LANDSCAPE INCISION PROCESSES FAVOUR BUSH ENCROACHMENT OVER OPEN GRASSLANDS IN THE TWO EXTREMES OF SOIL MOISTURE BALANCE IN ARID ZONES ACROSS SOUTHERN AFRICA AND AUSTRALIA

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ABSTRACT

Different plant forms compete for limited resources and various factors influence outcomes. Usually overlooked, the physical environment, particularly the soil profile, is not only a key factor, but also a dynamic one. That is, the edaphic environment in which plants are rooted cannot be mapped once and then taken as "covered". Soils are essentially biologically modified sediments and remain in a state of flux in terms of physical earth processes (erosion, transportation and deposition). These processes fundamentally control conditions for plant growth, principally through control of Soil Moisture Balance (SMB). We describe two extremes of SMB and how incision processes are required to allow establishment of woody plants in what are naturally grasslands or similar. The physical landscape process (incision) is the same in both cases, but the enabling factor in terms of SMB is exactly the opposite for establishment of woody plants. This stark contrast underlines the need for ecologists to be landscape or "terrain" literate in order to understand the conventional "bio-centric" factors in their physical earth surface context. In other words, the stage in which biological interactions occur, is not static; rather it is part of the unfolding drama that is ecology.

INTRODUCTION

It has long been acknowledged that the soil environment exerts a very strong selective pressure on which plants can best grow in a place. This in turn is reflected in different types of vegetation within a farm. We also know that grazing exerts selective pressures that favour different types of plants, depending on how that grazing is managed. It is also acknowledged that bush encroachment is self-reinforcing; that the less soil moisture there is available to soft perennial grasses due to bush uptake, the more bush will dominate them under unrelenting grazing pressure.

What is not well understood, nor mentioned in the national review of bush encroachment in Namibia (De Klerk, 2004) or elsewhere (Ward, 2005), is the importance of major changes to the physical environment that directly affect SMB (Tinley, 1982). Traversing open grasslands, it is not uncommon to find a donga (gully) supporting the only woody vegetation in the landscape. However, it takes a deeper understanding of how landscape incision affects SMB and therefore enables the development of this woody vegetation, in order to step beyond the simple correlative understanding of a donga and bushes within a grassy landscape.

SMB is essentially the amount of moisture retained within a soil and available for plant uptake (i.e. not including crystalline water). In the typically driest landscapes, the soil is often free draining and rainfall low, such as around the majestic eminences of the plains west of Windhoek (e.g. Spitzkoppe) or the similar granite inselbergs of arid Western Australia (Curry *et al*., 1994). These mountain fringing landscapes with shallow skeletal soils are typically devoid of woody vegetation layers because the soil is not moist long enough for many woody plants to establish within a climate of low and unpredictable rainfall. Interesting though is that nearby such extremely quick drying soils will be quite contrasting, slow drying soils in different landscape process settings and they are also largely devoid of woody vegetation. In such cases, however, the soil is saturated too long for woody plants to establish; they are literally drowned. The two scenarios therefore share the same climate and dominant plant forms (in a broad sense), but for quite different reasons.

In between these two extremes of SMB, there is a complex and fascinating competition between different plant forms with differing vital attributes (Noble & Slatyer, 1980; Walker *et al.*, 1981). This more contested area often covers the overwhelming majority of a drainage ecosystem or rangeland region (Pringle *et al*., 2006) and has been the focus of most research and thought to date regarding bush encroachment (Ward, 2005; Joubert *et al*., 2008). This most widespread part of the SMB spectrum is indeed where much bush encroachment is occurring and justifies the focused attention it has received to date. However, what is happening within landscapes at the extremes of the SMB spectrum are also important and present interesting challenges in terms of how limited resources are deployed.

In this article we attempt to explain how important it is to include terrain factors in ecosystem understanding and in particular, to understand the dynamics of physical earth surface processes that have particularly strong influences on biological dynamics, mostly through SMB.

SCENARIO 1: HYDROMORPHIC GRASSLANDS AND SIMILAR VEGETATION FORMATIONS

Seasonally inundated terrain process elements can occur wherever water is naturally ponded, but are most frequently associated with the most hydrologically active "drainage alley" (Pringle *et al*., 2006) or drainage catena which encompasses upland dambos, valley-side tributary floodout fans, floodplains and lacustrine environments, as well as coastal floodplains. These elements are naturally nested; an aquatic system (e.g. a water hole or swamp) may be part of a wider seasonally inundated floodplain.

What they have in common is that woody plants cannot establish within them because their root systems are in saturated (anaerobic) conditions for too long. They germinate and then die (Tinley, 1977). In his doctoral studies of the Gorongoza ecosystem, Tinley clearly demonstrated this “drowning” effect. He also explained how the breaching of the soft sediment base level that created Urema Lake was by hippo migrating south to remaining river pools in the Pungwe River in prolonged dry seasons. The area that was previously seasonally inundated quickly contracted and bush encroachment by fever trees (*Acacia xanthophloea*) followed. This then accelerated the recession of the previously fatal (to woody species’ seedlings) saturation front as mature woody plants enabled their juvenile counterparts to survive wet seasons by helping to dry out more soil. This pattern led to age-size belts reflecting recruitment events since desiccation (unplugging of the Urema Lake), with older and taller fever trees on high points and progressively smaller plants towards the encroaching front (Tinley, 1977).

An interesting feature of Tinley’s Gorongoza studies was that the Urema Lake at the foot of Mt Gorongoza at the southern end of the Great African Rift Valley developed and existed because a valley-side tributary created a sediment floodout fan across the valley floor, hence building a natural “dam wall” (Figure 1). This sediment fan is what the hippo breached, triggering aggressive donga development upslope, downward spiralling SMB and an explosion of woody plant encroachment in a positive feedback loop.

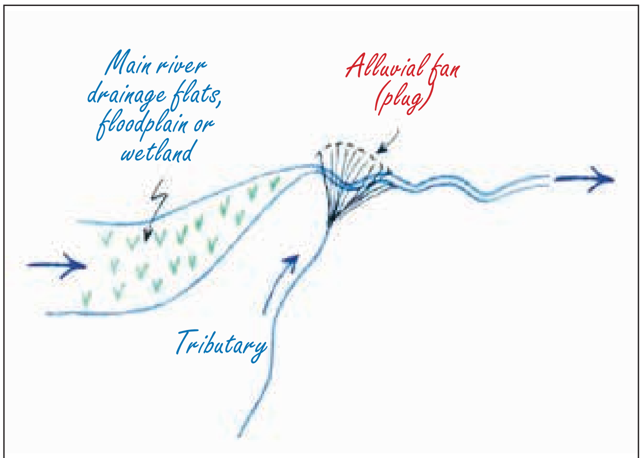

Figure 1. Diagramatic illustration of how a natural “dam wall” may form by a valley-side tributary creating a sediment floodout fan across the valley floor.

The Blanco Flats east of Tarkastad in the Eastern Cape Province of South Africa are essentially *Acacia karroo* scrublands inhabiting donga systems and surrounds. The senior author’s family owned Cyrilhurst Farm, which included most of these flats until recently. “They have always been thornveld” was Hugh Pringle’s uncle’s view. We know they were once open vlei grasslands because “old timers” well recall this (e.g. Sandy Stretton regarding his father’s observations when he worked in the area and personal communications with Hugh). The previous owner of Blanco Resort recalled to Hugh how there were stories that horsemen hated crossing the Blanco Flats, not because of the four metre (in places) deep dongas (which weren’t yet there), but because the vlei grass seeds used to get through their upper trousers and cause sores. The Blanco Flats were quite different when they were a seasonally inundated wetland system, rather than the thornveld donga system they are today.

The Blanco Flats were probably “unplugged” by the access track to farms where the flats drained out with the Bottlegaat River just upstream of the Cyrilhurst farmhouse (Cyrilhurst was owned by Hugh’s family for over 50 years). The relationship between the Blanco Flats and the Bottlegaat River is difficult to assess, such has been the impact of historic overgrazing, which includes the use of the area as a cattle concentration camp during the rinderpest plague early last Century. Interestingly and in support of the proposition above, the old wagon track rises across the Blanco Flats over a steep escarpment onto the Tarka Flats – a donga system now dominated by *Acacia karroo* and “beyond repair” (according to the local Department of Agriculture staff in Queenstown, many years ago). This incision and then invasion of an aggressive scrub species resonates with the same issues in south-western USA (Cooke & Reeves, 1976) and Australia (Tinley, 2001).

There are numerous accounts of hippo in the wider (mostly southern) Karoo from the nineteenth century. They require aquatic habitats and though there is no suggestion that they inhabited the Blanco Flats, they were certainly recorded near Queenstown (Sandy Stretton and the records and publications of the museum in Port Elizabeth) and are now nowhere in proximity. Formal documentation of hippo occurrence is recorded by Skead, and he and others relate the demise of hippos to hunting and draining of habitat for cropping (Skead, 2007). What needs to be appreciated is that natural aquatic habitats once existed in the Karoo. Farm dams may thus be important surrogates.

There is also strong field evidence of the previous existence of persistent aquatic habitats within the grasslands of the Bottlegaat River ecosystem in which the Blanco Flats occur, but these may have been limited to in-channel pools as opposed to the unincised vleis that are the focus of this article. Large freshwater mussel shells within a donga (Hugh’s personal observation following on from the more detailed work of Carl Vernon) suggest that sections (probably pools) of the Bottlegat system supported aquatic habitats. The mussel shell found on Newstead Farm was in a donga tributary to the Bottlegaat River and clearly not obviously from an in-channel pool. It could have come from an in-channel pool by a “back flood”, where flows went back up tributary dongas when they could not get through the main channel quickly enough for the flow behind. While mussels are typically associated with pools along waterways, it is possible that they (and other isolation-adapted aquatic species) may have occupied intermittent pools in the floors of vleis and this should be examined more thoroughly.

The extent, however, to which aquatic systems occurred in these seasonally inundated landscapes is a secondary issue to the loss of these broader, critical drought buffering and most productive landscapes that are in varying stages of becoming run-off thorn veld. This secondary issue simply reminds us how different the landscapes were before they were "developed" and our need to find out what went wrong and why, before embracing alternative, potentially obfuscatory explanations of current landscape trends in key landscapes for livestock and cohabiting wildlife such as carbon fertilisation of the atmosphere (which may well be happening).

In both the Urema Lake and Blanco Flats examples of unplugged seasonally inundated and bush and tree-less systems, extraordinarily productive grasslands with aquatic habitats (definitely in the former and possibly in the latter example) turned to scrublands due to unplugging of seasonally inundated landscapes. They are impoverished as a result for wildlife, livestock and humans. Much has been "lost" and we believe the situation is not self-healing as quickly as it is accelerating. Draining and clearing for agriculture are also obvious factors that need to be considered in long term planning, in a post "sustainable yield" paradigm.

It should also be borne in mind that erosion is not the only culprit (but can drive other factors). New deposition can create niches that dry out more quickly than surrounding, lower habitat. Thus bush encroachment often starts on natural convexities within seasonally inundated features and at the rising margins, but can also occur on sediment splays overlying the original saturated surface. Another cause of bush encroachment can be the diversion of run-on by a water harvesting feature such as a road incised into the landscape across the inlet flow path. This complexity reinforces the need for a hierarchical approach to landscape literacy. The causes of ecosystem malaise may well be far off-site, especially in wetland systems.

Local degradation by overgrazing, undergrazing or inadequate recovery periods (for instance) can also make the soil less able to take up surface water and this can lead to the survival of woody seedlings where they would previously have drowned. Thus natural grasslands can be severely modified by grazing management, even if their critical base levels (e.g. sediment sills) are still in place. Conversely, innovative grazing strategies can be employed to enhance infiltration, reduce evaporation (with litter mulch) and further buffer seasonally inundated grassland systems against bush encroachment.

There is much to be learnt on how to protect the integrity of the remnants of our remaining, most valued landscapes and the wider ecosystems upon which they depend and are inextricably linked functionally.

SCENARIO 2: QUICKLY DRYING LANDSCAPES

Granitic landscapes are typically of low fertility, especially where soils are developed on etched, unweathered granite regolith. Soils are essentially a thin layer of quartz grains over a sloping, impervious rock substrate. The only perennial plants they can support are xerophytic grasses such as *Aristida* species in Australia and *Stipagrostis* species in Namibia. However, woody plants can establish where soils do not dry out as quickly as is normal elsewhere; around rock outcrops and wherever incisions are cut into the landscape. The latter physically draw water to them (Pringle *et al*., 2011) and hence can create wooded drainage lines within a largely parched, xerophytic grassland or ephemeral herb field. This pattern is easily observed as one travels westwards towards Swakopmund from Okahandja. Rainfall declines to the point where the only bushes are restricted to landscape incisions. This is even more obvious on the road between Henties Bay and Khorixas. This pattern is common to land systems such as Norrie and Challenge in arid Western Australia (Curry *et al*., 1994; Pringle *et al*., 1994).

In this case it is the increased hydration through increased drainage that enables woody plant seedlings to establish. Rather than dehydration of seasonally inundated natural grasslands as discussed in the previous scenario, hydration is the key to woody plant establishment in otherwise xeromorphic grasslands (Figure 2).

It is the combination of low and unreliable rainfall and shallow skeletal soils that restrict woody plant establishment. The plants cannot access enough water to progress from seedlings to juveniles. This is expressed spatially in the landscape; woody plants increase in prominence within arid catchments where there has been enough moisture for their seedlings to survive.

It should be recognised that abnormally high, recurrent rainfall can provide adequate SMB long enough for woody plants to establish successfully in areas that they would not normally establish in. Woody plants can develop adequately far reaching root systems to survive the "normal" dry regime. Thus one might encounter woody vegetation in landscapes that might seem too xeric. However, the prevailing pattern of plains devoid of woody plants with shallow skeletal soils is normal in both southern African and Australian arid zones (Tinley, 1982; Pringle, 1994).

WHERE TO INTERVENE AND WHY IN DISRUPTED ECOSYSTEMS

Some difficult decisions exist regarding what to do about these geomorphic disruptions. In the first scenario, where decline in rain use efficiency, habitat diversity, agricultural and subsistence living resource value as well as biodiversity are usually obvious, the unplugging of seasonally inundated terrain process elements can generally be regarded as "undesirable".

Critically, new "nickpoints" should not be created and this will require some participatory learning. How existing (thereby expanding) problems are dealt with requires programmes that are driven by motivated landholders. We hope to address these issues through the Southern African Scientific Service Centre for Climate Change and Adaptive Land Use (SASSCAL) Task 41, to at least start tackling a very big problem.

In contrast, in the second (extreme arid) scenario it might be argued that the geomorphic disruption (if indeed man-made) has had little effect on the wider landscape and has locally increased habitat diversity and perhaps enhanced living resources (e.g. firewood) (Abel, 1997) – at least in the

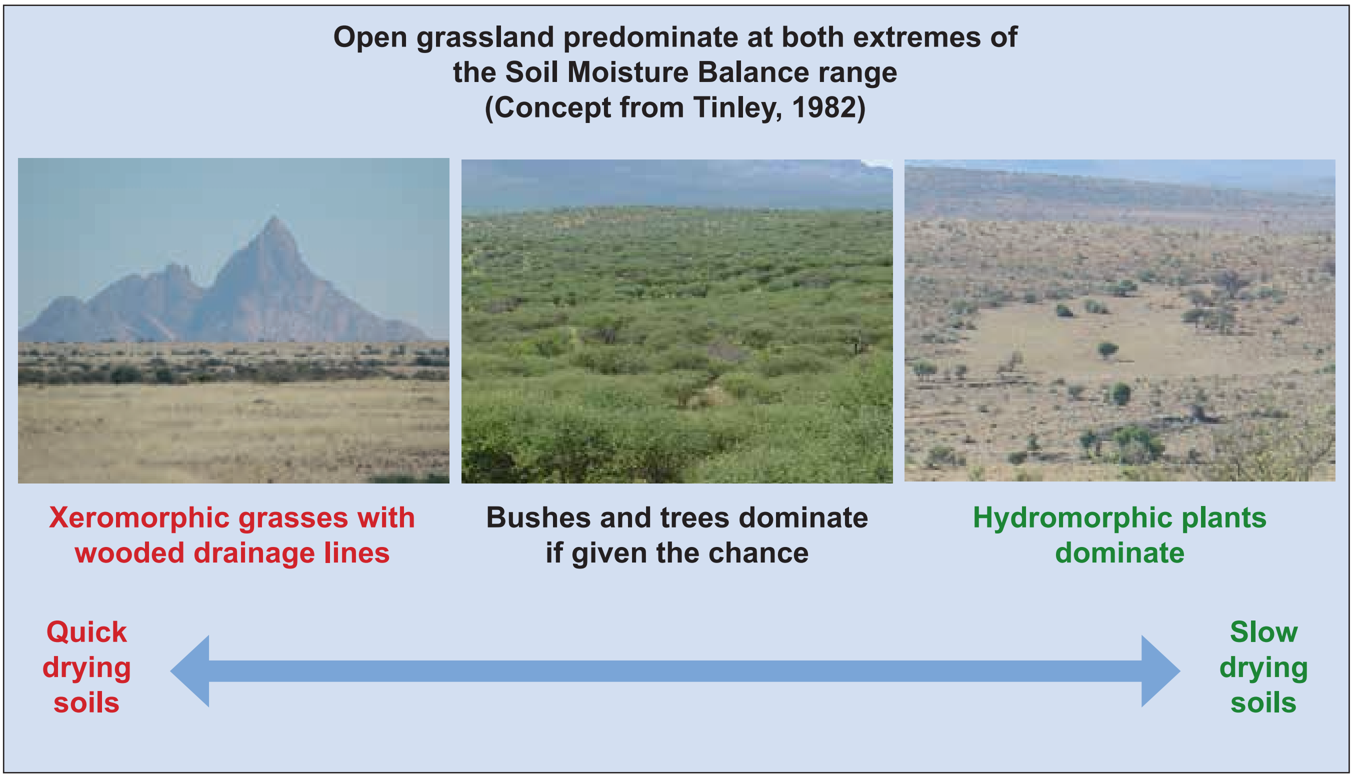

Figure 2. Diagram to illustrate the range of SMB and associated rangeland vegetation.

Figure 3. A hydromorphic grassland approximately 30 km south-west of Windhoek is getting incised by an elongating donga with its current head position indicated by the arrow.

short term. Furthermore, being xeric landscapes of generally low agricultural value, the return on restoration investment ("bang for the buck") may be quite low.

While acknowledging that where to invest management resources is an intrinsically personal, value-based and situation-contextualised decision, we suggest as a broad guideline that the focus be on restoring seasonal inundation in scenario one for the reasons stated above. This is particularly important where the relative importance of these drought buffering landscapes and habitats are highest for humans and wildlife: the arid areas of central and southern Namibia (south of Etosha, but including the Kunene).

Examples from Namibia's Highland Savanna are illustrated by Pringle *et al*. (2011), Kauatjirue *et al*. (2010) and in Figure 3. Examination of Google Earth images by the authors (led by Ken Tinley) reveals that hydromorphic grasslands occur at various intervals for the entire length of Namibia on the continental plateau from Kunene (Figure 4) to the North-Central and Kavango Regions, around Otavi (Figure 5) and all the way south virtually to the Orange River catchment (east of Keetmanshoop). This preliminary investigation indicates that most of these key drought buffering landscape process elements (seasonally inundated areas or "soggy landscapes") are under threat of being unplugged by headward incision or already incised and drying out.

FITTING REPAIRS TO LOCAL CONTEXT

It is important that any repair projects are locally driven and therefore contextualised within the local land management culture, even if that requires some transformation (Adams, 1987) (Table 1). Thus, for similar landscape situations one might use heavy machinery in one case and the herding and kraaling of cattle in another. As a rule, the more one calls upon heavy machinery, the greater the risk of dissociation occurring with the ecosystem as one shifts to an "engineering" command and control psyche.

The flip side is that there are extreme problems that machinery can deal with quickly and cost effectively which less interventionist approaches might not be able to solve or will take so much time as to be unrealistic. There is clearly a place for heavy machinery (bulldozers, loaders, graders, etc.) in context.

Dissociation from the ecosystem is a blight of agricultural development globally; especially wherever heavy machinery has become part of the land management culture and massive changes have become easier to implement. The traditional process of small tests "to see if it works" has often disappeared. The environmental devastation of the south-west of Australia and its eastern Murray Darling Basin are examples of where technology outstripped or usurped

Figure 4. Google Earth image of an area north of Erora Village in Kunene Region. The top swamp (A) is already unplugged as the inlet channel (B) is now connected directly to a donga cut back from the right and also stripping away the swamp from its overflow area (C). There are other limbs (D) of this donga system that have cut their way south (down in the image) to link with dongas etching back and expanding in the Erora valley (not shown, to the south). The swamp at the bottom right-hand side of the image (E) is quite healthy, but now has a lateral initial cutting back into it along animal paths (F). A lateral headcut (G) is now heading to a sharp scour bend overflow (H) and will lead inevitably to drainage capture. This whole area would have been seasonally inundated to varying degrees, but is clearly being increasingly drained by aggressively expanding donga heads (∞).

Figure 5. Upland hydromorphic grasslands east of Otavi. Notice the woody plants encroaching off the upper slopes and next to the incised track at the bottom right of the photograph.

Table 1: Attributes of sustainable and unsustainable water resources development (From Adams, W.M., 1987, p 321)

Theme	Sustainable	Unsustainable
Level of organisation	Local (village)	National/ international
Scale	Smaller	Larger
Approach to existing technology	Adaptive	Transforming
Project identification	Local	Regional/ national
Lead disciplines	Environmental, social	Engineering, economic
Approach to project development	Evolutionary and slow	Specific, planned and rapid
Approach to mistakes	Learn	Cover up and ignore

ecosystem understanding of what the landscape needed to support sustainable livelihoods. In rangelands, the issue is less obvious, but nonetheless important. The legacy of increasingly effective drained rangelands has much to do with concentrating infrastructure in those parts of the landscape least appropriate for intense pressure and leading inevitably to increased incision and declining rain use efficiency (Pringle & Tinley 2003).

The risk is that engineering can be seen as a solution for overgrazing and engineering caused problems, be that a wagon track across the Tarka Flats or bush clearing with massive chains and machines in eastern Australia. How to fit into and be a positive part of the ecosystem can easily be lost in the vain and often delusional pursuit of ecosystem domination through overpowering technology towards selfish aims. This has never worked anywhere. The degree to which technology is used, needs to be carefully assessed in ecosystem context.

Through SASSCAL Task 41 the authors are investigating the nature of bush encroachment in what were natural grasslands, principally in the rangelands of Namibia, but with allied projects in Australia. The impetus of SASSCAL Task 41 Landscape Literacy is to improve our understanding of the interactions between physical and biological ecosystem patterns and processes and our management thereof.

CONCLUDING REMARK

Much of this work is built on Ken Tinley's original approach and work across southern Africa and is now being taken up in SASSCAL Task 41 with new partners and ideas in Namibia. Projects are already progressing in Australia and an international knowledge network beckons. Apart from his doctoral thesis, Tinley did not publish much of his data or work afterwards, because he was too busy working out what others could not understand in other places – and he is trying to retire. Through SASSCAL Task 41, we will test Ken's ideas and build on the opportunities of other fertile minds with an eye on the landscape. Our key message is that biological interactions occur within a dynamic, physical landscape with reciprocal feedbacks and if you overlook this, you will most probably misunderstand your system of interest.

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REFERENCES

ABEL, N., 1997. Mis-measurement of the productivity and sustainability of African communal rangelands: a case study and some principles from Botswana. *Ecological Economics* 23: 113–133.

ADAMS, W.M., 1987. Approaches to water resources development. In: D. Anderson and R. Grove (Ed.) *Conservation in Africa: people, policy and practice.* Cambridge, Press Syndicate of the University of Cambridge. pp 307–325.

COOKE, R.U. & R.W. Reeves, Eds. 1976. *Arroyos and Environmental Change in the American South-West.* Oxford, Clarendon Press.

CURRY, P.J., PAYNE, A.L., LEIGHTON, K.A., HENNIG, P. & BLOOD, D., 1994. An inventory and condition survey of the Murchison River catchment and surrounds, Western Australia. *Technical Bulletin*. Perth, Department of Agriculture, Western Australia.

DE KLERK, J.N., 2004. *Bush Encroachment in Namibia*. Windhoek: Ministry of Environment and Tourism, Government of Namibia.

JOUBERT, D.F., ROTHAUGE, A. & SMIT, G.N., 2008. A conceptual model of vegetation dynamics in the semi-arid Highland savanna of Namibia, with particular reference to bush thickening by *Acacia mellifera*. *Journal of Arid Environments* 72(12): 2201–2210.

KAUATJIRUE, J., SHAMATHE, K., PRINGLE, H.J.R. & ZIMMERMANN, I., 2010. Restoration of a gully system in the Highland Savanna of Namibia. In: Schmiedel, U. & Jürgens, N. (Editors): *Biodiversity in southern Africa*. Volume 2: Patterns and processes at regional scale: 255–259. Göttingen & Windhoek: Klaus Hess Publishers.

LE HOUEROU, H.N., 1984. Rain use efficiency: a unifying concept in arid-land ecology. *Journal of Arid Environments* 7: 213–214.

NOBLE, I.R. & SLATYER, R.O., 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. *Vegetatio* 43: 5–21.

PRINGLE, H.J.R., 1994. *Vegetation. An inventory and condition survey of the north-eastern Goldfields, Western Australia.* H. J.R. Pringle, A.M.E. Van Vreeswyk and S.A. Gilligan. Perth, Department of Agriculture, Western Australia: 118–127.

PRINGLE, H.J.R. & TINLEY, K.L., 2003. "Are we overlooking critical geomorphic determinants of landscape change in Australian rangelands?" *Ecological Management and Restoration* 4(3): 180–186.

PRINGLE H.J.R., VAN VREESWYK, A.M.E. & GILLIGAN, S.A., 1994. An inventory and condition survey of the north-eastern Goldfields, Western Australia. *Department of Agriculture Technical Bulletin*. Perth, Western Australia, Department of Agriculture, Western Australia.

PRINGLE, H.J.R., WATSON I.W. & TINLEY, K.L., 2006. Landscape improvement, or ongoing degradation: Reconciling apparent contradictions from the arid rangelands of Western Australia. *Landscape Ecology* 21: 1267–1279.

PRINGLE , H., ZIMMERMANN, I. & TINLEY, K., 2011. Accelerating landscape incision and the downward spiralling rain use efficiency of Namibian rangelands. *Agricola* 21: 43–52.

SKEAD, C., 2007. Historical evidence of the larger mammals in the broader Eastern Cape, Centre for African Conservation Ecology, Nelson Mandela Metropolitan University.

TINLEY, K.L., 1977. Framework of the Gorongoza ecosystem, Mocambique. D.Sc. Thesis (Wildlife Management), University of Pretoria, South Africa.

TINLEY, K.L., 1982. The influence of soil moisture balance on ecosystem patterns in southern Africa. In: B.J. Huntley and B.H. Walker (eds). *Ecological Studies*, Volume 42: Ecology of Tropical Savannas. New York, Springer-Verlag. pp 175–192.

TINLEY, K., 2001. Scrub encroachment of productive grasslands: soil moisture balance. Proceedings of the Northern Australia Beef Industry Conference, Kununurra, Western Australia.

WALKER ,B.H., LUDWIG, D., HOLLING, C.S. & PETERMAN, C.S., 1981. Stability of semi-arid savanna grazing systems. J*ournal of Ecology* 69: 473–498.

WARD, D., 2005. Do we understand the causes of bush encroachment in African savannas? *African Journal of Range and Forage Science* 22(2): 101–105.