ASSESSING DESERTIFICATION IN ARID AUSTRALIA USING SATELLITE DATA

Gary Bastin and Vanessa Chewings, CSIRO Division of Wildlife and Ecology,
PO Box 2111, Alice Springs, NT 0871, Australia

ABSTRACT

Large paddock size, complex vegetation patterns and variable rainfall combine to make assessment of grazing impact difficult in Australia's arid and semi-arid lands. Satellite data are useful in separating adverse grazing effects on vegetation cover from that caused by spatial and seasonal variability. Grazing is focussed on watering points and cover varies systematically with distance from water to produce a "grazing gradient". After good rains, vegetation cover is fully restored close to watering points if landscapes are not degraded while the persistence of a gradient indicates land degradation or desertification. Two operational methods for objectively determining desertification over large areas are illustrated. We also show how the results of analysing satellite data can be effectively verified with airborne video data.

INTRODUCTION

Australia's arid and semi-arid lands (the rangelands) occupy 75% of the mainland, some six million sq. kms. Of this area 58% (3.48 million sq. kms) is grazed by sheep and cattle as commercial livestock enterprises. Individual landholdings (sheep and cattle ranches) range in size from hundreds to thousands of sq. kms.

Ranches are fenced into a few, to many, paddocks; the paddock being the individual management entity. Paddocks may contain several sources of drinking water for livestock (i.e. watering points) and because animals must return regularly to these water sources to drink, grazing activity tends to be concentrated around water. Areas further from watering points are grazed less intensively and less often. However, livestock do not exhibit a simple radial pattern of decreasing grazing usage with increasing distance from watering points because their grazing activity is also influenced by the palatability of available forage (Low *et al.*, 1981). Large paddocks generally contain several different vegetation communities, each community having a different preference for livestock because of the suite of species present. The hierarchy of grazing use amongst vegetation communities may change as rainfall alters the relative attractiveness of the different plant species present.

The arid rangelands of central Australia have a highly variable rainfall and droughts are frequent. Vegetation growth responds to infrequent rainfall events as a pulse where, depending on the timing and size of the event, growth peaks and then declines as moisture again becomes limiting (e.g. Noy-Meir, 1973). The growth pulse following each rainfall event is of considerable importance because it determines the amount of forage available for grazing by livestock, often for some months. It also presents major opportunities for plant reproduction, growth and recruitment. Land managers (pastoralists) thus face a difficult task in matching animal numbers to forage availability resulting from erratic rainfall. They must also ensure that favoured grazing areas in the large and spatially complex paddocks are not damaged by over-utilisation.

DESERTIFICATION

Desertification is essentially a human rather than a physical problem and occurs when land use exceeds land capability. Methods that seek to assess the extent of desertification must therefore be specific to land use. In the rangelands, desertification caused by excessive levels of grazing can involve adverse changes in the species composition of pasture, loss of vegetation cover in some areas leading to accelerated erosion, and replacement of herbage species by unpalatable trees and woody shrubs in other areas. All processes result in a decline in grazing productivity.

Ground-based assessment of desertification usually involves a trade-off between approximate methods, which give broad spatial coverage but are subjective and non-repeatable, and precise methods which only apply to very small areas and are not representative of diverse landscapes. Satellite data, which are available for whole regions and have frequent coverage, offer the opportunity of objective and repeatable information. However traditional definitions of desertification, such as extent of rill and gully erosion or adverse changes in the species composition of vegetation, cannot easily be used to assess the extent and severity of desertification using remotely-sensed data. New criteria must therefore be developed based on surrogate indicators (Pickup *et al.*, 1994).

Spectral indicators of desertification

The low spatial resolution of satellite data means that it is generally not possible to detect and measure small features in the landscape such as rills and gullies. Nor is it possible to detect the mix of plant species present at a site, or change in species composition over time. However, the spectral contrast between bare soil and vegetation or different levels of vegetation cover at the scale of whole landscapes can be used to develop surrogate measures of desertification. Examples of the distribution of bare soil and vegetation in spectral space as measured by a truck-mounted radiometer are shown in Figure 1. This figure shows a clear separation between bare soil and vegetated targets in the parallelogram which makes up the visible-green / visible-red data space. There is also no obvious separation between dry and green vegetation when measured in terms of perpendicular distance from the soil line represented by bare targets at the top of the data space. This means that at the scale of both Landsat MSS and TM pixels, perpendicular distance from the soil line provides an index of both dry and green vegetation cover. The PD54 index (Pickup *et al.*, 1993) uses this principle and provides estimates of vegetation cover which correlate well with ground measures of cover (in the range r=0.8-0.9). The procedure for calculating the PD54 index is shown schematically in Figure 2.

Combining spectral indicators with spatial and temporal information

In the large paddocks of Australia's arid rangelands, free-ranging cattle return to sources of drinking water every one to three days. This spatially predictable aspect of grazing behaviour can be used as a partial solution to the problem of separating natural change in the vegetation from that caused by desertification. Vegetation cover typically decreases towards watering points to produce a "grazing gradient" (Pickup 1989). This concept is depicted as the lower solid line in Figure 3. Cover increases after significant rainfall and, where cover in the vicinity of watering points is fully restored to those levels present at some distance from water (upper line in Figure 3), grazing effects are temporary and no long term damage has occurred. However, where the gradient persists (dashed line - Figure 3), then some form of damage has

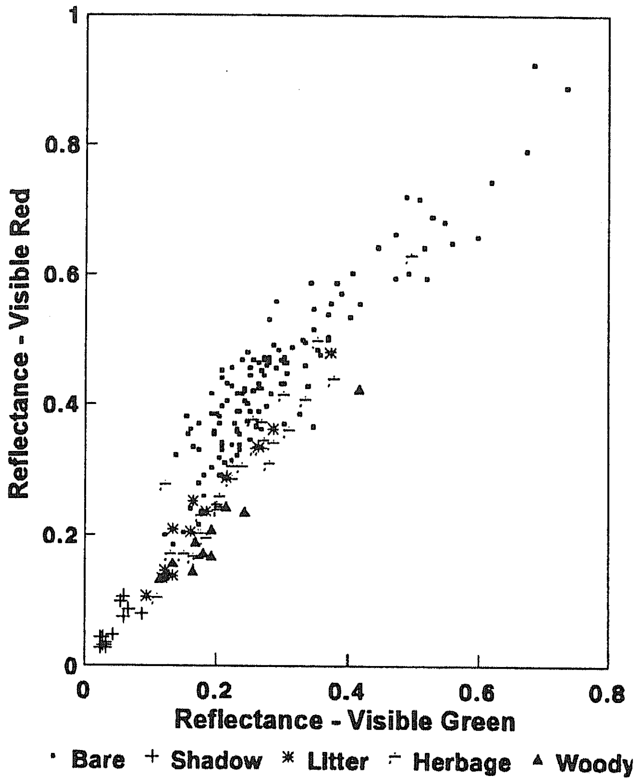


Figure 1. Truck-mounted Exatech radiometer data in the visible-green and visible-red spectral bands showing the structure of the bare soil-vegetation data space. (Figure adapted from Pickup *et al.*, 1993.)

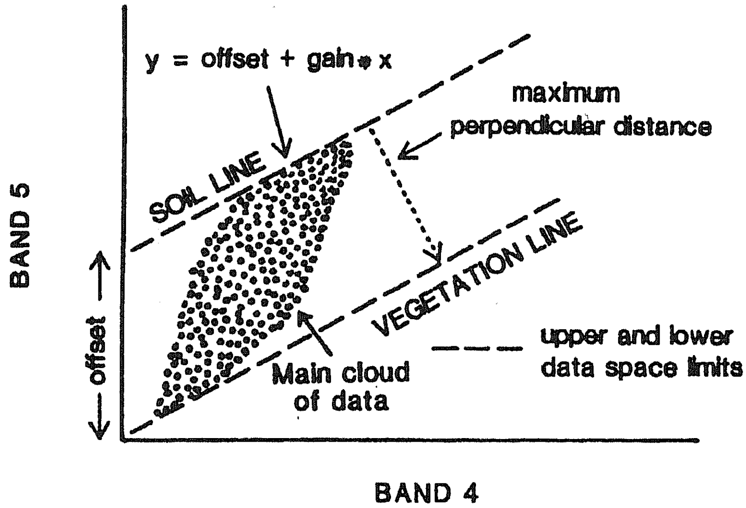


Figure 2. Parameters used to describe the Landsat MSS Band 4-Band 5 data space and to derive the PD54 index. (Figure adapted from Pickup *et al.*, 1993.)

occurred. We thus define desertification in the arid rangelands as *a grazing-induced reduction in the amount of vegetation cover likely to be present after the best growth conditions experienced in a reasonable time* (Bastin *et al.*, 1993).

GRAZING GRADIENT ANALYSIS

Grazing gradients are detected at the paddock scale by calculating average cover levels at increasing distance from watering points. This can be done by radiometrically standardising dry and wet period satellite data, calculating the PD54 index of vegetation cover from the visible-green and visible-red spectral bands and incorporating spatial information which controls grazing behaviour. Such information includes the locations of fences and natural barriers (e.g. mountains) which form paddocks, distance from watering points and the boundaries of vegetation communities which influence grazing preference. We call this form of grazing gradient analysis the **wet period average cover** (WPAC) method. A variant of this approach, the **resilience method** (RM), is used to produce an image showing where vegetation response to rainfall is above or below that which might be expected given little or no grazing impact (Bastin *et al.*, 1996). Below-expected response often results from desertification and can be indicative of low productivity in the long term. Above-expected response indicates a resilient landscape which may be in good condition, recovers well from defoliation by grazing and is likely to be productive.

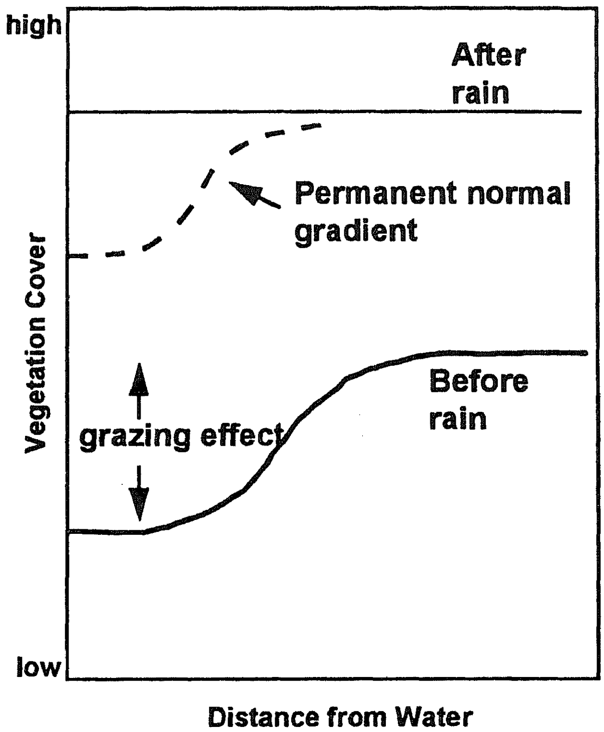


Figure 3. A normal grazing gradient. Vegetation cover increases with distance from water in the dry-period (solid line). Cover is either fully restored close to water after rain (horizontal line) or a permanent gradient (dashed line) is maintained.

Wet period average cover method

The wet period average cover method has been used to determine the extent of desertification attributable to grazing across 38,000 sq. km. of central Australia (Bastin *et al.*, 1993). Three characteristic patterns emerge where gradients are present: the normal gradient, the composite gradient and the inverse gradient. Typical examples of these patterns are shown in Figure 4. Normal gradients involve a progressive increase in average cover with distance from watering points. In some instances the gradient disappears after substantial rainfall indicating that the grazing effect is temporary. In the most degraded situations, the gradient often persists for between four and ten km from water. These persistent gradients are generally associated with the most preferred vegetation communities that have had an extended period of heavy grazing. These areas are often intensively grazed to the point where all edible forage is removed at times. Reduced cover results in increased runoff and erosion producing a less favourable soil environment and less moisture for pasture re-establishment following rain. Landscapes with less erodible sandy soils tend to be less permanently affected by grazing. Soil disturbance by trampling adjacent to watering points may enhance rainfall infiltration while the accumulation of livestock excreta marginally increases soil nutrient availability. This produces increased growth of unpalatable ephemeral herbaceous species and the composite wet-period response depicted in Figure 4. Inverse gradients are generally associated with dams in areas of predominantly woody vegetation. These areas receive additional runon water following good rains, are prone to shrub increase and have a greatly reduced supply of palatable forage (Friedel *et al.*, 1990). Grazing animals are forced to forage further from water producing the inverse dry-period gradient of Figure 4. Vegetation may fully recover across the entire area of the vegetation community following rain or it may always remain higher in the vicinity of watering points. Landscapes with very little palatable forage are relatively unaffected by grazing and often have no discernible gradient in vegetation cover with distance from water.

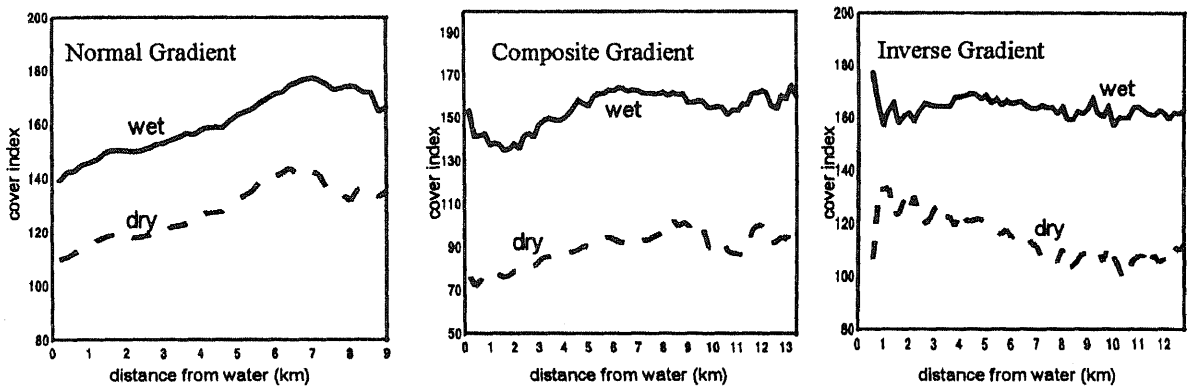


Figure 4. Examples of typical dry- and wet-period grazing-gradient types obtained from the analysis of Landsat MSS data across 38,000 sq km of arid rangeland grazed by cattle in central Australia. The cover index is the PD54 index of Pickup *et al.* (1993).

Resilience method

While WPAC is suitable for describing the state of a whole vegetation community, it provides no information on the location of areas with above- or below-average vegetation growth, apart from their distance from watering points. The resilience method can handle this problem of location-specific data. In keeping with local variability caused by moisture redistribution, soil differences, past grazing, etc., each location should have an expected response to rainfall (Pickup *et al.*, 1994) which represents behaviour in an ungrazed or sustainably-grazed situation. Observed response can be compared with expected response and areas which are below acceptable limits identified and mapped. The difference between observed and expected response then provides a measure of the resilience of the vegetation community.

Expected cover response is calculated as a linear regression between initial (dry-period) cover class and cover response following a major rainfall. Because cover response is partly dependent on the initial cover level (i.e. cover can increase only marginally where initial cover is high), residuals from the regression are scaled by the variance of cover response stratified with respect to initial cover.

The resilience image for the vegetation present on calcareous soils in a paddock following approximately 300 mm of rainfall in March 1989 is shown in Figure 5. Areas showing good vegetation response (i.e. darker appearance) are in better condition. Country surrounding a new water supply added midway along the northern fence in 1982 had some of the best response seven years later; evidence that until 1989 at least, this part of the paddock had been sustainably grazed. Conversely, some of the poorest response is concentrated in the south west portion of this 217 sq. km paddock - around a large dam which, for many years, was the main water supply in the paddock. Correspondingly, the "island" of calcareous country east of this dam is relatively remote from water and shows no adverse effects of grazing. Below-average response of vegetation south west of this main water supply may have occurred for a number of reasons. The most likely explanation is that this area is badly infested with rabbits and they have severely degraded the pasture.

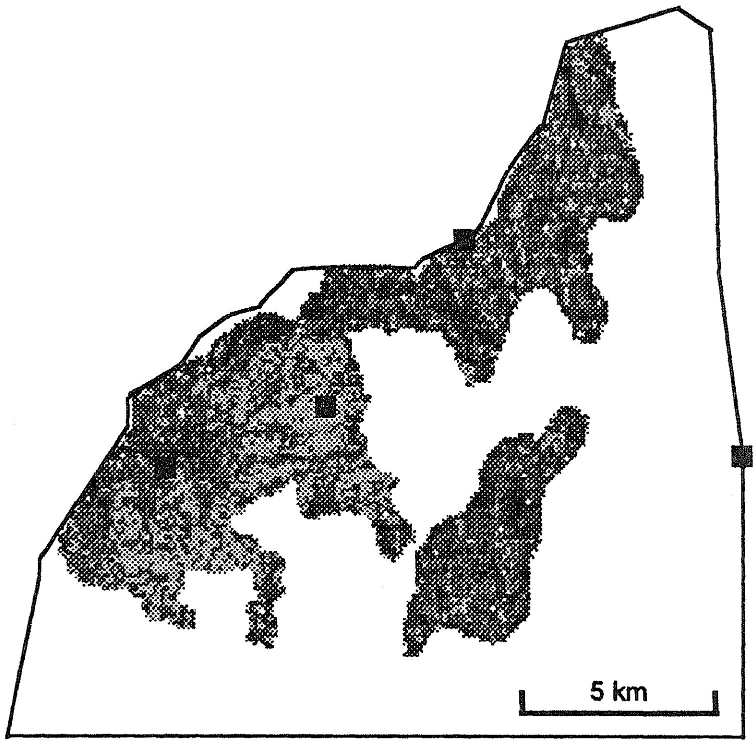


Figure 5. Resilience image of a calcareous landscape using February 1988 (dry period) and May 1989 (wet period) PD54 data. Cover response varies from bright, indicating poor response, through grey to dark which indicates the best response. The locations of watering points are indicated by solid squares. White areas represent less preferred grazing areas within the paddock. The resilience values of these areas are not shown so as to improve the clarity of the figure.

The resilience image can be compared with aerial photographs and verified in the field. The information portrayed is useful for paddock management because it suggests where further development (e.g. fencing or water reticulation) and reclamation activity are best directed. In this example (Figure 5), increased livestock production could result from shifting grazing pressure onto lightly grazed country to the east of the main watering point. This adjustment could be achieved by reticulating water through a pipeline. Reducing stock numbers in specific areas combined with rabbit control and suitable land reclamation techniques should assist the degraded country to improve in productivity. In the longer term, images can be produced following future good rains in an entirely repeatable manner and the output used to assist in determining the extent of desertification under continued, or changed, grazing management practices.

VERIFYING ANALYSES OF SATELLITE DATA USING VIDEOGRAPHY

Ground truthing of satellite data using conventional ground-based vegetation survey techniques is very difficult given the spatial complexity of the large areas commonly assessed. To reduce this problem, we have developed an airborne videography capability. This consists of four cameras, each fitted with a different filter in bands similar to the visible and near-infrared channels of the main remote-sensing satellites. The cameras are mounted in a frame in a small aircraft and frames are grabbed directly to the hard disk of a computer. Images are corrected to remove the effects of spatial distortion and differential illumination (Pickup *et al.*, 1995) and are then analysed using standard image processing techniques to produce estimates of vegetation cover.

Using image classification, we have found good agreement between the video data and estimates of vegetation and soil components made on the ground (Figure 6). Agreement is highest when categories of interest are spectrally distinct in each video image. In video data at coarser pixel resolutions, obtained by flying higher, we have used the PD54 index to estimate vegetation cover. We have then been able to compare this measure of vegetation cover with that derived from contemporaneous Landsat TM data processed to produce the same (PD54) index of cover. Figure 7 illustrates an example of good agreement in vegetation cover obtained from the two data sources for a highly patterned area of floodplain in central Australia.

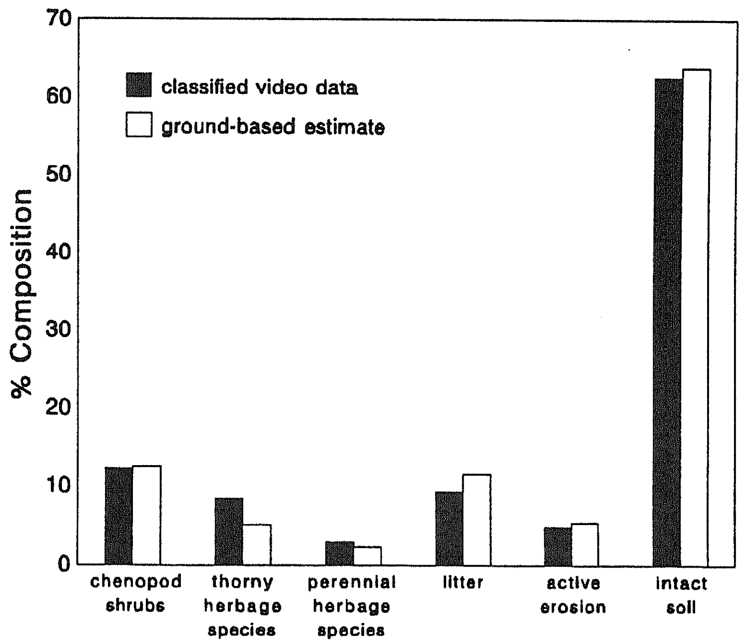
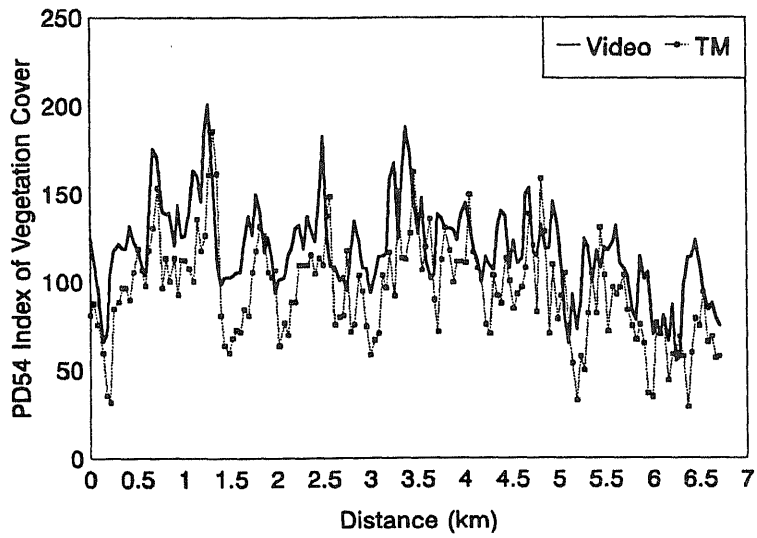


Figure 6. Comparison of percentage cover categories obtained from classified video data with ground-based measurement for a floodplain site in central Australia.

Based on these results we are confident that aerial videography can largely replace conventional ground-survey techniques in verifying satellite data. We are now routinely using the video system to acquire imagery at a range of pixel resolutions. These data are either classified or processed to the PD54 index to produce estimates of vegetation cover on what is often spatially complex landscapes. In this way, we are progressively verifying the results of our grazing gradient analyses made over extensive areas in central Australia.

Figure 7. Comparison of PD54 cover index values derived from contemporaneous and co-registered Landsat TM and video data for a floodplain vegetation community. The video data were acquired at 1 m pixel resolution and resampled to 30 m. Higher PD54 values indicate higher cover up to a maximum of 254 (note that the two data types have not been calibrated to each other).



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