediately after drought can greatly reduce plant growth in future rainfall events (e.g. Hodgkinson 1992). Thus, desertification might occur as a series of step changes in which latent degradation is precipitated by droughts with land condition maintained at a particular level or recovering between droughts or during wetter periods (e.g. Noy-Meir & Walker 1986).

Whether this model is correct or applies uniformly across the highly variable rangelands remains to be tested. Certainly, there were examples during the early stages of pastoral development of stock numbers expanding during wet periods and remaining high during the early stages of drought with a resultant decline in land condition and permanent loss of carrying capacity. Nowadays, it is much easier to move animals out of drought affected areas and grazing is spread more evenly across the landscape, reducing impact per unit area, so this problem should not arise to the same extent. Also, Pickup et al. (1997) demonstrate declining condition on a semi-continuous basis in some areas exposed to substantially increased grazing pressure during the last 10 to 15 yr even though conditions have not been particularly dry. At the same time, already degraded areas show no further loss of land condition. This suggests there may be more than 1 pattern of change present. Thus, when an area is newly exposed to grazing or grazing pressure increases substantially, condition declines to a particular level and then stabilises until further disturbance occurs such as during major droughts.

5. POLICY IMPLICATIONS

Policy approaches to desertification should focus on sustainable land use. This means that a wide range of biophysical and social processes, including climate variability and climate change, must be addressed together. Translating this into action in the rangelands is fraught with difficulties. Ecosystems are still adjusting to the impact of European settlement and, in many cases, natural resources continue to degrade. Climate variability adds to this pressure and the continuing cost-price squeeze on agriculture has increased the vulnerability of enterprises which rely directly and indirectly on grazing. Many of these enterprises do not have the capability to restructure or to change their management practices to something which matches land use with land capability, so the downward spiral continues. Indeed, much of the sheep rangelands and some areas of cattle grazing are no longer economically viable given current prices (Wilcox & Cunningham 1994). Social pressures are also increasing, leading to growing insecurity about land tenure and property rights. These have arisen because of recent legal decisions on aboriginal land rights and an increasing vocal environmental movement questioning whether grazing should be permitted at all in the rangelands given their apparent susceptibility to degradation. Not surprisingly, the policy response to these issues has been varied, confusing and sometimes contradictory. Some of these responses are summarised below.

At the national level, strategies on drought, biodiversity and rangeland management have been developed and are being applied to varying degrees (Commonwealth of Australia 1995, ANZECC/ARMCANZ Joint Working Group 1996). Climate change scenarios have also been prepared and updated but there has been little operational planning given the large uncertainties remaining in the predictions. Also, climate variability, land degradation, economic problems, and land tenure issues are seen as more immediate issues.

Land administration is a state government responsibility and state agencies are in varying stages of adjustment from a development ethos to one of sustainability. Agencies in individual states sometimes find themselves with conflicting goals because of this. Pastoral land tenure systems also reflect the shift from development to sustainability goals. Most now have covenants which emphasise maintenance of land condition rather than minimum stocking levels or amount of infrastructure (Ledgar 1994). Tax concessions to promote land clearing have also been removed and there are now regulations to limit or prevent it in most states. At the same time, there continues to be a reluctance to apply sanctions, even where there are breaches of regulations related to the maintenance of land condition. Virtually all agencies promote voluntary compliance and prefer persuasion to the ‘big stick’ approach.

At the enterprise level, the emphasis is on promoting self reliance and reducing vulnerability to drought. Property management planning is widely promoted by government and gains taxation concessions as do soil conservation works. The impact of climate variability can be reduced by income averaging over several years for taxation purposes rather than assessing tax liability on a year-by-year basis. This encourages provision for drought years. Direct drought subsidies have been reduced and the criteria for declaring an area drought affected and therefore eligible for support have become more stringent. Financial assistance for measures designed to improve on farm productivity are available through the Rural Adjustment Scheme as are grants to help farmers leave the land where properties are not economically viable. Property consolidation in areas where holdings are too small is also being encouraged in some areas (e.g. Williams 1995), although the pace of change is relatively slow.

One notable feature of Australia's approach to dealing with land degradation has been the development of community processes. The National Landcare Program provides financial assistance and an organisational framework for more than 2200 community groups engaged in a wide variety of programs but with an emphasis on self-help activities. The effectiveness of these groups varies but they have been very important in raising awareness and mobilising support. Their impact on the land largely remains to be seen.

While a range of policy responses have been developed which deal with some of the problems in the rangelands, the fundamental issues remain. Climate variability at the intra- and inter-annual scales imposes huge variations in production and farm income which the financial and taxation systems of the nation find difficult to cope with in a sympathetic manner. Climate variability at the inter-decadal scale imposes major changes in the biophysical environment, but these remain poorly understood and largely unrecognised in either policy or day to day management. Land use conflict dominates the policy response and focuses attention away from the condition of the land. Given that conflict, governments seem unwilling to embrace the range of solutions and commit the resources necessary to implement proposed policies such as those presented in the draft National Rangelands Strategy (ANZECC/ARMCANZ Joint Working Group 1996).

6. CONCLUSIONS

Australian rangelands have long been subject to climate change but have been exposed to desertification processes only recently with the advent of European settlement. The impact has been substantial but large areas are still in relatively good condition compared with other parts of the world with similar climate and land use.

There is evidence to suggest that desertification has been episodic with the maximum impact occurring when grazing is first introduced, during dry periods, or both. At present, the desertification rate seems relatively slow because of present climatic conditions and the fact that most of the country has already experienced the initial effects of pastoral development.

The level of success of policy interventions in halting or reversing land degradation remains to be seen. Most policies are too new to have had much effect. However, there are some indications that current rainfall conditions over large parts of rangeland Australia are relatively favourable, so if policies are to be effective, now is the time. The pressures which produced land degradation in the past are still present to some extent so a return to drier conditions could well offset many of the gains being made.

Australia's experience and level of success in dealing with degradation in dealing with degradation is typical of many developed countries with arid and semi-arid regions. The building blocks for effective action are increasingly in place but the results will not be known for decades. The European land use experiment continues, the consequences remain unknown, but ignorance of the ecosystem is no longer an excuse for failure.

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