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Research Article

Landscape improvement, or ongoing degradation – reconciling apparent contradictions from the arid rangelands of Western Australia

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Abstract

Recent quantitative site-based monitoring and qualitative aerial and ground traverses provide contrasting assessments of the health of much of the arid shrublands of Western Australia extensively grazed by livestock ('rangelands'). Although these results seem incompatible, we explain the apparent contradictions based on landscape succession processes operating at multiple levels of ecological organisation. Specifically, we suggest that the intact areas in which site-based monitoring is conducted are contracting as catchment canalisation and desiccation increase. However, the impacts of these processes have not yet become manifest at the site scale. The site-based system addresses important regional questions. These relate to the large, relatively intact areas away from most active surface flows, which should be a focus for resource conservation, given practical limits to repairing widespread degradation with low management inputs. We provide a complementary set of questions to provide a more comprehensive audit of rangeland dynamics in the context of underlying hierarchical landscape patterns and processes that might threaten intact areas. We recognise the need to match questions and levels of ecological organisation and the implications these have for sampling. We also recognise the difficulty in producing concise statements of change for clients when reporting on complex ecological issues and processes. Without a clearly articulated, and well understood, hierarchical model of pattern and process within which apparently contradictory findings can be reported meaningfully, policy makers may be confused by the results, with the consequent risk of policy inaction.

Introduction

Two apparently contradictory assessments of recent change in rangelands have emerged from the arid shrublands of the Gascoyne–Murchison region of Western Australia. Watson and Thomas (2003) reported widespread positive change in perennial plant dynamics at Western Australian Rangeland Monitoring System (WARMS) sites. By contrast, Pringle and Tinley (2003) reported that the region was characterised by inexorable desiccation and scrub encroachment of floodplains. These assessments were both made from data collected in the late 1990s and early 2000s and were both from a range of locations in the Gascoyne–Murchison area used for livestock grazing. Were one or other of the assessments wrong? Can both be right?

We suggest that both assessments were correct and that the two results are not incompatible. They can be reconciled by understanding landscape processes based on hierarchical models (Pringle and Tinley 2003). These models should involve broad to fine scale patterns and processes, hierarchical dynamics involving inter-level relations (Allen and Starr 1982; Allen et al. 1984; O'Neill et al. 1986; DeAngelis and Waterhouse 1987; Levin 1992; Wu and Loucks 1995; Pickett et al. 1999; Wu and David 2002) and the context and implications of local (in this case site-based) sampling within this holistic framework (Fuhlendorf and Smiens 1998). The challenge is to present this information in a way that allows end users to understand that the two results are compatible. Different parts of a hierarchically structured system can behave quite differently (Fuhlendorf and Smiens 1999; Ryerson and Parmenter 2001). In central Australia, for example, Friedel et al. (1993) showed that vegetation dynamics over seven years differed on at least five distinct soil types within a single paddock (170 km^2).

Understanding change in rangelands requires understanding heterogeneity, both spatial and temporal (Friedel 1994; Illius and O'Connor 1999, 2000; Briske et al. 2003, 2005). We not only need hierarchical models of rangeland patterns and processes, we also need complementary feedback (monitoring) systems to support our improved understanding and management of them. This is not simply a matter of monitoring at more sites or implementing broadscale remote sensing; it is a matter of matching objectives and key questions within the hierarchical model with appropriate techniques and technology (Pickup 1989; Smyth and James 2004). If such monitoring systems are clearly articulated then apparent contradictions will be seen in context, allowing resources to be directed to those parts of the hierarchy most in need of attention.

Our main aim is to address the question of why there is an apparent contradiction in the findings of two rangeland assessments in the arid shrublands of Western Australia. We begin by briefly describing the two systems of assessment in the Gascoyne–Murchison area and the conclusions arising from them. We then present a model to reconcile the apparent contradiction in these conclusions. We emphasise the need for a hierarchical model of rangeland ecosystems in order to accommodate nested patterns and processes in ecological organisation (Bergkamp 1995; Briske et al. 2005). The consequent implications and requirements for within-landscape (land unit, Christian and Stewart 1953) to catchment scale monitoring that address these issues are discussed. Finally, we discuss the difficulty of producing simplified information about complex ecological systems and processes and the policy risks inherent in producing summarised messages.

The study area and climatic context

The apparent contradictions were reported from the Gascoyne–Murchison Strategy region of Western Australia (Figure 1). Most of this area is arid with between 190 and 250 mm annual mean rainfall (Anon 1998). On the south-west coastal and southern margins annual mean rainfall reaches almost 300 mm, although less than 10% of the area would receive annual mean rainfall of more than 250 mm. Most rainfall is received in two 'seasons', May to July and January to March. Summer rainfall is the less reliable of the two, although its effect can be significant due to large events of intense rainfall as a result of summer cyclones, tropical depressions or thunderstorms (Anon 1998). While some grasslands occur, most of the region occurs as halophytic low shrublands or acacia scattered low woodlands (Wilcox and McKinnon 1972; Curry et al. 1994).

The assessments of Watson and Thomas (2003) and Pringle and Tinley (2003) were both made from data collected in the late 1990s and early 2000s and were both from a range of locations in the Gascoyne–Murchison area used for livestock grazing. During the period in which quantitative changes were assessed and the qualitative work was undertaken, the region received a sequence of seasons which, if not the best ever, were certainly in the top three sequences since records began in the 1890s.

Rainfall was sufficiently low in 1992/93 that '*serious drought*' became a primary reason for the

Figure 1. Gascoyne–Murchison Strategy area.

formation of the Gascoyne–Murchison Strategy. However, a sequence of high summer and winter rainfall in the late 1990s was matched only by similar sequences in the mid 1920s and mid 1960s. By 2001 the 10-year moving average was the maximum recorded for many parts of the region. This sequence of good rainfall finished abruptly in 2000 with very dry conditions experienced in 2001 and 2002.

The systems of assessment

WARMS was developed to provide a means of reporting to government on changes in Western Australia's rangelands used for livestock grazing. The entire system consists of a set of about 1600 (numbers vary slightly from year to year) fixed ground-sites installed at an average of 1 site per 60,000 ha across the State's pastoral areas (Watson and Novelly 2004). The focus is on assessing the dynamics of the perennial vegetation and on recording standard Landscape Function Analysis (LFA) attributes (Tongway and Hindley 2004). Shrubland sites are one of two site types used in WARMS and are the type referred to in Watson and Thomas (2003). On these sites, along with LFA, a direct census technique is used to follow the individual fate of all woody perennial plants. Canopy size is also assessed. Perennial plants are used because of the belief that perennial species composition and density are reliable indicators of rangeland health, particularly when considered against the potential of that habitat. The area of each site depends on the density of the vegetation, but most sites have a total transect area of between 150 and 1200 m^2. The sites are reassessed at a frequency of five to six years.

At the regional scale, sites were stratified by broad vegetation type using a combination of pastoral productivity, fragility and areal extent. At the local scale, sites were located on examples of the rangelands designed to provide information about areas comprising the largest proportion of the landscape at that local scale (detailed in the section below "WARMS site location within the hierarchical model").

The analysis of change on these sites is based on comparing a particular attribute at one time of assessment with the same attribute at the next reassessment. These attributes include plant density and canopy size both by site and by species, species richness, frequency of occurrence and demographic information such as recruitment rate. The overall judgement about whether range health is increasing or decreasing depends on knowledge about the relationship between rangeland health and perennial vegetation (Hacker 1984, 1987; Watson et al. 1997).

The Ecosystem Management Understanding (EMU) Project was developed within the Regional Environmental Management Programme of the Gascoyne–Murchison Strategy as a means of building ecological literacy amongst all landholders, but most notably pastoralists and conservation estate managers (Pringle and Tinley 2001a; Tinley and Pringle 2002). A major part of the EMU Project involves reconnaissance aerial surveys at 100 to 200 m above ground level with landholders to identify critical control points and threats to most valued grazing areas. Critical control points include features that encourage the slowing, spreading and ponding of surface water and range from rock bars across major rivers to subtle sills of sand maintaining small ephemeral pans (Pringle and Tinley 2003). They are relatively small areas whose functional status affects considerably larger surrounding areas. Threats to intact, most valued areas include active gully heads that might for instance breach a wetland sill (Tinley 1977; Pringle and Tinley 2003).

During aerial reconnaissance, we take digital photographs with 3.2 megapixel cameras with up to three times zoom of key features that we believe may be the basis for future focus of land management. These are not highly technical, controlled remote sensing, rather they are reasonable quality photographs of critical issues for discussion and further investigation. After flights, we run through our collection of digital photographs using a television monitor, along with a Thematic Mapper satellite image (1: 100,000 scale, usually, using the visible bands). With our observations from the flight and the satellite images, we plan targeted ground traverses in order to visit these key features, which range in focus from broadscale catchment function to local habitat integrity. Comprehensive photographic records have been kept and presented at conferences (Pringle and Tinley 2001b; Tinley 2001; Tinley and Pringle 2002; Pringle et al. 2003). Our qualitative assessments of catchment-scale problems are based on this approach, though we have recently commenced a research programme with which to start quantifying these frequently observed and photographed process patterns.

The apparent contradictions

Positive change in the rangelands of the Gascoyne–Murchison was reported using data from 223 WARMS sites (Watson and Thomas 2003). Substantial increases in woody perennial density were observed for both the majority of sites and the majority of species. The average increase in density for all sites was 47% and for all species was 59%. The changes were similar for species known to increase under pastoralism (i.e. commercial livestock grazing) and species known to decrease. Canopy cover increased on 96% of sites, by an average of 81%. Species richness by site increased by an average of 15% and on 91% of sites there were at least as many species at reassessment as at installation (average period was 5.25 years). Recruitment was widespread spatially and common for nearly all species where sample size was sufficiently large. The change in all these attributes suggests improvement, with the caveat that some of the results reflect scrub encroachment, albeit found at approximately the same rates as other, more desirable, species.

By contrast, through the EMU Project, Pringle and Tinley (2001a) found an almost universal pattern of landscape incision, up-slope cascading erosional processes and resultant desiccation ranging from whole catchments to individual landscape features. Desiccation occurs because increasingly more surface water is lost from landscapes and catchments in eroded channels (landscape incisions). Major changes to vegetation have been wrought, including scrub encroachment of intermittently inundated landscapes or woodland dieback on perched interfluves in sheetwash plains (Pringle and Tinley 2003).

Of particular concern is the almost universal fragmentation and scrub encroachment of seasonally inundated fertile grasslands and the breaching or silting up of ephemeral wetlands. Both habitats support distinctive plants and animals and so have particular importance for both resource and nature conservation. It is highly likely that these fertile areas are also key drought buffering habitats; responding to small and local rains and providing episodic respite to plants and animals through normal periods of generally low rainfall (Morton et al. 1995; Illius and O'Connor 1999, 2000; Pringle and Tinley 2003).

A conceptual model of catchment pattern and process

Fundamental to the understanding of pattern and process is a hierarchy of salience (Tinley 1987), an approach that puts into context and order of priority different factors operating at different temporal and spatial scales (see also Coughenour and Ellis 1993; Wu and David 2002). Pringle and Tinley (2003) place minor emphasis on general within-landscape (land unit) patterns and processes. These local dynamics in the model are often entrained in much higher order, broader scale dysfunction.

Pringle and Tinley (2003) have assessed qualitatively that catchments in the area concerned are desiccating and losing rain use efficiency, due to incision of critical base levels and subsequent gully and then lateral erosion. Landscape incision and consequent accelerated erosional processes drive the desiccation process. The catchments concerned have experienced historically excessive grazing and consequent losses of topsoil and ground cover (Wilcox and McKinnon 1972; Curry et al. 1994). A coincidence of increased run-off due to decreased ground cover and nickpoints (local incisions) initiate the cascading erosional processes. Widespread erosion is exacerbated by high intensity rainfall events, which typically occur in summer (Anon 1998). The nickpoints provide the incision upon which accelerated water flows operate with increased erosive power. Nickpoints may range from a breached rock bar across a major river to subtle incision from a track across a sluggish drainage lane.

The field evidence shows how nested accelerated or initiated landscape incision and lowered base-levels lead to desiccation (Figure 2a, b and Box 1). The impacts of desiccation are most readily and quickly observed in and around the active areas of landscape succession, but increasingly influence landscapes further from focal alleys of concentrated drainage as surface flows are increasingly attracted to these points of accelerated exit from successive landscapes heading down catchment. This 'siphoning' of sheetflows leads to lateral widening of incised drainage tracts (Figure 3).

Vertical incision processes within drainage tracts may decelerate as they hit hard substrates typical of the region (Wilcox and McKinnon 1972; Curry et al. 1994), which occur naturally as cemented soil horizons (hardpan) and switch predominantly to erosion by lateral retreat (etching by micro-terrace erosion) away from concentrated drainage tracts. As this slower, but inexorable lateral stripping proceeds, surface flows from increasingly greater distance from the incised channel are entrained in the canal system. This increases the loss of water from landscapes (Figure 3). The desiccation is therefore driven by both the development of canalised drainage networks through accelerated run-off and incision; and the associated lateral landscape stripping through micro-terrace retreat when channels reach hard substrate and can no longer act to minimise stream energy through vertical incision. The actual channels, which may vary from less than a metre across to river channels tens of metres wide, nonetheless occupy relatively little of any drainage basis. It is this

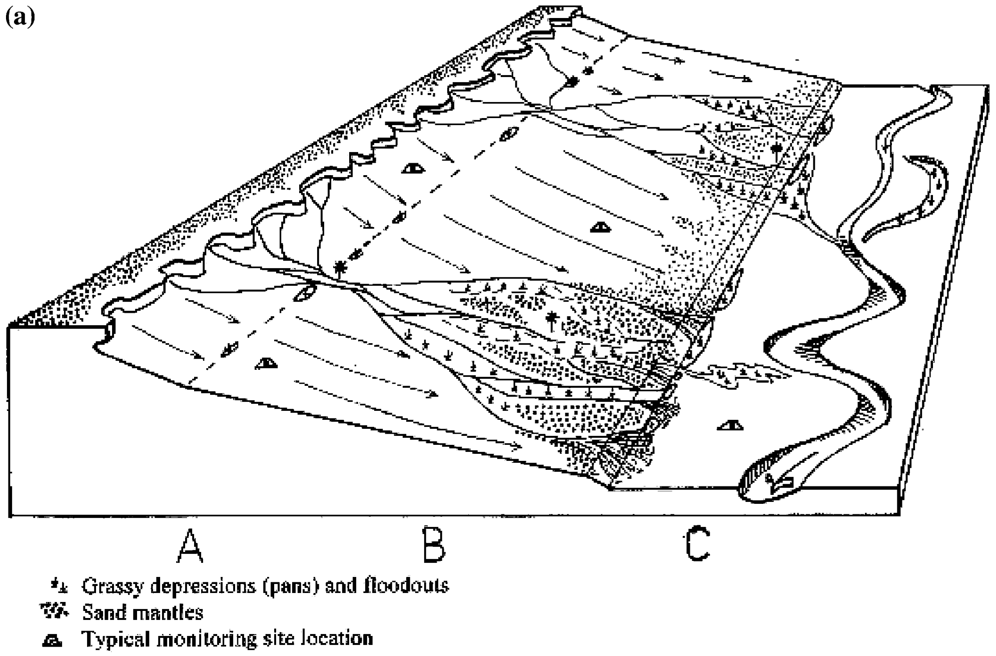

Figure 2. (a) Schematic of a healthy river floodplain and valley side. (b) Schematic showing canalisation of a river's floodplain and valley side. Figure 2b shown with (bottom) and without (top) vegetation.

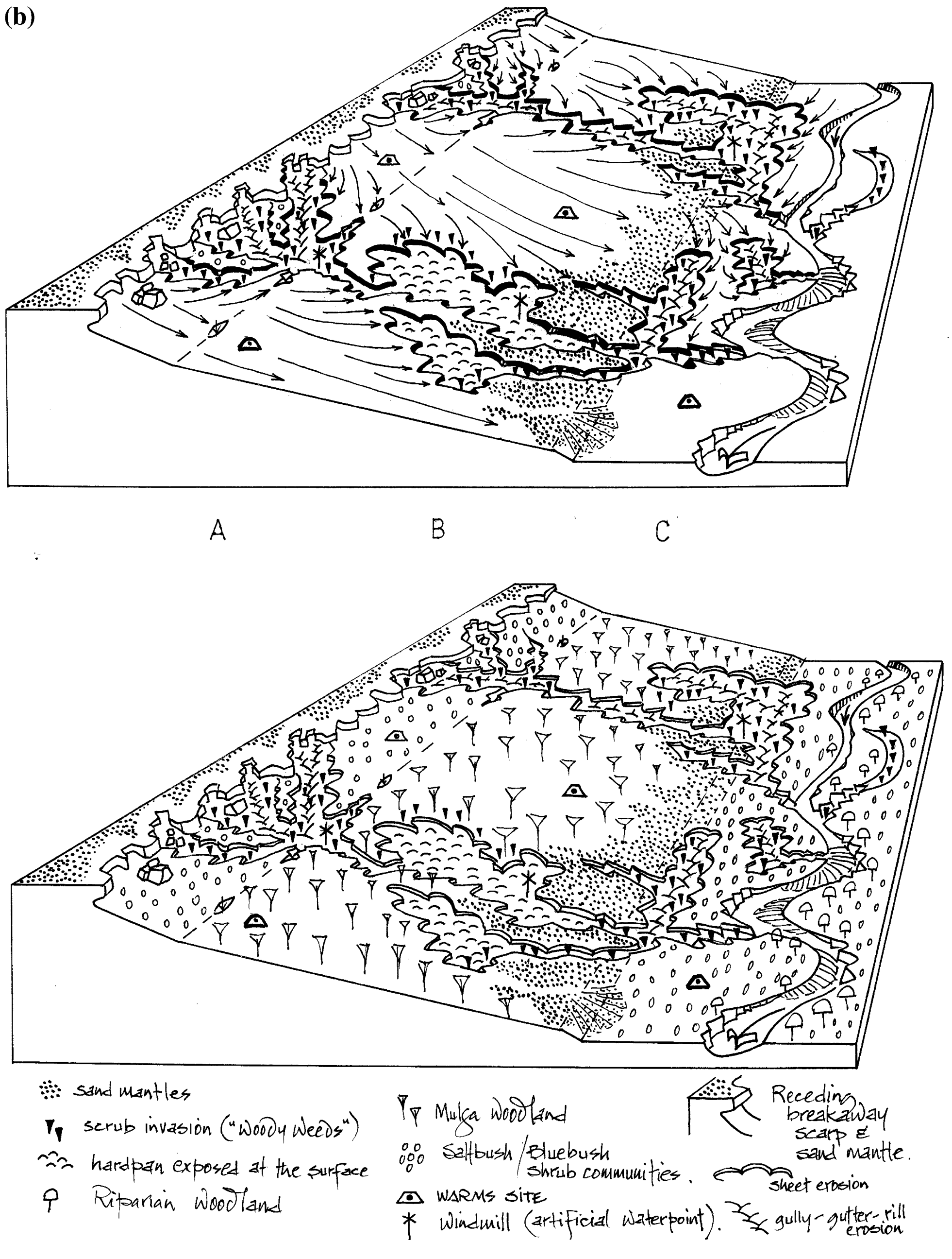

Figure 2. Continued.

combination of limited spatial occurrence and far reaching desiccating influence that makes this problem of incision-driven rangeland water starvation a largely overlooked phenomenon (Pringle and Tinley 2003). Even the concentrated drainage alleys in which incision processes most frequently occur usually occupy less than 10% of any drainage basin or its tributary components (Curry et al. 1994).

This means that while areas furthest from the alleys of concentrated drainage exit and which depend on sheetflows from upslope are largely unaffected, these areas are being stripped laterally out from the alleys. These functionally intact areas

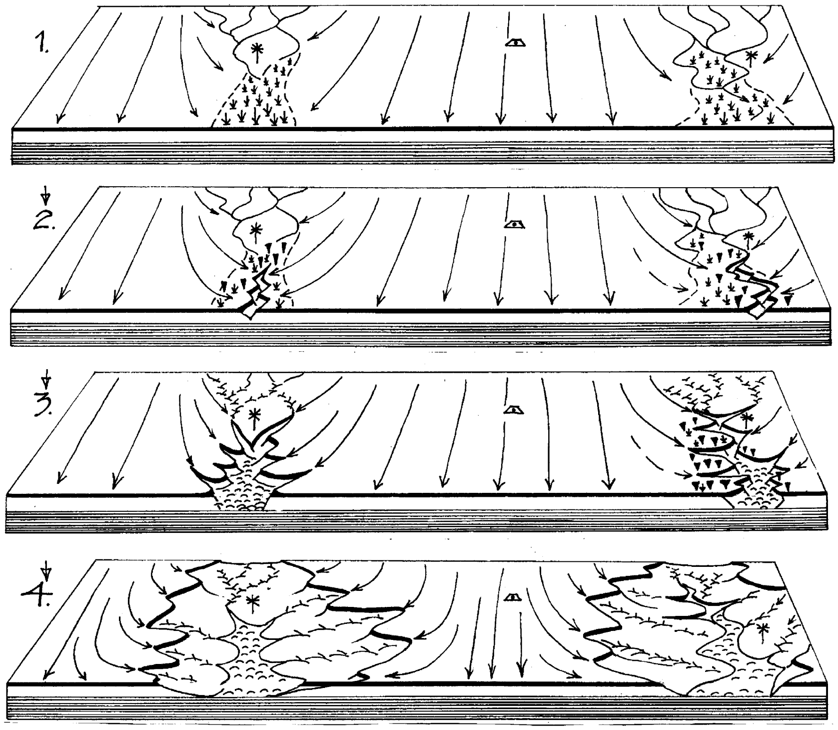

Figure 3. Schematic showing incision and accelerated desiccation of a sheetflood plain. Legend is as for Figure 2b.

are therefore contracting; even if this process is very slow. Similar contracting is also occurring at the edges of distributary fans below the key-line because successively less water floods out, and what floods out is recaptured, by channels that now link the key-line to the exit point of the valley side. Thus these incised alleys are out of control. They are slowly reducing soil moisture balances at increasingly greater distances away from them, favouring species better adapted to desiccating soil profiles and making plant growth increasingly episodic (in time) as run-off increases and deep soil storage declines (Tinley 1982). Spatially, plant growth becomes less variable as subtle variations in soil moisture balance are lost through erosion and accelerated run-off (Ludwig and Tongway 1995; Pringle and Tinley 2003).

Vegetation responses to desiccation generally involve loss of palatable dwarf shrubs (in areas with texture contrasting soils) or perennial grasses (in areas with clay soils) and either the baring of the ground or replacement by scrub species, such as curara (*Acacia tetragonophylla*, species names throughout from Green 1985) (Pringle and Tinley 2003). Similar patterns have been observed in northern Australia and in southern Africa (Tinley 1977, 1982). Essentially, plants that thrive on extended periods of positive soil moisture balance tend to be replaced by plants more adapted to shorter periods of positive soil moisture balance (Tinley 1982).

With the spread of erosion from gullies to lateral retreat, desiccation is accelerated as sheet wash flows on interfluves are more effectively captured by the gully network as micro-terraces coalesce (Figure 3).

WARMS site location within the hierarchical model

By design, almost all WARMS sites were installed 'outside the alley'. The majority were installed at greater, rather than lesser distances, from the erosion alley. After stratifying by vegetation type at the regional scale, WARMS sites were located on the largest grazed area of the required vegetation type within each paddock (or grazing area where there were no fenced paddocks). They were also located towards the centre, rather than margins, of each vegetation type. Extremely dynamic areas, *Box 1.* Explanatory notes for Figure 2a and b: Canalisation of a river's floodplain and valley side.

Zone A: Breakaway scarp and footslope zone

Breakaways (cliffs) with fragile footslopes of texture contrasting soils and concentrated tributary drainage zones, which may be weakly rilled or guttered (Figure 2a).

Artificial watering points are commonly sited on the key-line contour between footslope and sheetflood plains, where grassy claypans are often found along the break in slope in healthy catchments (Figure 2a; junctions of Zones A and B).

Concentrated trampling and grazing in fragile footslope areas out from artificial water points initiates stripping of sandy topsoil, which fragments as a matrix of sodic clay subsoil expands. Rill, gutter and gully erosion cut back along tributary zones of more concentrated flow, while micro-terrace erosion accelerates headward and laterally from incisions in more concentrated drainage areas Figure 2b).

Severe incision of the tributary drainage system and sheet erosion in inter-fluve areas effectively turn the whole footslope and pediment zone into a 'tiled roof' with negligible capacity to harvest surface flows (Figure 2b).

Zone B: Valley-side sheetflood plains

Despite effective bevelling of valley sides, subtle changes of slope at the key-line contour break of slope result in a flip from tributary to distributary flow in healthy catchments (Figure 2a; junction of Zones A and B).

Extensive very gently sloping ($< 0.5\%$) sheetflood plains support mulga (*Acacia aneura)* low woodlands over shallow (< 30 cm) red loams on ferruginosiliceous hardpan, lower areas with sandy banks support tussock grass understoreys (Figure 2a). Sandy topsoils are stripped away by excessive grazing and accelerated sheetflow velocities exacerbated by incised local base levels. Scattered xerophytic shrubs replace grassy understoreys, particularly turpentine bush (*Eremophila fraseri*) and cassias (*Senna* spp.) (Figure 2b).

Drainage alleys support denser mulga woodlands and have scattered grassy (e.g. *Eriachne flaccida* and *Eragrostis setifolia*) concavities, which become more common where drainage alleys form floodout fans, which may support savanna vegetation in good health (including the grasses *Eulalia fulva, Themeda triandra, Iseilema vaginiflorum*) (Figure 2a). However artificial watering points are commonly located within this alley and local incisions from vehicle or livestock tracks initiate inexorable headward gully retreat, canalisation and replacement of savannas and grassy concavities with species poor scrub associations (Figure 2b). Few savanna floodouts remain because of the focus of infrastructure and livestock activities in these areas. Curara (*Acacia tetragonophylla*) scrublands are now normal in incised floodouts.

Zone C: River and floodplains (bottomlands)

Floodplains of chenopod shrublands with grassy sump areas and grassy depressions along the margins of the floodplain and sheetflood valley side. Riparian levee banks support river gum (*Eucalyptus camaldulensis*) and coolibah (*Eucalyptus victrix*) gallery woodlands (Figure 2a).

Artificial watering points commonly located at the floodplain-valley side transition, particularly in areas of more concentrated tributary flow (because groundwater supplies were shallower and better quality and quantity than elsewhere when hand-dug wells, rather than bores, were typically used). Concentrated livestock traffic focus activity on most fragile part of valley side as well as livestock tracks linking river pools to damp spots and the terrain junction, initiating and exacerbating canalisation (Figure 2b).

Excessive (preferential) grazing reduces ground cover and leaves soils exposed to accelerated flows from dysfunctional valley sides and river floods. This leads to stripping of sandy topsoils, exposing sodic subsoils which only support perennial scrub vegetation when canalisation (in the form of lateral gully retreat from the river, see below) provides focused water flows and lower soil salinity (Pringle and Tinley 2003) (Figure 2b).

Bared catchments result in more erosive river flows which break through local base levels and entrain rapid down-cutting of river channels (King 1963), leaving floodplains perched above most river flows and susceptible to headward gully erosion due to the lowering of local base levels. When gullies cut back from the river and through the terrain junction with the valley side at an area of concentrated drainage, the likelihood of rapid canalisation of the entire valley side is high (Figure 2b).

Increased sediment fluxes through the down-cut river channel tend to silt up river pools.

like gully heads, were avoided. Where patchiness in vegetation was evident, the sites were located to straddle the main variation if less than about 100 m across, or located in the most representative patch, if patch diameter was greater than 100 m. In Figure 2a and b typical locations of WARMS sites are shown; away from the corridor of active landscape succession in all three major sectors. Not all WARMS sites will eventually be affected by lateral stripping and declining soil moisture balance, some sites were located on run-off or run-in areas or towards the higher parts of catchments.

While it is not possible to definitively describe where all WARMS sites were located in relation to the alley, site details for WARMS sites include codes for systematically identifying land form and location in land form (Tongway and Hindley 2004). In the Gascoyne–Murchison area, 50% of sites have a land form code of 'level plain' (i.e. $< 1\%$ slope in an area of < 9 m relief) and 52% a location in land form code of 'flat'. Taken together, 46% of sites were located on the 'flat' of a 'level plain'. Only 15% of sites were located on the 'lower slope' and only 1% in 'stream channels'.

Reconciling the apparent contradictions

Both assessments of change are correct based on the field evidence of ecological organisation and environmental legacy. In brief, the WARMS sites are located to represent where most of the livestock grazing occurs, but avoiding highly dynamic areas. This has almost certainly excluded those smaller parts of the landscape that reflect both the impacts of canalisation and desiccation, and incision-driven landscape replacement processes described previously (Pringle and Tinley 2003). WARMS sites are generally in landscape positions away from historically severely degraded areas associated with the alleys of accelerated run-off, incision and lateral stripping and so will be amongst the last to experience consequent local desiccation and stripping of soil profiles.

WARMS provides information about changes within widespread, functionally intact areas of the rangelands. They are not located at landscape edges, they are also not located on landscape transitions where geomorphic processes of erosion and deposition lead to spatial land succession and major changes in vegetation.

Some areas of most fertile landscapes remain intact but are under threat. Thus, some expansion of WARMS sites into remnant floodout grasslands (see Figure 2a, b) might be warranted, although the threats are as much to do with gully heads cutting back towards them from down-slope as local grazing pressures. Rather, information needs to be collected using complementary approaches at multiple scales of observation. This very important issue is addressed below.

Hypotheses to help design and test a monitoring system – the future for these rangelands if desiccation progresses unchecked

In order to design a more complete monitoring system, it is first necessary to set up hypotheses about the changes likely to occur as the desiccation of catchments continues. In this way, observations can be compared against expectations (Watson 1998). Some of these are already evident as it is not as if the desiccation of catchments is just beginning. Far from it, lowered base levels, increased canalisation and landscape 'leakiness' causing severe desiccation of soil profiles is typical. In fact, this dysfunction is so old that it is sometimes seen as the natural state, rather than an impact of land use (personal observations of HP and KT from discussions with pastoralists in the field through the EMU Project).

The impacts of canalisation and declining soil moisture balance will depend on geomorphic context (Pringle and Tinley 2003). Essentially, the further away an area is from the alley of most active landscape succession, the less influential will be the lowering of local base levels on landscape stability and function.

Intermittently inundated grasslands will be gradually replaced by scrub species within river floodplains (Figure 2a, b; Zone C) and in the alley of active landscape succession (Figure 2a, b; Zone B and Figure 3) (Pringle and Tinley 2003). Halophytic floodplain shrublands with generally fragile texture contrasting soils (Figure 2a, b; Zone C) will be increasingly at risk from overgrazing as stock rely increasingly on perennial species, which in turn will lead to their fragmentation and eventual collapse. They will more extensively become scalded surfaces of exposed B-horizon soil horizons with occasional accumulations of windblown sand supporting scrub species (Curry et al. 1994).

Areas dependent on harvesting throughflows such as mulga (*Acacia aneura)* washplains will become increasingly perched and vulnerable to die-back due to desiccation (Figure 2a, b; Zone B away from the erosion, Figure 3 inter-fluve sector). Run-off areas such as stony pediments and hills Figure 2a, b; Zone A) will probably be least affected as they are naturally dry and are least affected by off-site changes to base levels and surface flows. Floodout fans will initially contract from their edges and will eventually fragment and become scrub encroached as headward migrating gulleys become increasingly effective at draining floodout surface flows (Figure 2a, b; Zone B active valley, Figure 3). Sandy outwash deposits ('wanderrie banks') will eventually disappear to be left with a harder, less permeable clay loam soil supporting scattered xerophytic shrubs (e.g. turpentine bush, *Eremophila fraseri*), rather than mulga trees over wanderrie grasses (Pringle and Tinley 2003). This has happened already over much of the Gascoyne River catchment (Wilcox and McKinnon 1972).

As stated previously, WARMS was designed to track changes in the large, intact areas of the rangelands which represent where the majority of the grazing occurs. It may be decades before any trends attributable convincingly to these disrupted drainage regimes are detectable from WARMS data. Demographic inertia, and decelerating erosion will dull these influences away from alleys of most dynamic surface flows. As influential will be statistical 'noise' provided by factors such as spatially variable distance from watering places (Pringle and Landsberg 2004), classes of livestock, prominence of feral and native herbivores, configuration of land systems and so forth.

Confirmation of this process of desiccation is more likely to occur convincingly by monitoring the effects of interventions to redress the causes and symptoms of dysfunction (Murchison Land Conservation District Committee and the Ecosystem Management Unit 2002). The extraordinary success of a small pastoral family near Alice Springs, in central Australia, in dealing with the desiccation problems described in this paper, albeit over several decades, offers an immediate opportunity to develop ways of remotely sensing how to identify repaired versus desiccating landscapes within a district (Purvis 1986). Two of the authors (HP and KT) visited the Purvis property in July 2004 and saw the differences between original photographs of bare, scalded soils and the productive, mostly native grasslands that now exist in rainwater harvesting treated areas.

Towards an expanded and complementary system of rangeland monitoring

Contemporary rangeland monitoring needs globally to be upgraded to take into account these more recent issues in natural resource management. It is not enough to ask the same site-focused questions over larger areas using remote sensing. Rangeland monitoring needs to be restructured in a manner that accommodates different disturbances, patterns and processes operating at different scales and levels of ecological organisation (Wu and Loucks 1995; Pickett et al. 1999).

WARMS was not designed to monitor the full set of these hierarchical landscape patterns and processes (Holm et al. 1987). It was designed to provide information on those areas which occupy the majority of the region and where the majority of the grazing resource is found. These areas are away from the alley of concentrated surface flows.

However, government agencies and catchment groups need to gather sets of information regarding grazing impacts across the whole landscape. Three related and critical questions can be posed concerning the ecological functioning of the rangelands as a whole, as districts and as individual enterprises:

1. Are catchments becoming increasingly leaky and increasingly rain-use inefficient (or vice-versa)?
2. Are intact surfaces contracting and becoming fragmented, or expanding under repair settings?
3. Are intact areas improving or declining in condition?

What is needed is a combination of continued site-based monitoring to track changes in intact landscapes with a high degree of data rigour and detail i.e. plant by plant – quadrat by quadrat (as WARMS does) and some more extensive monitoring of spatial dynamics in selected areas of sensitive landscapes (Curry et al. 1994) and areas in which planation processes (ecosystem and landscape replacement) are most likely (Pringle and Tinley 2003). Various remotely-sensed approaches can provide the information here. These remote sensing approaches may be quite simple and profound, such as conducted by some pastoralists with a camera flying at about 100 to 200 m above ground level (Pringle and Tinley 2001a). For statutory reporting, more formal aerial photography, airborne videography or satellite-based approaches are possibly more appropriate (Eve et al. 1999; Ludwig et al. 2000; Bastin et al. 2002), but still need to be stratified and directed towards questions that come from a holistic, hierarchical model of landscape patterns and processes. We are not aware of any such approach to date in the rangelands (that is, one led by a hierachical geo-ecological model), although the underpinning principles and conceptual models exist (Tinley 1982; Pickup 1985; Allen and Hoekstra 1992; Wu and Loucks 1995; Pickett et al. 1999; Wu and David 2002).

The issue of course with all remote sensing approaches is the difficulty of getting wide area coverage. Low level aerial photography and videography can sample individual areas but not cover the state. Satellite platforms can cover the state but 71 LANDSAT TM scenes are needed to cover the pastoral areas of Western Australia. A mammoth effort would be needed to be able to report on all areas at a statutory level. It is difficult to implement an audit approach (i.e. sample ~10% of the area only) with satellites because of the need to process on a whole (or perhaps 1/2) scene basis. One approach would be to randomly (or sensibly stratify) a number of landscapes across the pastoral areas (say 10–50 per Shire) and then use low level aerial photography.

Reporting on complex systems where apparent contradictions might arise

There are inevitable difficulties in reporting simple messages arising from complex systems. The challenge is to keep the message simple, without ignoring or denying the underlying complexity (Nicholls and Wallace 2003). It is difficult enough to maintain a balance between presenting a simple message to end users while at the same time taking full account of the complexity within systems such as arid rangelands. Apparent contradictions in the message make the task even more difficult.

Why should it matter if such apparent contradictions emerge in the assessments of change? What are the risks if one or other of the assessments is used to the exclusion of the other?

If the positive message is propagated to the exclusion of the negative (i.e. the message is simply "The rangelands are improving.") then at the local scale, management will not have the opportunity to benefit from the warnings that monitoring provides. At more aggregated scales, land administrators will formulate institutional responses to a story of positive change and neglect those responses that address degradation. Conversely, if the negative message is propagated to the exclusion of the positive (i.e. "The rangelands are degrading.") then the debate about land use in rangelands will be biased towards the negative. Where both messages are received at once, those making decisions may be paralysed by the contradictions unless they can be understood within a hierarchical model of pattern and process.

In an ideal world land administrators and other institutional clients would have the time available and the skills to be able to assimilate complex messages delivered in comprehensive reports. Those reports would set out the issues, provide an interpretive basis to the data and provide caveats to the use of the data. Invariably however, such users, and even the general community, require information in packaged, summarised form (e.g. 'the 30 second grab' employed on the television news). Often the same piece of information is used multiple times, for a range of purposes and although the original authorship may be cited, the repackaging of the information often strips the caveats and interpretative nuances from the original. Frequently, only simple messages survive such as "The rangelands are improving" or conversely "The rangelands are degrading".

Conclusions

Site-based quantitative information and broader scale qualitative observations appeared contradictory, but when considered from a broad-scale geomorphic perspective, they are easily reconciled.

Rangelands globally need to embrace contemporary concepts such as Hierarchical Patch Dynamics (Wu 1999) in expanding monitoring and assessment systems beyond the traditional site-based focus. Importantly, geomorphic drivers of contemporary change need to be considered in any broadscale assessment of ecosystem dynamics (Pringle and Tinley 2003).

A hierarchical model of ecosystem patterns and processes allows for different messages within any catchment because factors and dynamics vary in time and space (Pickett et al. 1999). A complementary set of monitoring protocols using remote sensing of varying complexity and for use by both administrators and land managers could capture much of the apparently contradictory change.

The range monitoring literature has focused on the identification of key indicators and the techniques that can be used to monitor them. Explicit advice about precisely *where* to monitor in the landscape needs to be provided along with advice on *how* to monitor. These considerations need to be undertaken in the context of ecological complexity (Levin 1992; Wu and Loucks 1995) and be driven by more fundamental questions relating to ecological levels of interest than tools and techniques (Pringle and Hopkins 2004).

While the issues raised in this paper have interest from an ecological perspective, perhaps an equally important issue concerns the way complex messages are delivered to administrators and institutional clients, particularly when information is summarised into briefing notes or reports of one or two pages only.

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