Are we overlooking critical geomorphic determinants of landscape change in Australian rangelands?

By Hugh Pringle and Ken Tinley

The contemporary paradigm of range ecology is inadequate

Traditional range ecology has viewed ecosystem dynamics almost entirely in terms of the local and reversible impacts of grazing off-take (Dyksterhuis 1958). Yet plant community dynamics have since been acknowledged as being far more complicated (Connell & Slatyer 1977; Noble & Slatyer 1980; Westoby *et al.* 1989). Recent advances in the analysis of landscape function (Ludwig *et al.* 1997), remote sensing (Bastin *et al.* 2002) and biodiversity responses along grazing gradients (Landsberg *et al.* 2002) have improved the depth and spatial extent of our understanding in Australia. Previously less evident within-landscape patterns are now better understood, over larger areas of assessment more appropriate to scales at which rangelands are subdivided and managed.

In addition, much current research has been preoccupied with patch/interpatch interactions in Australia (Bastin *et al.* 2002) and overseas (Schlesinger *et al.* 1996; Breshears & Barnes 1999) and has overlooked the major role of base levels in influencing landscape change at all scales. In particular, base levels affect soil moisture balances (Tinley 1982) and phases of erosion, transport and accretion (Pickup 1985). While influential base levels are sometimes off-site; they are readily identified if the observer knows what to look for.

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Incised base levels and landscape desiccation

One example of landscape incision and lowered base levels is the emerging pattern that we have observed and photographically recorded from ground traverses and low-level flying (about 100–200 m above ground level) in many areas of Australia and Africa. This observation is of a strong pattern of increased drainage (often caused by wildlife or livestock incisions of natural levees and riparian sills) resulting in accelerated edaphic desiccation at a local landscape level. This may explain much of the vegetation change evident in these areas.

In detailed studies of the Urema Lake floodplain in the Gorongoza ecosystem of Mozambique, at the southern African end of the Great Rift Valley, Tinley (1977) clearly documented landscape succession brought on by drainage incision and resultant desiccation and scrub invasion of floodplain grasslands. Breaching (by Hippopotami *Hippopotamus amphibius*) of a valley-side tributary fan alluvial plug across the outlet of the Urema Lake and its surrounding floodplains led to insidious and progressive desiccation of the entire wetland system. Scrub invaded out from faint convexities (often associated with termite mounds) and the valley sides to predominate over large areas of floodplains.

The Australian areas in which this essentially geomorphic model of change has been observed include the chenopod shrublands of the Murchison River floodplains in Western Australia (Murchison Land Conservation District Committee and the Ecosystem Management Unit 2002) and a number of grassy floodplains including the convergent delta systems of northwestern Australia and those occurring across the 'Top End' of northern Australia (Pringle & Tinley 2001b; Tinley 2001).

Clearing, fire, herbicides and rest from grazing are traditionally recommended responses to scrub encroachment (Noble 1998; Scanlan 2002) that reflect an assumption that causal factors are largely contained within the more localized landscape. Scrub encroachment is usually explained in terms of local influences such as grazing pressure or lack of fire on competitive

Box 1. Landscape evolution of a segment of a major river and floodplain and its adjoining valley-side catchment

Fig. 1a describes seven principal zones.

Zone 1: Breakaway scarp zone (first break in slope): sand-mantled laterite duricrust (2–20 m in height) with narrow talus slope. Scarp retreat by basal sapping of underlying kaolin and mass wasting. Mantle sand may be washed off scarp crest onto pediment.

Zone 2: Scarp footslope zone: shallow duplex soil with thin brittle sandy topsoil (4–8 cm) subject to surface stripping by rill and sheet erosion where disturbed; over saline clay subsoil (20–40 cm) subject to scalding where exposed; over hard-setting granite saprolite and kaolin. Supports halophytic low shrublands with small grasses (e.g. *Eragrostis dielsii*). Upper parts of Sherwood land system (see Curry *et al.* 1994) for example.

Zone 3: Contour keyline zone (piedmont angle, second break in slope): inflection of slope from faintly steeper scarp slope to flatter gradient of main pediment grading into sheetwash tributary plains and lower sand fan zone. The wash and rill tributaries from the scarp footslope slow, scour or pond along the slight break in slope and converge at a low point to fan out over the pediment.

Zone 4: Pediment grading into tributary sheetflood plains and fan distributaries: very low gradient slopes (< 0.5%) of leached, shallow (to *c.* 30 cm) neutral to acidic clay loams over red-brown silica hardpan; supporting 3–6 m height mulga (*Acacia aneura*) woodland. Traversed by grassy flat drainage lines (4a) and scour depressions (4b), with quartz mantling in upper tracts and sand sheets and banks between drainage lines in lower tracts. Scrub and perennial wanderrie grass cover. Lower parts of Sherwood land system, more extensively Belele and Yanganoo land systems.

Zone 5: Linear valley-side pediment junction with major river floodplain. Third break in slope with scour depressions (cracking clay vertisol pans), overflowing by seasonally marshy drainage lines to the main river course.

Zone 6: Segment of major river floodplain: within reach of most overbank flooding, including recharge of billabongs (6a) and other depressions. Floodwaters exiting plain back into the main channel at low points in the levees (6b).

Zone 7: Segment of major river and adjoining floodplain on either side held in place by ponding effect of rock bar plug (7a). Levees on both banks *without* cliffed banks (7b).

Fig. 1b is an illustration of land surface succession and desiccation caused by erosion incision of base levels in the same cross-sectional valley segment.

- Erosion in each land facet can be entrained by breaching and lowering of the secondary base level in the main river channel formed by the rock bar (7a). Result is trenching of the river bed, cliffed banks (undercut and slumping) leaving behind the now higher level of perched floodplain condition in reach of only major floods).
- Incised channels cutting headward through the floodplain in turn breaching the outlets of billabongs and pans (6b). In turn, cutting across the floodplain (zone 6) and floodplain/valley-side linear junction (zone 5) and into the sand fans (zone 4), thence up-slope eventually to the valley-side catchment source area at the breakaway zone (1).
- And/or sheet, rill and gully erosion can be initiated in, and spread from, different parts of the same landscape segment as a result of local terrain disturbances (e.g. tracks or cattle paths, Fig. 2), these patches enlarging and coalescing.

Specific changes within zones:

- Erosion of scarp footslope and elimination of halophytic shrub community, scrub colonization by invasion along rill and gully cuts due to amelioration of soil moisture and salinity conditions along incisions (zone 4).
- Keyline drainage neck incised, pans breached and colonized by scrub thicket (typically curara; *Acacia tetragonophylla*).
- Gully and nickpoint breaching of fan distributaries and run-on areas (zone 4).
- Floodplain (zone 6): coalescence of sheet erosion resulting in stripping (truncation) of topsoils and elimination of saltbush habitat. Replacement is by bare scalded flats, eventually invaded by scrub (typically bardi bush; *Acacia victoriae*) along surface incisions or areas of topsoil accumulation.

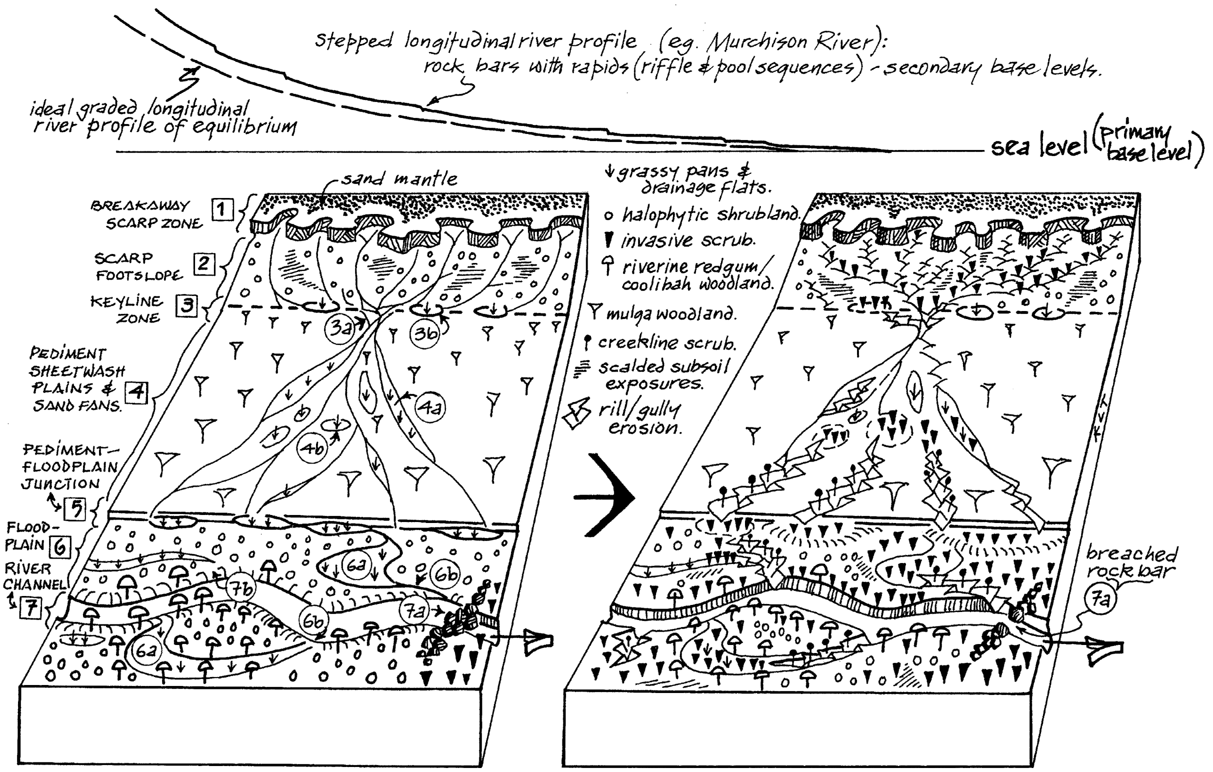

Figure 1. Segment of major river and its floodplain with adjoining valley-side catchment. (a) Landscape in dynamic equilibrium (minimal erosion). (b) Same landscape in active, erosion driven transformation.

interactions with grasses (Walker 1974; Archer 1994; Scholes & Archer 1997; Scanlan 2002) and subshrubs (Burnside *et al.* 1995), although externalities such as climate are considered (Scholes & Archer 1997; Breshears & Barnes 1999).

The idea that grasslands persist due to buffering that makes encroachment unlikely in certain circumstances (Jeltsch *et al.* 2000) is critical, but the process-state and control points that ensure that buffering persists need to be recognized and managed. The control points (base levels in our model) may be local, but they are just as likely to be some distance way. Landscape level desiccation of soil profiles due to drainage incision has, in some areas, been shown to have a direct bearing on the transition from treeless grassland to scrubland (Tinley 2001, 1982) and may well drive affected savanna systems to woody dominance over grasses in other areas not yet studied with a geomorphic perspective on landscape dynamics.

Diagnosing catchment dysfunction in arid Western Australia: A preliminary case study

Together with local pastoralists in the arid zone of Western Australia (e.g. Murchison Land Conservation District Committee & the Ecosystem Management Unit 2002), we have built a model of catchment dysfunction at two principal levels (see Figs 1,2). The first is at the level of catchment drainage organization; from watershed (e.g. a range or breakaway system) to bottomlands (in this case a river). The second level (Fig. 2) is a vivid example of local desiccation; whereby an ephemeral wetland is breached, losing it's critical drought refuge/buffering role and distinctive biodiversity (Box 1).

While evidence in Australia that scrub encroachment of seasonally flooded areas is related intimately with landscape desiccation consequent of incision is largely observational rather than 'scientific', other effects are well established scientifically. For example, denudation of vegetation under unremitting grazing stress, may lead to declining moisture balance from a stripped topsoil environment, exposing bare sodic subsoils and reinforced and prolonged in the bare state by scalding (Pringle 2002).

In the Murchison River catchment we have noted typical patterns of scrub encroachment associated with gully systems cutting back from river channels through levee banks and out into floodplains. These gullies have often been initiated by stock tracks accessing river pools, a pattern we have also observed in the tropical floodplain grasslands across northern Australia (many personal observations and photographs from the ground and air by the authors). A common clue to these land succession processes is the age/size distribution of plant functional types. When scrub species have clear patterns of topographic encroachment expressed by increasingly smaller/younger plants (subtly downslope from valley sides or off convexities, or more obviously when colonizing gullies) there is strong evidence that

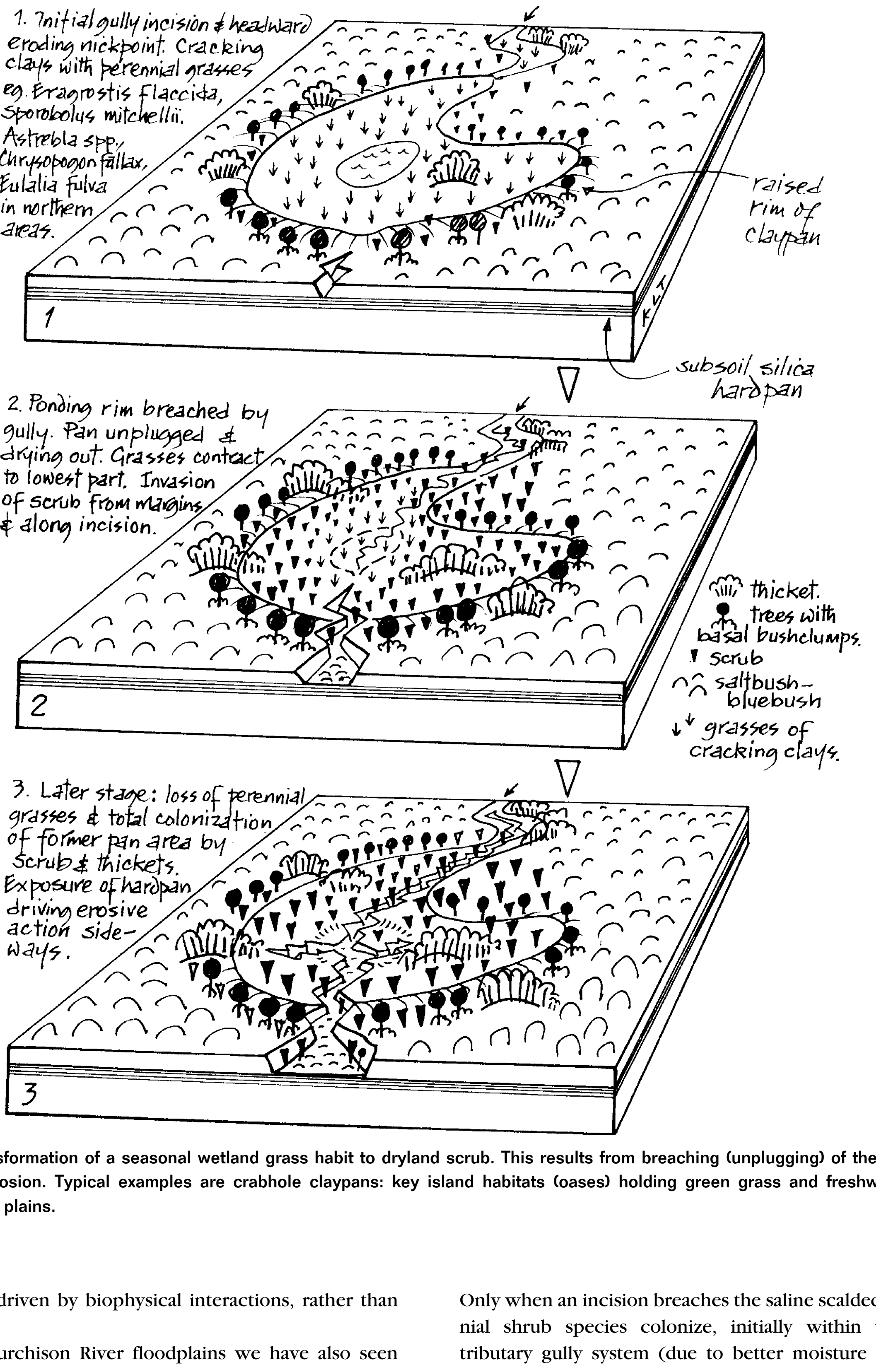

Figure 2. Transformation of a seasonal wetland grass habit to dryland scrub. This results from breaching (unplugging) of the ponding rim by headward gully erosion. Typical examples are crabhole claypans: key island habitats (oases) holding green grass and freshwater longest on saltbush–bluebush plains.

change is being driven by biophysical interactions, rather than grazing *per se*.

Within the Murchison River floodplains we have also seen vast areas that once supported chenopod shrublands (Curry *et al.* 1994) now containing extensive scalded areas interspersed with scrub-dominated sandy accumulations of previous topsoil. Only when an incision breaches the saline scalded flats do perennial shrub species colonize, initially within the expanding tributary gully system (due to better moisture conditions and decrease of sodium).

Looking upslope of floodplains, near Mount Magnet in arid Western Australia, we have seen a different impact of landscape incision and desiccation. Large areas of valley-side tributary sheetflood plains supporting Mulga (*Acacia aneura*) low woodlands have incised, near-parallel, drainage lines running through them. The interfluves are now effectively perched above the sharply incised (rather than gently depressed) run-through drainage lines and consequently, Mulga deaths are widespread and the 'zebra-stripe' groves they normally form are often only recognizable by bands of decaying logs. (For simplicity's sake, this pattern is not represented in Fig. 1, landscape sequence zone 4.) Interestingly, when small gully heads have cut laterally back from the incised drainage lines, young scrub species are frequently observed colonizing the gullies, following the gully heads back into the perched interfluves. In this instance, a new episode of landscape incision is driving re-establishment of perennial vegetation into the perched area.

Desiccation generally leads to scrub encroachment in seasonally flooded landscapes, but on valley sides and pediments, desiccation can lead to death of woody species from water starvation (the opposite of scrub encroachment). Thus, the geomorphic context of any area under consideration is critical to an understanding (including modelling) of the dynamics, critical controls and restoration requirements of ecosystems.

Implications for restoring rangelands

We acknowledge that increasing local resistance to flows of wind and water (i.e. patch/interpatch conditions) by maintaining ground obstruction (Tongway & Hindley 1995) will retard land succession processes and aid local restoration, including the stabilization of gully systems. Local restoration in canalized catchments with nested patterns of lowered local base levels has occurred during runs of good seasons in the Gascoyne-Murchison region of Western Australia (Watson & Thomas 2002). However, we believe that the fundamental changes wrought by landscape incision prevail as an underlying influence towards increasing desiccation. We contend that effective rangeland restoration requires that base levels are restored such that the tendency for topsoil stripping and desiccation is addressed in a step-wise fashion down the catchment. This geomorphic approach will address primary causes at multiple scales (at nested base levels) and enable effective restoration of productive bottomlands.

Before considering patch/interpatch dynamics, we would investigate whether the landscape of interest is receiving more or less flow than it might once have, and whether that flow is being drained more rapidly than it might once have been. Then we would look at internal landscape dynamics. To illustrate, on Billabalong station in the Murchison River catchment, a mix of intervention strategies had all failed to restore perennial vegetation and landscape function to a flood-out plain. When a group of pastoralists and ecologists travelled up-slope, we quickly agreed that the plain could only be restored when the water flows onto it had been calmed. Intervention to treat the striking impacts in the flood-out plain becomes an eventual, rather than immediate objective (Murchison Land Conservation District Committee and the Ecosystem Management Unit 2002).

Our hierarchical geo-ecological approach is in strong contrast to the almost sole focus on intensive mechanical intervention at the points displaying worst symptoms, sometimes far removed from incisions causing desiccation and dysfunction (Hacker 1989).

Ecological restoration of widely dysfunctional rangelands may need combinations of fire, herbicides and special grazing management. However, we suggest that these may need to be secondary activities. Symptoms management will continue to be a disheartening addiction if it is in confrontation with inexorable land succession processes that increasingly change the local conditions for plant growth through positive feedback loops (Whisenant 1999). If scrub is encroaching due to floodplain leakage and edaphic desiccation (Tinley 2001, 1982), merely attacking the scrub – however, effectively – is likely to be of temporary value. The best mechanical, fire or biological treatments will not change breached floodplains' increasing tendency to favour woody plant species, whose germinating individuals would have been drowned during previously longer periods of seasonal inundation (Tinley 1982, 1977).

Through the 'EMU exercise' (Pringle & Tinley 2001a), we recommend low input approaches at strategically located points of intervention such as lowered base levels and natural drainage bottle-necks. Our fundamental approach is to calm and spread surface water flows using sieves or filters as opposed to blockages in most cases. Importantly, we emphasize starting from the source areas and working downwards in order to harness naturally occurring processes to drive restoration from within. This also preconditions hydrologic regimes on fertile bottomlands, allowing low key interventions that will receive more frequent, but calmed surface flows.

Current and future research

We have a manuscript near completion describing causes, symptoms, indicators and possible remedial action for dysfunctional catchments in the arid zone of Western Australia to complement more locally focused approaches to rangeland assessment and restoration (Curry *et al.* 1994; Tongway & Hindley 1995; Whisenant 1999; Watson & Thomas 2002). We are also developing a substantial participatory research project with the Murchison Land Conservation District Committee to test these ideas in a major tributary system of the Murchison River.

We acknowledge contrary quantitative evidence of our hypothesis of inexorable rangeland desiccation in our primary region of study, the Gascoyne-Murchison Strategy region of Western Australia (Watson & Thomas 2002). However, we note too that the widespread recruitment of a range of plant functional types (not just scrub species) occurred in response to a succession of good seasons and the sites sampled were intentionally located on large areas of relatively uniform landscapes, rather than at dynamic edges. We propose that a major research effort is required to expand our understanding beyond patch-scale dynamics within broad landscapes. If we are correct, the contemporary rangeland management paradigm of within-landscape management of patch dynamics is often not sensitive to major driving influences on landscape and vegetation change and hence the fundamentals of sustainability in the arid zone which has to do with soil moisture balance.

We suggest that this research effort should prioritize a number of potentially fertile research questions. Is a broader geo-ecological context cascading down into more intimate salience a legitimate starting point in pursuing harmony with the land (Tinley 1991)? How do we start quantifying ecosystem patterns and (more importantly) how does their behaviour vary with stresses that overlap and interact at catchment scales? Is this fertile ground for research?

Concluding comments

We acknowledge that contemporary pastoralism is about managing dysfunctional catchments, which are generally a legacy of the past. In particular, the historic placement of fences and watering points in critical control points (such as keylines, which is common) have set in train broadscale geomorphic processes that now threaten the rangelands, their catchments, landscapes and habitats. Even the best floodplain grasslands or saltbush shrublands may be at risk if base levels have been lowered and a new episode of erosion and desiccation has commenced.

In this context, we contend that a continued failure to commence analysis higher in the hierarchy of ecological patterns and processes (Allen *et al.* 1984) severely limits our understanding of rangeland dynamics and how to manage, monitor and restore rangeland ecosystems. We suggest that local disruption of higher level geomorphic processes at critical control points in catchments often entrain far-reaching physical land succession processes that drive transitions in vegetation. Indeed, these transitions may involve complete ecosystem replacement from grasslands or savanna to thickets and forest. Despite substantial effort, these transitions have not generally been reversed effectively by traditional agronomic approaches to management of symptoms – in our view largely because of an excessive focus on site-based problems without due regard to geomorphic and catchment context and resultant landscape processes (Fig. 1).

We suggest that a hierarchical, geo-ecological approach is required in managing rangeland ecosystems. That is, rather than starting at the finest scales, and scaling upwards to explain system behaviour (e.g. Ludwig *et al.* 2000), we suggest that the system of interest needs first to be defined within its broader context (Tinley 1991). Then it can be assessed in terms of nested hierarchies of key components and interactions (O'Neill *et al.* 1986).

We believe that a hierarchical geo-ecological approach will result in better understanding and more realistic modelling of rangelands that will hopefully lead to better land management. Ecologically sustainable rangeland management will 'fit' – rather than 'fight' – nested ecosystem patterns and processes.

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