Assessment of Australia's grasslands and rangelands by spatial simulation

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Abstract A spatial modelling framework for assessing the condition of Australia's grazing lands has been developed. A case study for Queensland has been completed and has been operational during the 'recent' drought (1991 to present). The second stage of the project (Aussie GRASS) involving the national collaboration of state agencies and CSIRO divisions is described including an analysis of available regional models of plant growth, issues of extension, satellite data and biophysical data sets. The case study in Queensland demonstrated that a spatial modelling framework could successfully integrate climate data, natural resource data, remote sensing, historical agronomic research and simulation modelling to provide useful and objective assessment of drought conditions.

1. INTRODUCTION

'Unless we can calculate that x number of stock on y pasture with z rainfall will produce α liveweight, β soil erosion and γ change in grass basal cover, then we don't have a pasture science' (adapted from Dr. Joe Ebersohn circa 1979).

As this quote suggests, the quantitative assessment of the condition of Australia's grasslands and rangelands continues to be a difficult problem because of the complexity of the biophysical system which includes the interaction of high spatial and temporal variability in resources and climate. Pastoralism in Australia occurs in zones of high year-to-year rainfall variation. Heavy utilisation by animals during drought years causes the loss of desirable perennial plants and reduces protection for the soil surface (e.g. Gardener et al. 1990). It is only when data on animal numbers and pasture growth are combined that important indices of sustainable resource use (pasture utilisation and plant cover) can be derived (Johnston et al. 1997). For Queensland, a near-real time capability for calculating pasture utilisation and cover has already been developed (Brook 1996). The approach involves running a pasture growth model (GRASP, Littleboy and McKeon 1997) on a spatial basis (5 km grid) over the entire State (1.7 million km^2). This system is currently generating products on a monthly basis in Queensland. Because of the high spatial variation in climate and resources (vegetation, soils, topography), regional ecosystems differ in terms of which physical and biological processes are most important. As a result, different simulation models of soil water balance and plant growth have been developed over the last 30 years allowing simulation of specific regional grazing systems. These models have usually been developed to investigate the impact of management options for pastures, stocking rate and herd/flock composition on animal production, finances and (sometimes) sustainability. These models have typically been derived from agronomic experiments, resource monitoring and grazing trials. As such, these models represent the best available regional knowledge accumulated over the last century of agricultural research organised in a systematic and predictive way. The models have been tested in the real world of agricultural enterprises, they can be linked to remotely sensed data of key variables and are supported by an ongoing network of agricultural research. This paper describes the development of the second stage of the national project (Aussie GRASS) to use the above regional modelling capability to assess the condition of Australia's grazing lands from the perspective of the driving climatic and biophysical processes.

2. A CASE STUDY: A BIO-PHYSICAL BASIS FOR ASSESSING NORTHERN AUSTRALIAN GRAZING LANDS

In northern Australia, grazing occurs largely on native grasslands and woodlands. The native pasture zone is highly variable with respect to both soil type and climate, and experiences large year-to-year and decade-to-decade variation in rainfall. The variability of this environment affects pasture production, animal production, carrying capacity and profits (McKeon et al. 1990). The potential for degradation of this resource means that both Government and Industry have a responsibility to monitor the condition of the resource, and to derive sustainable management practices which account for year-to-year variation in climate and pasture production. The recent availability of seasonal rainfall forecasts based on El Niño/Southern Oscillation (ENSO) suggests that improved management options may be available and are likely to be used by industry (Paull and O'Sullivan 1997).

The grazing industries of northern Australia are based on pastures of perennial and annual grasses. Subjective assessment of pasture condition across Queensland (Tothill and Gillies 1992) suggest that 18% are in degraded and 42% in deteriorating states. Modelling studies suggest that changes in pasture composition (pasture degradation) is determined by **pasture utilisation (pasture eaten ÷pasture grown**, McKeon et al. 1990, Day et al. 1997). Land degradation (soil loss or reduced infiltration capability) is determined by **surface cover** (Gardener et al. 1990) which is highly correlated with **standing pasture dry matter**. Standing pasture dry matter is the net result of the addition of pasture growth, losses by animal consumption (pasture eaten by domestic, feral and native fauna) and losses by natural detachment. **Stocking rate** affects the processes of pasture growth, detachment and animal consumption. Thus quantification of the interaction of stock numbers (stocking rate) and pasture growth is fundamental to (1) understanding processes of pasture and land degradation, (2) defining acceptable resource management practices, (3) monitoring resource use, and (4) forecasting risk of degradation (Johnston et al. 1996, Day et al. 1997). It is on this basis that a spatial modelling framework has been developed for Queensland to simulate in near-real time and to forecast pasture growth and utilisation variables.

3. A SPATIAL MODELLING FRAMEWORK FOR QUEENSLAND'S GRAZING LANDS

The first stage of the project (QPI20) was completed in 1996 as described in detail in two major reports (Brook 1996, Day et al. 1997) and the main findings are summarised here. In this stage Queensland was treated as a case study building on previous work commenced in 1991 which integrated climatic analysis, remote sensing and simulation modelling to provide regular and objective assessments of drought in Queensland (1991 to present). Field studies of pasture growth (Day et al. 1997) and supporting simulation studies (Johnston et al. 1996, McKeon et al. 1996) had shown that seasonal rainfall explained only 40% of the variation in seasonal pasture growth. Independent validation studies indicated that models of soil water and pasture growth could explain 50-70% of observed variation (Day et al. 1997) by accounting for resource attributes such as tree density, available soil water range, nutrient availability, different species eco-physiology, and, most importantly, the temporal distribution of seasonal rainfall. For drought analysis, a key feature is the lack of above ground growth of perennial grasses in response to low seasonal rainfall. From these analyses it was hypothesised that simulation of pasture growth across Queensland would provide a more relevant and objective assessment of a drought situation, and also simulate the major forces driving land and pasture degradation.

The approach developed for Queensland involves running a pasture growth model (GRASP) on a spatial basis (5 km grid) over the entire State (1.7 million km^2). GRASP calculates a daily soil water budget using four soil layers and the processes of run-off, drainage, soil evaporation, and grass and tree transpiration from inputs of rainfall and other climate variables. Soil parameters include available soil water range for each layer, maximum rate of bare soil evaporation and infiltration parameters. A plant growth index is calculated from a soil water index, plant growth response to average temperature, solar radiation, and nutrient availability. At low green cover, plant growth is calculated as a function of this growth index, plant density and potential regrowth rate. As green cover increases, plant growth is calculated from a combination of radiation interception, transpiration and vapour pressure deficit.

The main plant and soil parameters can be derived by calibrating the model with data collected using a standard field methodology (Day and Philp 1997). In Queensland GRASP has been calibrated for a broad range of pasture communities (>40), soil types and climatic conditions for >75 grazing exclosures over a number of years resulting in 175 site by year combinations. GRASP has also been evaluated over a range of grazing pressures on ten major grazing trials in Queensland (Day et al. 1997).

The spatial version of GRASP requires inputs of spatially interpolated rainfall and climate (maximum and minimum temperature, humidity, solar radiation, class A pan), soil and pasture types, tree density and stock numbers (Carter et al. 1996). Soil parameters were estimated for each soil class based on information derived from extensive soil surveys together with exclosure data. Pasture parameters were derived by developing general parameter sets for each pasture community based on data from grazing exclosures. A major source of spatial variation in pasture growth is tree density. GRASP simulates the competitive effect of trees on pasture growth through relationships between tree basal area and tree transpiration. Tree basal area for each pixel was estimated from an analysis of a time series of NOAA NDVI images and field measurements across the state (Danaher et al. 1992).

An extensive field survey of Queensland was undertaken by two field officers from January 1994 to August 1995. Over 220 000 visual estimates of standing pasture yield were recorded during 122 000 km of travel in 256 days of field work. Calibration harvests were carried out during each day. Pasture parameters for each pasture community were derived by optimising the model with a subset of this extensive field survey data. Close agreement was found between the pasture community growth parameters (e.g. transpiration efficiency) from the extensive field survey data and those from the grazing exclosure data set.

The case study in Queensland demonstrated that it was possible to combine climate and resource information from a wide range of sources using an operational spatial modelling framework. The framework was general enough to include similar information from other states and prototype simulations of pasture growth over the whole continent were demonstrated (Carter et al. 1996). Similarly, the inclusion of a different type of plant growth model (wheat) was demonstrated. Analysis of selected data sets of pasture growth and yields collected in other states indicated the need for regionally specific models to capture the dominating vegetation and landscape processes at different locations (McKeon et al. 1996).

The major outputs of the first stage were directed at government drought policy by providing objective assessment of the Queensland drought (1991 to present). All outputs (climate, remote sensing and pasture simulations) were found necessary to continually assess conditions in an objective way. The major achievement of the system was the capability for objective assessment of the extent of drought conditions when analysis of rainfall alone disagreed with local assessment. Most operational effort was directed to the above 'big picture' needs, leaving a major gap in on-property and regional application (Paull and O'Sullivan 1997). In the initial stage to address this problem, the needs of primary producers for climatic information of this type were assessed in 'Managing for Climate' workshops as part of the Property Management Planning (PMP) process (O'Sullivan 1995). Follow-up surveys after the workshops indicated the potential use of climatic information including the use of ENSO-based forecasts in stocking rate decisions.

4. AUSSIE GRASS - THE PROJECT

Aussie GRASS is a national project funded by the Land and Water Resources Research and Development Corporation (LWRRDC) with collaborators in Queensland, Western Australia, South Australia, New South Wales, Northern Territory and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The project has several main tasks which are represented as sub-projects.

4.1 Southern pastures

Three models that have been developed for parts of this region: the shrublands model IMAGES (Agriculture Western Australia, Hacker et al. 1991); the central Australian ARIDGRO model (CSIRO DWE, Hobbs et al. 1994); and the western NSW SEE-SAW model (CSIRO DWE, S. Marsden, Canberra). These three models, along with GRASP, are being examined in a 'desk top' study to compare how they simulate the important processes of the pasture system. The models are also being examined for their input data requirements, ease of calibration and potential for incorporation within the existing spatial modelling framework. While a model may be very accurate, spatial data requirements may preclude it. Suitable data sets from the southern pastures zone are being identified and will be used to test the ability of each model to account for observed variation in key variables such as pasture growth and standing dry matter.

4.2 High rainfall zone

The GRASSGRO model (CSIRO PI, Moore et al. 1997) is intended for use in temperate southern Australia including Mediterranean-like regions. GRASSGRO is useful where paddocks, grazed by sheep or cattle of any breed, are limited to pastures based on annual or perennial grasses and forbs, but not where shrubs or trees contribute to the diet of animals. At present, GRASSGRO simulates pastures of phalaris, sub-clover, perennial ryegrass, cocksfoot, annual ryegrass, capeweed, white clover, lucerne and a few other species. The authors of GRASSGRO are working to extend the range to native species as well as other sown species and different cultivars.

4.3 Northern Territory and Kimberley rangeland

Meat Research Corporation (MRC) funded research in the North Australia Program (NAP2) involved the establishment of exclosure sites (R. Dyer and M. Cobiac) and calibration of the GRASP model for 22 sites throughout the Victoria River District (VRD) and Katherine regions. A range of pasture communities, soil types, climatic zones and land conditions are represented. As a result, the GRASP model has been parameterised for a range of pasture communities and land conditions within the VRD.

Accurate estimates of fire scars and burnt areas are important for simulating carry-over pasture from previous years. Currently NOAA data is provided by Department of Land Administration, WA, to produce fire history maps of the NT and the Kimberley. Large areas of the Top End of the NT and the Kimberley are burnt each year. These images provide a potentially powerful tool for fire and pastoral management but have undergone little, if any, ground truthing. This issue is currently being addressed in a Rural Industries Research and Development Corporation (RIRDC) project.

Upon selection of the appropriate model/s for the relevant land system or zone, the next phase is to calibrate and validate the model and output on a spatial basis.

4.4 Extension

Products from the operational Queensland spatial model (Paull and O'Sullivan 1997) will provide the basis upon which the Aussie GRASS extension products will be developed but which will be modified and refined via participative processes in a series of iterative consultations and facilitated workshops. Training of extension officers is necessary to provide an understanding of the Aussie GRASS products, how to use them in conjunction with seasonal climate outlook information, and how to promote them. This will be achieved by Queensland extension officers facilitating training workshops in all collaborating states. Most collaborating organisations have established or are developing suitable 'self-help' information systems in addition to the traditional mass media outlets and technical leaflets, e.g. access to timely information by poll fax or access to the World Wide Web on the Internet. Testing of the products with primary producers, agribusiness, local drought committees, catchment managers, and government land and policy administrators in the pastoral industries of Australia will be essential to get feedback on: the value of a particular product in making property management decisions; presentation format - is the product user-friendly with the information expressed in the most useable form?; is there a related product which would be useful in making property management decisions? Products will then be modified in accordance with client needs. It is also important that Aussie GRASS products be integrated with other extension and training activities such as PMP workshops and information systems/tools designed to help graziers manage for climatic variability, e.g. the DROUGHTPLAN products (Paull and O'Sullivan 1997).

4.5 NOAA data

NOAA satellite imagery is of importance to land managers for the measurement of vegetation greenness and has been used by various agencies to map drought extent. QPI20 used NOAA images to develop a national tree density map (Danaher et al. 1992). The NT Bushfire Council and the Department of Land Administration, WA, use NOAA imagery to map fires and fire scars. NOAA data have also been used in QPI20 to validate the spatial accuracy of simulated green cover. Unfortunately NOAA data are received by a variety of organisations, historically they come from a number of satellites and are processed to a number of standards. Despite some previous attempts, a national standard of current and archived data is not available to agricultural and environmental agencies. This project aims to conduct a totally comprehensive national consultation, with a research imperative backed by LWRRDC involving examination of the current NOAA receiving stations and processing methodologies; the facilitation of an agreement between the concerned parties on the best way to calibrate, navigate, composit and mosaic NOAA data (current and historical); and the correction of data for radiometric effects, water vapour, ozone and clouds.

4.6 Point and spatial data sets

Collaborating parties are improving the spatial data sets associated with Aussie GRASS, in particular:

* better resolution Geographic Information Systems (GIS) coverages of native and improved pastures;
* validation of the NOAA tree/shrub density map by undertaking local foliage projective cover and tree basal area measurements;
* GIS coverages of cropped areas;
* including available and appropriate land mapping data from the Murray Darling Basin program;
* soil parameters such as wilting point, field capacity, infiltration, depth and Principal Profile Form description;
* documentation and computerisation of historic pasture and grazing trials;
* maps of macropod and feral animal density;
* general land use mapping;
* stock numbers data, and improved heuristics for stock distribution across the landscape;
* temporal changes between grazed and un-grazed states in national parks, reserves, military training areas and reversion of grazed areas back to vacant crown land;
* spatial validation of pasture yields along the states and NT road networks as in QPI20;
* the density of stations in the volunteer rainfall network and facilitating the linking of these new sites into the Bureau of Meteorology network; and
* spatial validation of the model with NOAA satellite imagery as in QPI20.

5. CONCLUSIONS

Historically, governments tend to react after observed degradation events (McKeon et al. 1996). The above system provides the necessary information that could facilitate action before land degradation occurs, including the simulation of driving forces in real-time and forecast risks of degradation (Day et al. 1997). While the above components of this information system are being assembled, current research is concentrating on the financial assessment of grazing management options available to individual producers in order to reduce the risk of degradation. A general process model, as is being developed in this project, also allows other issues such as climate change and landuse change to be examined.

Aussie GRASS represents the second stage of a bold undertaking of collaborating state and Commonwealth agencies to systematically address the issues of sustainable management of Australia's grazing lands. In stage one, a case study for Queensland demonstrated that a spatial modelling framework could integrate previously unrelated data sources including climate, natural resource, remote sensing, historical agronomic research and simulation models. The system became operational during the 'recent' drought providing an objective assessment of drought impacts in Queensland. By linking to other projects in the Managing for Climate Variability Program, the issues of on-property application are also being addressed.

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