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RANGELANDS AND GLOBAL CHANGE

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1. INTRODUCTION

1.1 Definition of Global Change

Although global change is often equated to "climate change", or even to "global warming", it encompasses much more. The working definition of global change adopted by the International Geosphere-Biosphere Programme (IGBP) and much of the global change research community includes three components (IGBP, 1990): (i) change in atmospheric composition, (ii) climate change, (iii) change in land use. Of these, both changes in atmospheric composition and land use are well documented and are occurring now. There is still some debate about climate change, since it is too early to detect an unmistakable signal of anthropogenically forced climate change above the noise, but there is widespread agreement within the scientific community that changing atmospheric composition will lead to climate change (Houghton *et al.*, 1991).

Land-use change is usually associated with developing countries, where dramatic changes in land cover are occurring (e.g., the conversion of humid tropical forests to agricultural uses). However, change in intensity of existing land use may also play an important role in global change, particularly with respect to emission or sequestration of greenhouse gases. In the context of Australian rangelands, the most readily varied component of the system is stocking rate, and if this changes (for example, in response to policies promoting "sustainable development"), the rangelands' role in biogeochemical cycles could also change.

The primary change in atmospheric composition, as far as terrestrial ecosystems are concerned, is increasing CO_2 concentration. To some extent tropospheric O_3 is also increasing, but its potential impacts appear to be more serious for crops than for rangelands. In the Northern Hemisphere atmospheric concentrations of sulphur and nitrogen oxides are also high due to anthropogenic sources. These species have a fertilising effect on vegetation at moderate concentrations but can become toxic at higher levels.

The third component of global change is climate. For terrestrial ecosystems the most important features of climate are temperature and precipitation, and for Australia's rangelands, the single most important feature is precipitation. Two other factors, wind and radiation (as determined by cloudiness) may change with climate change, but they are not as significant now in determining vegetation composition and structure as is precipitation.

For precipitation, changes in the patterns and distribution of rainfall events, particularly their seasonality and storm intensity profiles, will be as or more important than changes in mean values in their impact on plants in terms of moisture availability. The hydrological characteristics of the soil and temperature, as it influences the evaporative demand of the atmosphere, are also important factors in the water balance.

1.2 Secondary Effects

In addition to these direct effects of global change on ecosystems, there are a number of secondary effects which, for Australia's rangelands, may be more important than the direct effects. The first of these secondary impacts is fire. Rather modest changes in rainfall and temperature which significantly increase or decrease fire frequency may eventually lead to large changes in vegetation structure and composition which would be difficult to predict from changes in climate alone.

Other secondary effects include changes in the distribution and dynamics of pests and diseases, direct impacts of climate on herbivores, and climate-induced changes in land use (e.g., encroaching cultivation with increasing rainfall).

1.3 Scenarios of Future Climate

Current analyses of the impacts of climate change on terrestrial ecosystems use as a guide scenarios of future regional climate generated by General Circulation Models (GCMs). It should be emphasised that these GCM outputs are not predictions. Although predictions of general features of future climate on a global scale (e.g., increasing average global temperature) have a high degree of probability, detailed and accurate predictions of future climate change at a regional level are not yet possible.

Nevertheless, it is instructive to examine the recent climate change scenario for Australia's rangelands for the year 2030 as produced by CSIRO's Climate Impact Group (1991). The scenario suggests an increase of 2-4 C for inland areas, with the higher end of the range for the drier, southern areas. Rainfall may increase up to 20% compared to 1990 in the summer rainfall region (NE two-thirds of the country), with the following other features:

- monsoon more intense but monsoon trough not further south;
- less certain overall decrease of 0-20% in winter in the winter rainfall region (SW third of country);
- local changes could be two or three times larger due to topographic effects;
- general increase in rainfall intensities;
- possible marked increase in heavy rain events;
- longer dry spells in mid-latitudes

Other features of a possible 2030 climate for Australia's rangelands include a change in extreme events in both magnitude and frequency - more very hot days, fewer frosts, more floods and dry spells. A significant projection, particularly for the more arid areas, is a 5-15% increase in potential evaporation with increasing temperature.

2. THE RANGELANDS

There are four main types of rangelands, as defined by the Global Change and Terrestrial Ecosystems (GCTE) core project of the International Geosphere-Biosphere Programme (IGBP) (Steffen *et al.*, 1992):

- cold, humid: hill pastures (e.g., many of the "improved" pastures in the developed Northern Hemisphere countries);
- cold, dry: the Mongolian and Argentinean steppes;
- hot, humid: wet, tropical savannas;
- hot, dry: arid tropical, sub-tropical and even some temperate rangelands.

Most of Australia's rangelands belong in the last category, with perhaps a narrow strip of wet savanna in the far north and some areas in the far south bordering on the cold systems. However, for the purposes of this discussion, we concentrate on the arid and semi-arid rangelands that cover much of Australia.

These lands have the following characteristics:

- they often feature the coexistence of grasses and trees or other woody species;

- vegetation distribution is controlled by soil type and landscape factors;
- primary productivity is related to rainfall;
- fire is often an important factor in controlling vegetation composition and structure;
- grazing is the most extensive land use.

3. CURRENT UNDERSTANDING OF GLOBAL CHANGE IMPACTS

3.1 Overview

Despite the areal importance of Australia's rangelands, relatively little work has been done on potential global change impacts on the structure, composition and function of their ecosystems. The first overall analysis was published four years ago (Graetz *et al.*, 1988), and there has been little additional work since then. However, it is unlikely that the conclusions of this earlier study will be modified significantly until considerable improvements are made in the regional scenarios of future climate.

We examine the potential impacts of global change on Australia's rangelands by considering three interacting drivers of change: precipitation, fire and land use. For the purposes of this analysis we ignore the effects of elevated CO_2 and temperature as being secondary compared to precipitation. Most of Australia's rangelands are typical arid systems in that they are "water-controlled"; their productivity is determined by the flow of water through them (Graetz *et al.*, 1988).

We consider in turn the impact of these interacting driving forces on several aspects of Australia's arid ecosystems:

- vegetation distribution and composition - what species or species guilds (i.e., functional types) are present where? What will happen to the major vegetation associations?
- vegetation structure - what will happen to the woody:grass ratio?
- net primary productivity
- erosion - how will increased rainfall and changing land use affect degradation processes?
- biological diversity

3.2 Vegetation Distribution and Composition

Vegetation distribution can be considered at a number of scales, but here we consider two: the large "regional" scale corresponding to a GCM grid cell (500 km) and the "landscape" scale more commonly associated with human management units (10 km). For the former, climate, primarily precipitation, is the dominant factor, and Australia's vegetation can be viewed as lying "in discontinuous, concentric arcs of decreasing cover and biomass approaching the central arid core of the continent" (Graetz *et al.*, 1988). At the landscape scale, physiographic or geomorphic features become important and vegetation associations are closely related to the underlying soil type. At finer scales, biological processes associated with vegetation types modify and control the edaphic environment.

How will global change affect the vegetation distribution in Australia's rangelands? With one exception, very little, according to the study by Graetz *et al.* (1988) in which the future distribution of two vegetation types - trees and shrubs - were predicted on the basis of changes in six environmental variables (mean annual radiation and temperature, annual precipitation, precipitation in the wettest month, seasonality of precipitation, and soil water holding capacity). The changes in these environmental variables were derived from a climate change scenario for the year 2030 AD.

Predicted changes in tree and shrub cover were surprisingly small. This was interpreted as a measure of the resilience of arid zone vegetation, but it may also show the controlling importance of edaphic factors, namely water holding capacity and available nutrients, which may not change much with climate change. The one exception, the most important change, involved the conversion of large areas of the southern chenopod shrublands into wooded grassland, which would have a significant impact on the sheep industry.

It should be noted that these predictions are based on change in climate alone, using a regression analysis based on present day vegetation distribution. Other factors, such as fire frequency and grazing intensity, were not considered. These latter factors will have important consequences for vegetation structure.

Changes in vegetation composition, particularly on the patch scale (10 - 100 m), are more difficult to predict. A promising approach outlined by Graetz *et al.* (1988) is that of functional types, in which plants are grouped into types based on functional characteristics, such as metabolism (C3/C4), phenology, demographic attributes (e.g., longevity, periodicity of germination events) and structure. Of special importance for global change research are the responses of functional types to changing environmental factors, such as precipitation and fire regimes. This approach has been adopted on a global basis by the Global Change and Terrestrial Ecosystems (GCTE) core project of the International Geosphere-Biosphere Programme (IGBP) (Steffen *et al.*, 1992).

3.3 Vegetation Structure

For the purposes of this discussion, we consider vegetation structure to be represented simply by the grass:tree ratio. Although this is a fairly crude representation, particularly at the patch scale, any attempt to refine it further is probably not warranted given the very sketchy nature of regional climate scenarios at this stage and the critical role of large-scale fires.

With respect to global change, fire has a dual nature. It is undoubtedly one of the most significant factors affecting the structure and composition of the rangelands, and indeed is used as a management tool to control the grass:tree ratio. Thus, it is a driving force for change.

However, the frequency, extent and intensity of fire are themselves affected by the other drivers of global change, rainfall and land-use practices. The net effect is complex and difficult to predict. Fire regimes are affected primarily by the biomass accumulation rate, the dryness of that biomass, and the intensity of grazing. Heavily grazed areas seldom burn; burned areas are much favoured by herbivores; periods of high rainfall lead to high vegetation biomass of lower quality (higher C:N ratio) and increased probability of fire; increased frequency and intensity of fire leads to a higher grass:tree ratio and therefore favours grazers; grazing tips the competition balance between trees and grass in favour of trees, and so on (Walker, 1992).

Global change may alter these relationships in one direction or the other. In the tropics and sub-tropics, extending south into the temperate zone, increasing summer rainfall (coupled with increasing CO_2) will most likely favour the C3 woody species over the C4 grasses. If, on the other hand, the rainfall comes in bursts with long intervening dry spells, fire frequency and intensity could well increase, favouring grasses. If grazing intensities are lowered in many areas, both because of a desire to reach an optimum level economically over the long-term (McKeon *et al.*, 1992) and because of a political and social move toward "sustainable development", this would also tend to favour grasses at the expense of trees. It is not clear from this type of analysis what will actually happen to tree:grass ratios in future. However, it is probably safe to say that human land-use practices in terms of management fires and grazing intensities will probably be the dominant factor, as it is today.

3.4 Vegetation Productivity

Given its direct dependence on moisture availability in arid ecosystems, net primary productivity is probably the easiest vegetation characteristic to predict. In general, on broad time and space scales, increasing rainfall will lead to increasing net primary productivity. However, this general prediction must be tempered at smaller scales by a number of factors which become important. One, of course, is the pattern of the increased precipitation - its seasonality, the intensity of storms, the interval between rainfall events, etc. - in relation to the phenological response of plants. A second is temperature, which affects the evaporative demand of the atmosphere and thus the amount of moisture available to plants and the rate at which soil moisture is depleted. Another is soil, which plays a major role in plant available moisture through texture, depth and in available nutrients.

3.5 Soil Erosion

Land degradation is a perennial issue in the rangelands, and is typified by the images of dust clouds over Melbourne during the drought of the early 1980s and the subsequent initiation of land care programs to improve the situation. That degradation can have regional consequences is evidenced by the layers of red dust that sometimes blanket the glaciers of New Zealand's Southern Alps (Mokura *et al.*, 1972).

Any increase in rainfall intensity and/or storm size will increase soil erosion by water, and the same applies to any increase in wind regimes in the arid zone. As long as the erosion constitutes redistribution within the landscape, it does not lead to degradation. When it reaches the level where there is a net loss of soil from the landscape (via streams and rivers), degradation becomes evident (Tongway and Ludwig, 1990).

An additional important factor is land use, primarily grazing intensities and fire regimes. These, in conjunction with the change in litter fall with changing net primary productivity, will determine the cover of the soil surface and the structure of its top layers, and hence its susceptibility to erosion.

3.6 Biological Diversity

Australia already has the world's highest rate of extinction of native mammals, largely due to loss of habitat from changes in land use and the introduction of predators and competitors (especially foxes, cats and rabbits). Human-driven pressures will likely continue to be the most important factor in future extinctions of Australian flora and fauna, with change in climate an exacerbating factor in some cases.

In the northern regions of Australia's rangelands - the wet-dry tropics - land-use patterns may combine with changes in climate, as projected in a CSIRO GCM scenario, to generate further pressure on some species (Williams *et al.*, 1991). At present the habitats and associated wildlife in the region are diverse and patchy, with migration and breeding patterns tuned to the cycles of rain and fire. Any significant changes in the intensity and timing of the wet-dry cycle may disrupt these patterns and threaten those species that exist now in only small patches of suitable habitat.

Arid-zone species may be particularly vulnerable if a general increase in rainfall causes a southward shift of their habitat. At present the least degraded parts of the arid zone are in the north, and species may thus be pushed southward into more degraded areas and therefore to higher probabilities of extinction. A good example of this is the bilby, which has already disappeared from the southern part of its range, where the impact of rabbits, foxes, and cattle has been the greatest. Possible climatic change could shift the climatically suitable areas for the bilby from its last remaining habitat into areas where it has already been eliminated. Other species which could be similarly vulnerable include the rufous hare-wallaby and the spectacled hare-wallaby (Williams *et al.*, 1991).

4. IMPLICATIONS FOR FEEDBACKS TO ATMOSPHERE AND FOR MANAGEMENT STRATEGIES

4.1 Feedbacks to Atmosphere

Walker (1992) analysed the significance of feedbacks from extensive agricultural areas around the world for greenhouse gas emissions and concluded that, in general, they are of minor significance on a global scale. The possible exception are the humid, savanna woodlands, where biomass burning releases a large annual flux of greenhouse gases to the atmosphere. It is not clear, however, whether burning in the savannas represents a net emission of gases to the atmosphere, as there is significant gains in biomass in the quiescent periods between fires. Further work (see below) is needed to quantify the overall effects of biomass burning in the semi-arid tropics.

Direct emissions of CH_4 from cattle and termites and the release and uptake of gases by soil are also important processes in the biogeochemistry of the rangelands. There is some speculation that savanna soils may be sinks for CH4 but it is unlikely that they are significant compared to the destruction of CH4 by OH radicals in the atmosphere, by far the most important sink.

Historically, the emission of CO_2 from the oxidation of soil organic matter may have been important. J. Williams (personal communication) has noted that in some areas overgrazing has resulted in loss of as much as two-thirds of soil C in the upper layers (from 1.5 to 0.5% C content in the top 10 cm of soil, or about 14 t/ha of C). If we take the amount of extensive agricultural land that has been degraded over the past 100 years to be $3.1 \times 10_9$ ha (Mabbutt, 1984), then the C loss to the atmosphere could be as high as 43.4 Pg over the period, or a rate of 0.43 Pg C Y-1. This is about one-tenth the rate of Australia's fossil fuel emissions. Australia's rangelands, which have suffered considerable soil degradation in many regions, contributed (and may still be contributing) its share to these emissions (D. Tongway, personal communication).

4.2 Management Strategies

Given the uncertainties in predictions of future climates, it is not possible to prescribe specific management strategies that should be adopted under global change. However, for the pastoral industry, a move toward an optimum and much more flexible stocking rate, advice consistent with "sustainable development" initiatives, would also be appropriate for global change. McKeon *et al.* (1992) noted that the stocking rates in many areas of Queensland's rangelands are presently beyond the optimum, both ecologically and economically (in the longer term). A reduction of rates would not only reduce and begin to ameliorate the degradation that results from overgrazing, it would also allow managers more flexibility in dealing with the changes in climatic variability and in frequency of extreme events that will likely accompany climate change. Short-term economic practices will have to be adjusted to allow graziers the flexibility to adopt lower stocking rates where they are presently above the optimum.

Another management option, at least in some parts of the rangelands, is the use of fire to control the grass:tree ratio. Where increasing rainfall and elevated CO_2 combine to favour woody species, fire regimes may need to be adjusted to retain the productivity of grasses.

Walker (1992) set out a three-stage process for developing a management strategy for semi-arid tropical ecosystems under global change:

i) An analysis of the environmental and land-use determinants of ecosystem dynamics, based on identifying the management/climatic combinations that lead to change, and developing them into a predictive model, of the state-and-transition type.

ii) Quantitative assessment of the relative pros and cons of each possible state with respect to the management aims.

iii) Deciding on a state (or a set of states) which optimise the aims, so far as possible, and using the model to develop an appropriate management strategy.

Currently Australia's rangelands are managed primarily for conservation, for Aboriginal uses, or for the pastoral industry. An intriguing possibility for the future is the deliberate management of rangelands as a continental C sink. As we noted earlier, there has been much degradation of these regions, with a concomitant loss of C to the atmosphere through oxidation of soil organic matter. A move away from practices that lead to degradation, particularly a reduction in stocking rates, could reverse this process and begin to sequester C as increasing levels of organic matter in the upper layers of soil. If future treaties on emissions of greenhouse gases allow nations to devise a mix of emission reductions and sequestration increases, Australia could, to some extent, meet its obligations by consciously sequestering C over large areas of the rangelands.

Gifford's continentally aggregated model of the Australian vegetation carbon budget, CQUESTA, gives some indication of the quantities involved (Gifford, 1992). Using his standard parameterisation of the model, Gifford concludes that Australia might be a net sink for CO_2, with a total annual sequestration of C into the Australian land mass of about 104 Mt C y-1 in 1991, compared to emissions from fossil fuel burning of about 75 Mt C y-1 and estimated net emissions from deforestation of 0-35 Mt C y-1. Of the total annual C sequestered, about 57 Mt C y-1 was being stored in the modelled soil organic pool (Gifford, 1992).

Sequestration of C will not occur uniformly across the continent; those areas with higher rainfall and thus higher net primary productivity will contribute relatively more. Therefore, although rangelands cover about 70% of Australia, they will not contribute 70% of the C sequestered. If we assume that they contribute only 25% to Australia's net primary productivity, their share of the sequestration of C into the soil organic pool would be about 14 Mt. This amounts to 20% of Australia's annual CO_2 emission from fossil fuels (often quoted as a reduction target).

For a deliberate strategy of C sequestration in the rangelands to be effective and acceptable, however, much better knowledge of soil carbon dynamics is needed (McKeon *et al.*, 1992). Accurate measurements of CO_2 emissions from soils and vegetation and of organic matter accumulation in soils under alternate stocking rates and fire regimes are of particular importance. Care must be taken in the measurement of soil respiration. For example, in the Nullarbor significant quantities of CO_2 are emitted from limestone during and immediately after rainfall. The most important point is that increasing C storage in rangeland soils is a "no-lose" strategy in that it will almost certainly also lead to higher levels of productivity and increased resistance to erosion and hence resilience to grazing pressure.

Although there are encouraging developments (e.g., the Landcare groups), most existing management strategies are inadequate for halting Australia's loss of plant and animal species under present-day conditions, let alone in coping with predicted climate change. Land-use patterns, in their effects on fragmenting the habitats of species, and their direct effects on habitats, are probably the most important factors.

5. FUTURE RESEARCH

5.1 Global Change and Terrestrial Ecosystems (GCTE)

GCTE is placing strong emphasis on semi-arid tropical savannas in its international research programme (Steffen *et al.*, 1992). This biome has been identified for high priority in both the elevated CO_2 and biogeochemical Activities of Focus 1 on Ecosystem Physiology. The objective of the elevated CO_2 work, which may eventually include a FACE (Free-Air CO_2 Enrichment) experiment on a savanna system, is to determine and predict the effects of elevated CO_2, interacting with other environmental factors, on the physiology of savanna ecosystems at the patch scale, and to investigate potential feedbacks to the atmosphere.

GCTE's research on changes in the biogeochemistry of semi-arid tropical ecosystems aims to determine the interactive effects of altered precipitation and changes in land use (particularly grazing and fire frequency) on the biogeochemistry of these systems along a moisture gradient. The research will be carried out along transects, with the Savannas in the Long Term (SALT) program in West Africa and the Northern Australia Tropical Transect (NATT) selected as initial GCTE gradients.

GCTE also has a Task specifically on the global change impacts on pastures and rangelands and the resulting effects on livestock production. The objective is to predict the effects of global change on pasture and range composition and production, and the consequent impacts on livestock. Rangelands and pastures have been classified into four climatic types (see section 2 above). Research groups will be developed in each one working toward a predictive understanding of global change impacts on productivity. The ultimate aim is a "generic" rangelands model.

5.2 Northern Australia Tropical Transect (NATT)

A proposal for an integrated atmospheric chemistry, biogeochemistry, and ecosystem dynamics research project for northern Australia has been put forward as part of the Australian IGBP proposal (Australian IGBP National Committee, 1991). The project aims for a predictive understanding of change in ecosystem function and structure under global change. It is based on a transect from Darwin in the north to near Tennant Creek in the south. An important applied component of the project is the development of modelling tools to assist in the management of Australia's rangelands under conditions of changing climate and atmospheric composition.

6. SUMMARY

Most important implications of this analysis for Australia's rangelands are:

i) Better predictions of climate change, both in spatial resolution and degree of confidence, are needed to progress beyond a broad-scale analysis of possible effects.

ii) Given that better projections of climate will become available, a "generic" rangelands model, incorporating a better understanding of system-level responses to changes in climate, atmospheric composition and management strategies, is needed to investigate the implications of global change.

iii) Based on our current state of understanding, it seems as though the changes in Australia's rangelands will be within the capabilities of managers to cope, over at least the next several decades, provided they are made aware of the likely local and regional changes as predictions improve, and provided they adopt flexible management strategies.

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