RECOGNISING AND MANAGING RANGELAND DYSFUNCTION BEYOND PATCH DYNAMICS: A PRELIMINARY ASSESSMENT IN ARID WESTERN AUSTRALIA

Hugh, J.R. Pringle[1*] and Ken, L. Tinley[2],

[1] Centre for Management of Arid Environments, Department of Agriculture Western Australia and Curtin University, P.O.Box 417, Kalgoorlie WA 6430.

[2] WA Wildlife Research Centre, Department of Conservation and Land Management, Woodvale, WA 6005.

[*]Corresponding author: email, mluso@iinet.net.au

Abstract

In this article we argue for a complementary approach to the prevailing focus on models related to local, patch dynamics in assessing the condition of rangelands. Mathematical aggregation of local assessments made within landscapes may hide, rather than reveal, critical patterns and trends occurring at greater scales and higher in the hierarchy of ecological organisation when interpretations are made using finely sampled data at few points. Spatial extension of many more fine scale observations through remote sensing may reveal malaise or recovery, but not why and where the drivers of change operate. Fundamentally, a single scale of observation is inadequate for assessing the dynamics of hierarchical phenomena such as rangeland ecosystems.

We recommend starting from the catchment as a unifying geo-ecological context and working downwards through geo-ecological organisation (hierarchical structuring of

key patterns and processes and their inter-level interactions). Starting at fine scales and scaling up is less effective because it risks missing a driving higher-level process' patterning and hence whole system behaviour is not detectable due to this initial oversight. It is riskier than starting higher and then focusing in on salient factors.

We believe that this recognition of a hierarchy of ecological organisation and salient factors within it renders illuminating perspectives on the nature of ecosystem dysfunction in rangelands.

This hierarchical, geo-ecological approach supports an innovative framework for repair that is cognisant of the dynamic and complex structure of rangeland ecosystem patterns and processes, from fine patches and fast variables to major river catchments and slow variables. The framework enables enhanced local successes by addressing higher level control points that may have caused, and probably exacerbate degradation within landscapes.

Keywords: catchment, condition, scale, hierarchy, rangelands, assessment

Background context

HP wrote the first draft of this paper at a national rangeland monitoring workshop held in Alice Springs in November 2002 (Smyth *et al.* 2003), following discussions with John Ludwig (CSIRO Sustainable Ecosystems). HP was concerned about the apparent absence of understanding and indicators of landscape function above the level of plant community, habitat or patch patterning within landscapes. HP and KT have now developed other publications (Pringle and Tinley 2003, Pringle *et al.* under review) relating to particular areas of rangelands and their organisation, dynamics and management (including assessment monitoring and repair). However, there still seems to be little attention being paid to "catchment ecology" in Australian rangelands. Some resistance to raising focus further up the ecological hierarchy is suspected. Therefore, in a mostly qualitative manner, we describe healthy and unhealthy catchments, how they become degraded and how they might be repaired. This is simply an attempt to broaden the discussion of rangelands management. The groundbreaking work of Geoff Pickup regarding these issues (notably in this Journal) is acknowledged from the outset.

The problem

Assessment of rangeland conditions continues to be conducted at fine scales of observation or sampling; mostly within landscape types (Bastin *et al.* 2002, 1994, Reynolds *et al.* 1999, State Of Environment Advisory Council 1997, Tongway *et al.* 2003, 1994). We have argued that from our experience, this limited focus overlooks key driving process patterns that are inexorably changing rangeland ecosystems that remain largely undetected, or perhaps misinterpreted (Pringle and Tinley 2003). In this article we aim to illustrate some of these process patterns based on our work in the Gascoyne-Murchison Strategy in Western Australia (Pringle *et al.* 2003) through the Ecosystem Management Understanding (EMU) Project (www.emuproject.org.au).

Geoff Pickup highlighted many of the shortcomings in point-based field assessments of rangeland conditions two decades ago (Pickup 1985, 1989). However we argue that a failure for these issues to be addressed is in part due to the dearth of capacity in physical earth sciences in the range ecology community in Australia and the prevailing focus on community and patch scale ecology (Pringle and Tinley 2003). It is quite likely that Pickup's work was understood by "biological-ecologists", but they may have lacked confidence and technical support in addressing Pickup's challenges head on. In Western Australia, we have taken up the challenges through the Ecosystem Management Understanding (EMU) Project (Pringle and Tinley 2003, Pringle *et al.* under review). Both authors are trained geomorphologists as well as ecologists.

Scale and hierarchy issues are seen as critical areas for research in order to manage natural resources in more sustainable ways (Allen *et al.* 1984). However, it is critical that we understand the impacts of our choices regarding the scales at which we choose to observe ecosystems (1996, Allen and Hoekstra 1992). We gain new understanding of reality when we adopt a holistic approach; even if this increases complexity. It is important that we model beyond our vision in the field, but select carefully those salient features that transcend and connect extraordinarily complex patterns, processes and inter-level relations (Allen and Hoekstra 1992, Allen *et al.* 1984, Tinley 1977).

In Australian rangelands, much progress has been made in extending spatially the observations that are made at fine (or local) scales of observation using remote sensing (Bastin *et al.* 2002, Ludwig *et al.* 2000). However, these approaches are essentially multiple local snapshots and extensions of traditional within-landscape scale observations (or finer). This focus is not purely Australian (Busby *et al.* 1996, Renner and Johnson 1942, Schlesinger *et al.* 1990, Society for Range Management

1983, Stuart-Hill and Hobson 1991). The focus is not on the variables of pattern and process that operate specifically at catchment and sub-catchment scales.

In this sense, the substantial progress in depth of understanding can be said to have addressed scale issues with minimal attention to issues of ecological hierarchy (Allen *et al.* 1984, Allen and Starr 1982, 1986). Nevertheless, this finer-scale work will play a major role in future monitoring and managing of rangelands, but could be complemented strongly by a more hierarchical conceptual framework for managing rangelands. That is, we suggest that a more holistic and vertically extended hierarchical model is required in order to understand why many fine-scale (within-landscape or "patch") changes are occurring.

By way of example, consider the land system concept developed in Australia (Christian 1958). A land system consists of a recurring pattern of landforms with characteristic soil and vegetation (land units) and can readily be recognised on aerial photographs using stereoscopes. Contemporary assessments of range dynamics tend to focus on patch dynamics, often only within selected units of a land system. How component land units interact within land systems and how toposequences of land systems within a catchment interact is rarely addressed(Pringle and Tinley 2003, Sparrow *et al.* 2003).

This article draws on work through the Ecosystem Management Understanding Project (www.emuproject.org.au) of the Gascoyne-Murchison Strategy in the arid zone of Western Australia 2000-2003 (Pringle and Tinley 2001, Pringle and Tinley 2003, Tinley and Pringle 2002). We have together over fifty years of field experience and share a strong urge to understand what we see within an integrated

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model, or overarching framework (Tinley 1982). What contemporary within-landscape models tell us about rangeland dynamics (Milton *et al* 1993, Schlesinger *et al.* 1990) does not explain convincingly many of our observations made from the air. We believe that a paradigm shift is required (Pringle and Tinley 2003).

The catchment (or 'drainage basin') is the fundamental unifying geo-ecological context of our approach (Tinley 1991). We acknowledge though that in some regions the catchment approach may be severely limited. The locally and internally drained karst landscapes of southern Australia's Nullarbor Plain are such an example (Gillieson *et al.* 1994). In this article we discuss a geo-ecological approach in terms of i) characteristics of healthy catchments, ii) key drivers of catchment changes, iii) symptoms of dysfunctional catchments, and iv) some approaches for restoring catchment integrity. "Integrity" (or being "intact") is regarded here as including patterns and processes reflecting minimal alteration from pastoral and other economic developments; most simply characterised by relatively high rain use efficiency.

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Patterns and processes within catchments and their hierarchically arranged components are intrinsically dynamic (as are associated inter-level relationships). Thus the evolutionary trends –most clearly observed when accelerated or initiated by human intervention (Pringle and Tinley 2003)- need to be accommodated within any context of "integrity". The issue of "integrity" in an ecological context is complex (Angermeier and Karr 1994, Wicklum and Davies 1995); our simplistic perspective serves our purpose here.

Our premise is that widespread rangeland degradation needs to be understood within a broader, geomorphic context (Pringle and Tinley 2003), as Pickup (Pickup 1985, 1989) proposed regarding the erosion cell concept. Contemporary within-landscape assessments do not readily enable such approaches (Bastin *et al.* 2002, Ludwig and Tongway 1995a, Pringle 1991, Rapport and Whitford 1999, State Of Environment Advisory Council 1997). In this article we attempt to describe indicators of catchment functional integrity and dysfunction, and how repair might be approached with a broader, hierarchical view of rangeland organisation.

We believe that with future management of rangelands based on increasingly better understanding of patch to catchment-scale patterns and processes, inter-level relations and critical control points, the cumulative assessments from remote sensing (Bastin *et al.* 2002, Ludwig *et al.* 2000) will more likely show desirable trends in space and time. Without this broader, hierarchical geo-ecological context though (Tinley 1982), we believe much rangeland restoration will continue to be symptoms-based and frustratingly unsuccessful (Hacker 1989, Whisenant 1999).

We have tried to minimise the use of specifically geomorphic terminology and have at times used colloquialisms. However we believe too that some broadening of the ecological vocabulary in this direction is long overdue if we are to include some of the slower and broader scale patterns and processes that influence rangeland degradation.

Assessing catchment integrity in the Gascoyne-Murchison Strategy area

Although there is repetition in the following sections – particularly in sections i) and iii)- we have resisted suggestions to provide an amalgamated list of indicators. We believe that the contrasting narratives describing intact and dysfunctional catchments need to be told independently and with the causal factors providing preliminary context for the latter. We have also resisted the urge to provide yet another table of indicators.

i) Characteristics of intact catchments

1. Sharply incised drainage tracts restricted largely to strongly sloping erosional terrain
2. Limited net export of resources (especially sediments and water)
3. High rain-use efficiency; strongly contrasting values at nested scales reflecting strong ecological organisation/differentiation
4. Strongly heterogeneous pattern and processes within component land systems/terrain elements
5. Clear boundaries between terrain process elements (eg run-through pediments, run-on floodplains)
6. Retention of intact (not leaking/breached) ephemeral wetlands at terrain process element junctions
7. Unaccelerated land succession processes
8. Long residence times of floodwaters on floodplains and their tributary floodouts
9. Nested series of base levels primarily set by geomorphic context, rather than by incision wrought by land use

10. Effective distributary (slowing and spreading) flow down-slope of pediments, with minimal incision
11. Strong across-slope differentiation on valley-sides reflecting subtle differences in soil, elevation and hence soil moisture balance
12. Effective overbank flooding with moderate events, rather than just after extreme rainfalls
13. Long periods of creek and river flow due to obstruction/infiltration in the catchment area (slower, longer lasting flows)
14. Slower, finely scaled erosion cells marching up-slope, allowing effective self-healing within landscapes
15. Longer, less "spiky" responses of primary productivity to rainfall, with strong differentiation between terrain process elements
16. Effective and persistent "greening up" of local ephemeral wetland features at terrain process element junctions in response to local rainfalls
17. Control of scrub encroachment by effective waterlogging in seasonally flooded areas in all terrain process elements (including uplands).

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ii) Key drivers of catchment change in the Gascoyne-Murchison region

This collection of drivers represents a synthesis of experiences with managers on the ground and from flying between 100 and 200m above ground level on at least 40 properties occupying over four million hectares in the region (Murchison Land Conservation District Committee and the Ecosystem Management Unit 2002, Pringle and Tinley 2003, Pringle *et al.* under review). It also builds on several decades of experience between us as landscape ecologists (e.g. Tinley 1977, Pringle *et al.* 1994).

1. Watering places in/near drainage tracts leading to incision, headward gully retreat and land dessication; particularly near key-lines at which drainage patterns should switch from tributary to distributary process states. (Note that abundant, shallow and fresh groundwater is usually abundant at these key-lines and it is normal, rather than exceptional, to observe watering points in these critically sensitive locations).
2. Water capture, erosion and down-slope desiccation due to poorly located and constructed access routes
3. Livestock pads breaching ponding sills in wetlands, including pans, billabongs, levee banks and convergent delta plugs.
4. Livestock pads linking erosion cells and initiating rapid headward gully erosion and landscape desiccation, particularly in floodout fans on valley sides
5. Excessive grazing pressure reducing ground cover and so obstructions to flows of wind and water, exacerbating/accelerating natural land surface succession processes such as i) sediment accumulation in pans and ii) the fragmentation and stripping of wanderrie bank sands (Mabbutt 1963b). Under accelerated surface flow velocities, local incisions are less likely to be self-healing within a landscape and more likely to initiate widespread canalisation and desiccation.
6. Low ground cover and canalised drainage networks leaving interfluve areas effectively perched above most water flow, and increased sediment output (or accumulation in endoreic drainage termini)
7. Landscape incision leading to more rapid draining/drying of floodplains, which in turn favours scrub species over previous hydrophilic floodplain grasses.

iii) Symptoms of dysfunctional catchments

1. Nested hierarchies of incised base-levels initiating canalisation and widespread sheet erosion with resulting landscape desiccation
2. Strongly canalised drainage networks connecting watersheds to exit/sump areas with severely reduced infiltration across the catchment
3. Scrub encroachment of leaking floodplains and other intermittently inundated surfaces as scrub seedlings are no longer drowned
4. Increasingly large rainfall events required for overbank flooding in deeper and wider channels
5. Ephemeral wetlands most prevalent in late successional stages (thickets or indistinguishable) with rare early stages (damp spots developing into vertic pans)
6. Shortened periods with moist soils hence shorter-lived vegetation responses to rainfall
7. Prevalence of plants adapted to desiccated edaphic environments (ruderal and scrub species) beyond run-off terrain
8. Reduced differentiation of responses to rainfall between terrain process elements as run-off and run-through predominate
9. Breaching, erosion and desiccation of ephemeral wetlands by gullies at terrain process element junctions
10. Increased prominence of bare soil and/or annual plant communities (and scrub in desiccating seasonally waterlogged areas)
11. Decline in prominence of perennial grasslands and chenopod shrublands; bare stages colonised after time along guttered erosion by scrub
12. Increased and expanding soil erosion (coalescence of bare and scalded areas)
13. Larger and faster eroding erosion cells, loss of self-healing capacity (Pickup 1985)

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14. Increasing "spiky" responses to rainfall across process terrain elements subject to run-on (due to desiccation)

15. Within landscape reduction in strength of finer-scale patterning (homogenisation) (Pickup 1985) and loss of radioactive nuclides (eg Pb210, Cs157) and migration downslope. Nuclides lost out of exoreic (out-flowing) catchments and accumulating in endoreic basin concavities (e.g. salt lakes and pans), unless redeposited up-slope by accelerated winds (e.g. Gillieson *et al.* 1994)

16. Increasing dominance of broader-scale physical geomorphic processes (e.g.landscape reversal, headward gully retreat) over finer-scale biologically-mediated processes (e.g. accumulation of wind-blown detritus as bush mounds under perennial shrubs).

iv) Some approaches for restoring catchment integrity

By catchment integrity we mean the capacity of a catchment's drainage patterns to shift from tributary to distributary and slower flow at key-lines on valley sides and for relatively high residence times of precipitation in wetlands and floodplains. In general terms, this means relatively high rain use efficiency within landscapes and their catchments.

1. Critically, identify lowered base-levels in drainage networks (including gully heads) and restore them as best as possible once the cause of their lowering has been addressed (e.g. reticulate water away from critical drainage pattern control points; encourage stock to travel across slope to favoured grazing areas using short fences within paddocks)
2. As above for breached wetland sills (the sills are the local base levels responsible for a wetland's existence)

3. Develop grazing strategies in line with the different behaviour of terrain process elements (particulary with respect to toposequences/catena responses to rainfalls), particularly in terms of strategic resting of fertile bottomlands and effective use of more "seasonal" landscapes (Wilcox 1963)
4. Choose types of livestock that will facilitate recovery (e.g. camels are soft-padded and browse, sheep have a split upper lip and tend to graze down to ground level baring much soil and reducing resistance to flows; conversely, goats graze perennial grass least if they have access to browse). What type of animal will enable an ecological fit in different circumstances?

The choice of techniques with which to restore ecological functioning within individual landscapes should focus on using natural processes to direct internally driven succession by recognising and entraining natural patterns and processes (Tongway and Ludwig 1993, Whisenant 1999).

Even if some rangelands once may have been suitable for livestock production, the changes that have been wrought upon them may now preclude traditional commercial aspirations. We believe that there is a strong need to investigate additional commercial opportunities to support a truly sustainable model of "Outback habitation". This may enable more flexible grazing management, including long-term rest or removal of grazing in some circumstances.

The importance of alternative and complementary uses of grazing lands cannot be underestimated in characteristically historically degraded rangelands. They offer the opportunity for people with a love for the land to remain and embark on a new, sustainable trajectory (Pringle *et al.* 2003). The alternative resources are there; institutionally obstructive settings may be the greatest barriers to change. At present, pastoral leases have to be used for grazing, even if this might be absurd in cases where climatic variability and the legacy of degradation renders the lease incapable of supporting profitable grazing as a sole enterprise (Anon. 1993). The whole basis of rangeland use and tenure needs to be addressed freshly (Holmes 1994, Stafford Smith *et al.* 2000, Wilcox and Burnside 1994). Otherwise, the patterns of catchment dysfunction will become worse as landholders find it increasingly difficult to be both profitable and ecologically sustainable graziers under an inexorable trend of increasing desiccation and declining rain use efficiency.

Synthesis and conclusion

Contemporary assessments of broadscale rangeland condition in Australia consist of aggregated site-based data (State Of Environment Advisory Council 1997) or spatially explicit, broad-scale accounts of within-landscape dynamics (e.g. Bastin *et al.* 2002, Ludwig *et al.* 2000). These assessments record the impacts of landscape change, not the causes. If monitoring is to be useful, it must have management context (Bosch and Booysen 1992, Stuart-Hill and Hobson 1991). Arguably, assessments of degradation within landscapes (Pringle 1991) seem to have encouraged development of symptoms-focused restoration, that is; within-landscape restoration (Hacker 1989, Tongway and Ludwig 1993). This focus on lower levels of ecological hierarchy is consistent with much contemporary ecosystem modelling (Breshears and Barnes 1999, Chapin *et al.* 1997, Garner and Steinberger 1989, Milton *et al.* 1994, Scholes and Archer 1997).

Contemporary explanations of patterns and changes, and proposed solutions, in Australia's Outback ecosystems remain mostly focused on internal factors that we can readily view like a doctor with a patient (HilleRisLambers *et al.* 2001, Milton *et al.* 1994, Westoby *et al.* 1989) . Yet these critical changes, which are mostly negative by assessment (State Of Environment Advisory Council 1997), fail to accommodate initiated or accelerated processes that may be inexorable and only dampened (Tinley 1977, 1982).

Even with local observation, a trained geo-ecological eye can sense the possibility that either a local observation implies profoundly wider implications, or that somewhere else in the catchment, something is out of kilter --as geomorphologists do as a matter of course. The problem in rangelands, as we see it, is that the overarching models that might sound the alarm are missing due to a focus on patch dynamics within landscapes. However, such geo-ecological views of within-landscape patch dynamics and function (beyond traditional plant community dynamics) are relatively recent breakthroughs themselves (Ludwig and Tongway 1995a, b, Tongway and Ludwig 1990, 1994). They will be critical components of co-ordinated catchment restoration of dysfunctional rangelands.

Degradation in Australia's rangelands is extensive (State Of Environment Advisory Council 1997) and effective restoration of widely degraded catchments is likely to require a catchment-level approach. Once drainage patterns become slower, more spread out and sinuous, local within-landscape approaches (Tongway and Ludwig 1993, Whisenant 1999) are more likely to succeed. However, until this more expansive approach is enacted, the success of local interventions is likely to be at best restricted to landscapes selected for resource-demanding treatments, rather than addressing the full scale at which degradation has occurred in most rangelands (Pringle and Tinley 2003).

Diagnosis and restoration of catchment integrity therefore requires far more than the collation of multiple fine-scale observations. Assessing and monitoring catchment integrity needs to be based on catchment models based primarily on geomorphology and hydrology (Mabbutt 1963a, Pickup 1985, Tinley 1982), rather than patch/inter-patch landscape ecology. Importantly, approaches to repair damaged catchments (rather than their visually worst affected components) are urgently needed. Within-landscape approaches are unlikely to result in the major shifts in process-states needed to address catchment scale dysfunction. Indeed, progress in addressing catchment-scale restoration may greatly enhance local landscape restoration (Murchison Land Conservation District Committee and the Ecosystem Management Unit 2002).

Grazing management such as resting strategies can only achieve so much in catchments that have large areas effectively perched above average sheetflows or subject to less frequent and less persistent flooding (Pringle and Tinley 2003). These areas are entrained in an insidious trend of increasing desiccation. Canalised drainage patterns need to be addressed by restoring *base levels* at major drainage confluences (where drainage tracts merge) starting at source areas and working downwards. Wetlands and floodplains may need to have ponding sills restored and reinforced. These strategic interventions will favour a flip from increasingly canalised and erosive drainage patterns and ineffective rain use, to slower, spreading drainage patterns more likely to deposit sediment than entrain it.

Finally, we recognise that the catchment-scale strategies so critical to effect meaningfully extensive rangeland restoration (Murchison Land Conservation District Committee and the Ecosystem Management Unit 2002) will demand many more resources than are immediately available. Thus, critical success factors will include:

1. Catchment-scale participatory planning
2. Strong community cohesion and individual self-reliance
3. Commitment to long-term management objectives
4. Achievable objectives in successively longer time frames
5. Some early successes, starting in source areas
6. Consistent, reliable Government support
7. Demonstrable support from community organisations.

We are all faced by cultural and institutional settings and trends such as globalisation. The loss of diversity, including biodiversity, may only be addressed by first acknowledging and assessing the hierarchical dynamic framework of our human-dominated ecosystems (Noble and Dirzo 1997) and only then can we address effectively the coal face of local homogenisation and vulnerability to externalities. A hierachy of "knowing" is needed to manage beyond the symptoms and effects. Once we appreciate the hierarchical nature of dysfunction and its multiple and interacting causes, we can start effectively to repair damaged ecosystems and understand and manage threats to remnant intact ecosystems.

Final comment

By no means is this qualitative narrative of the complexity of rangeland dysfunction we have observed individually and together to be regarded as a definitive assessment. While many of the ideas have emerged from and withstood scientific testing, the synthesis and framework have not. It is hoped that this narrative motivates a new focus of scientific inquiry, and does so in a truly participatory way such that the research and land management community are as one (see Sawa *et al.* 2004). We also hope that slower variables may become understood better, as the stage upon which our traditional foci, faster variables, play out their dynamics.

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