Rangelands NRM
Western Australia

Australian Government
Department of Agriculture, Fisheries and Forestry

Rangeland Rehydration

Re-covering the Red
using local knowledge

E.M.U.™ Ecosystem Management Understanding

2 Manual

by

Ken Tinley & Hugh Pringle

a.

b.

c.

Frontispiece: Geomorphic succession - breakaway land surface replacement sequences (similar at all scales).

(a) Laterite breakaway of 'old plateau' sandplain surface (Kalli LS) supporting wattle woodlands of wanyu and mulga.

(b) Small breakaway of erosion headcut in the duplex soil of a footslope.

(c) Micro breakaway of topsoil the same height as the camera lens-cap. In each example the upper oldest land surface is eroding back and contracting. Newest land surface is the lower pediment in (a), and the exposed subsoils in (b) and (c).

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Dedication

This manual is dedicated to Karen 'Kaz' Collins (nee Johnson). Kaz was a passionate landscape ecologist and an enthusiastic supporter of the EMU/ESRM process. She worked for many years in the rangelands of other parts of Australia before moving west to work in ESRM where she was instrumental to the success of that project. Her infectious enthusiasm and disarming smile won over all who met her. The Murchison/Gascoyne region of Western Australia and the broader Australian rangelands lost a patriot of sustainable landscape management when Kaz passed away recently. This manual is a tribute to her passion and the arid country that she loved.

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Preface

This manual is for extension facilitators and is a complement to the Field Guide for landholders (pastoralists in particular). Facilitation of field-based management skills is a hands-on exchange of knowledge and know-how between the visiting facilitator and resident pastoralist. By means of the participatory EMU™ (Ecosystem Management Understanding) approach a reciprocal learning process occurs focused around a baseline mapping exercise in which the landholders (often husband and wife) draw their local knowledge on map overlays in answer to some 15 questions **(Table 1)**.

The mapping is a simple yet profound process. It is the graphic means of organizing pastoralists' local knowledge in relation to the landscape patterns, processes and linkages. This visually emphasizes present stage or condition, identifies where they want to go, forms the basis for keeping track of change, and with ongoing monitoring, tracks progress towards their management goals. Most importantly it forms the template to experiment, learn and adapt. As the composite of map overlays is a graphic expression of their local knowledge, the process becomes owned by the participants.

EMU facilitators do not teach or lecture but rather demonstrate and expose participants to other ways of seeing and doing things in a holistic integrated way in landscapes that are continually changing. They promote thinking and practising of creative management based on an expanding ecological awareness and knowledge. EMU facilitators learn from pastoralists and improve their capacity in a positive feedback loop of reciprocal learning.

An initial doubt in anyone starting out in the field of facilitation with people who live and work on the land is that 'I don't know enough'. A basis to gaining confidence is the acceptance that nobody knows everything, but that there is the need to know the key elements of the subject and build on these. In the rehydration component of ecology the key is 'knowing where to tap' **(Box 1)**.

The targets of extension are the pastoralists and pastoralism together with land health and biodiversity conservation. The EMU approach has been tried and tested over 12 years in a variety of rangeland communities, including Aboriginal owned stations, in Western Australia and Northern Territory, and more recently in South Australia and Namibia. It is important to remember that pastoralists generally have a profound distrust of government agendas and policies that for them are generally disabling rather than enabling. Hence all the station information and local knowledge mapped by the pastoralist and partner remains the property of the present or subsequent lease holders, i.e. the map recorded information belongs to the particular station.

The training of facilitators will comprise of a weeks field induction or alignment course on a station covering subjects such as landscape ecology, pastoral management, and how to run station workshops. The latter requires an understanding or an appreciation of human behaviour and adult learning processes to discover how to interact to motivate participants toward creative and practical outcomes (Ison & Russell 2000; Sonnekus & Breytenbach 2000).

Alignment between participants in any process allows for effective and sustainable utilisation of resources – particularly when they come from different cultures (Sonnekus & Breytenbach 2000).

The indoor alignment phase (mapping knowledge on clear overlays) is followed by on-station experiential learning; exploring together with field ecologists and pastoralists how to read the signs of the land and their meaning, both from ground and aerial perspectives. Subjects covered would include: introduction to the station ecosystem framework by means of overlay mapping, soil and vegetation types, landsystems, succession and indicators of condition and trend in a drainage unit context.

In this manual we have created a reference of factual, conceptual and philosophical information as well as a broad ecological background for facilitators to use together with their own knowledge and ongoing experiences.

As the EMU approach is innovative and multidisciplinary and deals with different peoples and cultures, it has to be adaptable to fit different circumstances. Good EMU facilitators have to be "all rounders" to understand the basics of many disciplines related to community based Rangelands Natural Resource Management (NRM) and team players to access additional expertise as required.

The most effective means of spreading ecological literacy across the rangelands is by means of the Pyramid System of learning where one facilitator trains say 6 pastoralists from several adjacent districts. When proficient, those individuals who turn out as best facilitator material then each train 6 more pastoralists in their own district and so on. The most effective interactive knowledge transfer is pastoralist to pastoralist. This leaves the original facilitators free to move further afield and develop the same process, and in addition to be available for running refresher courses.

It is important to remember that though ecosystems are extraordinarily complex, the first and ultimate orchestrator of vegetation patterns, forms, successional processes and land health is the movement of moisture in a landscape. This needs to be understood in the context of drainage process units.

Soil moisture is the driver of almost everything in rangelands. Well managed, it invigorates ecosystems, livestock and wildlife as well as enterprises and rural communities. Water is the lifeblood of rangelands and its management is the focus of this initiative. We acknowledge that there are other, complementary issues such as ecologically-based grazing strategies and smart marketing, but none of them can be effective if the rainfall is not captured into productive soil locally.

KT & HP

The order of figures is subject related, not in order of citation.

Acknowledgements

This initiative owes much to the persistence of Greg Brennan, Department Agriculture and Food WA, who has never let up the pressure on us to consolidate Ecosystem Management Understanding (EMU) into a form that can be extended more widely than we can do first hand. Without Greg's persistence it would not have happened and we are deeply grateful to him for his ongoing support of our work.

Many thanks to Rangelands Natural Resource Management, Western Australia (WA) who have funded this work through Caring for Our Country, a Commonwealth Government initiative. Brian Warren, General Manager of Rangelands NRM WA, has been particularly helpful and understanding as we have expanded the project well beyond original plans for a focused rangeland rehabilitation guide.

Great thanks to Lynne Tinley for her ongoing typing and editing support, and for being a sounding-board for ideas. Thanks to our trainees who reinvigorated the EMU process: Peter-Jon (PJ) Waddell, Annabelle Bushell and Sally Black. PJ Waddell has again, as with the Rehydrating the Rangelands Field Guide, performed a vital service of diligent editing.

For computer-graphic transference of our mock-up document to a subfinal stage great thanks to Kay McAuliffe (Red House Creations) and the Durack Institute of Technology, Geraldton. To Danielle Cameron-Brown of Printline Graphics, Fremantle, our gratitude for refining the final document to publication quality stage. Also thanks to Nicolai Handevitt-Haar, director of Printline, for his technical guidance at all times.

Finally, we acknowledge the excellent job done by our ESRM successors and hope we have included their developments adequately.

Box 1: Knowing Where to Tap

Knowing Where to Tap

Ever hear the story of the giant ship engine that failed?

The ship's owners tried one expert after another, but none of them could figure our how to fix the engine. Then they brought in an old man who had been fixing ships since he was a youngster.

He carried a large bag of tools with him, and when he arrived he immediately went to work. He inspected the engine very carefully, top to bottom.

Two of the ship's owners were there, watching this man, hoping he would know what to do. After looking things over, the old man reached into his bag and pulled out a small hammer. He gently tapped something. Instantly, the engine lurched into life.

He carefully put his hammer away. The engine was fixed!

A week later, the owners received a bill from the old man for ten thousand dollars. "What?!" the owners exclaimed, "He hardly did anything!"

So they wrote the old man a note saying, "Please send us an itemised bill."

The man sent a bill that read:

Tapping with a hammer……..$2

Knowing where to tap…….$9,998

Effort is important, but knowing where to make an effort in your life makes all the difference.

Susi Cerati
Women Spirit magazine n.d.

Introduction

At the outset it must be stated that these two handbooks on rangeland rehydration are not just about re-moisturising landscapes. As everything is connected to everything else in ecology, it would be quite pointless rushing around putting in sieves all over the station when the groundcover is depleted and there is little total grazing control or any of the other fundamental management requirements such as: conservative stocking rates that maintain pasture vigour, cover and topsoils (permeability and decreased runoff); mosaic burning; seasonal alternation of upslope grazing in the dry and downslope in the wet; other forms of intermittent grazing (e.g. Bartle 2002; Le Houerou 2006). If the grazier's response to rehydration is like another new fad or gimmick it becomes a pointless exercise and if it disappoints (or fails) is dismissed as a waste of time.

Without groundcover of perennial plants the tiled-roof effect remains and soil moisture recharge does not occur. Perennial grass cover and intact topsoils are mutually dependent. There is unlikely to be any help from rehydration techniques if "more of the same" pastoral management continues. That is why successful demonstration examples of different methods in a variety of terrain situations is fundamental to where and how in a landscape rehydration can be successful. After 150-200 years of pastoralism in Australia there is an imperative for ecological conservation management of the rangelands to be applied - in which maintenance of biodiversity, and its role in supporting ecological and economic resilience, is paramount.

Where and how to recover drainage, soaks, springs and floodplains is easy to understand and apply whether one is an illiterate tribal herder or a scientist. The advantage the tribal herder has is by being nomadic. Not confined to one place or to one station, they have room to manoeuvre and the see-sawing of their seasonal life changes have much larger swings. By migrating, well-used or over-used country has a chance to recover and a variety of feed gets the chance to survive and set seed in different habitats, which in turn can maintain healthy stock and people **(Box 2)**.

Whereas pastoralists confined to paddocks and one or two landsystems means the positive or negative tipping points are more sensitive or finely responsive. Hence, more easily the potential for degradation to tip into expanding, longer lasting, down-swings (or spirals) with habitat simplification and the resultant loss of ecological and economic resilience. This means that all round healthy sustainable pastoralism has the best chance of being realised where it is managed according to ecological and biodiversity conserving strategies based on an intimate local knowledge of the 'Nature of Place'.

In order to do this, pastoralists need to learn more about the make-up of their station landforms and vegetation, and how they function interactively. It's no longer enough for a grazier to know a few local plants and little about the soils. To be able to identify the precursor indicators of soil erosion and successional changes in plant cover composition for example is vital. Are the run-on areas viable? Where is the erosion? Is it spreading or healing? Is the woody weed invading in key pasture areas or only where the land has been disturbed by roads and tracks? Keeping a finger on the pulse by monitoring and recording the changes taking place provides the information feedback loop that is vital for tracking and keeping station health and integrity in balance. There is a need to deepen understanding and enhance management adroitness for adapting to change.

If you are a tribal pastoralist it is simple to follow the four basic rules about rehydrating the land: (1) 'Where' to intervene in the drainage, (2) look upstream first to see if the drainage needs calming before doing anything, (3) look downstream to see where you want the flow to go when it passes the 'where' intervention site, and (4) only then, the 'how' (e.g. brushwood filters and /or stones and logs), or (5) if too hard – migrate. That is all nomadic pastoralists need to know about rehydration because they already have intimate ecological knowledge of their wide-open landscapes without fences.

The situation in the confined geographic space of a fenced-off and paddocked station is totally different. Here only part of the station, maybe less than half is suitable for stock rearing. In order to manage in an ecologically holistic way the pastoralist would need to understand the ecological make up and functioning both within the station and its surroundings. If the station's location is in a major catchment it is important to know its situation in regard to downstream or upstream effects.

In order to manage in an ecologically holistic way the dynamic ecological context is that bounded by drainage divides at all scales – down to the smallest tributary. Pastoralists now have to do something new in regard to landcare – more whole, more interrelated. Just applying rehydration enhancement by itself can be a pointless exercise if the management remains 'more of the same' with little knowledge or care of land processes, and a lack of total grazing control.

The Australian pastoralist in contrast to the tribal extended family may only have his partner to rely on. This results in a much more complex juggling of priority tasks that have to be done **(Figure 7)**. Now the four basic rules of rehydration expand into a plethora of issues, often particular to the station, that need to be identified and dealt with (Section D in Field Guide). This is where EMU has for the past 12 years introduced pastoralists on how to use a map-based approach for recording their station's particular landscape make-up, to identify problems and to record monitored information identified from aerial and ground traverses.

Government landcare and community support is crucial. Demonstrating examples of different methods in a variety of landscape situations, and mutual aid and sharing of knowledge amongst landcare members is fundamental. It is important that some structure is developed to support increased understanding, but rather than be led by scientists, it needs to be a genuine partnership between pastoralists and scientists. This will ensure relevance of research findings and also avoid really incongruous ideas gaining credibility. Transfer of information between local pastoralists, regionally and wider is critical. Knowledge must be nurtured, not controlled.

Some particularly successful pastoralists do little formal monitoring of their land. However, they are so intimate with their landscapes that they get away with it. Most pastoralists are not in this situation and some form of monitoring will enhance their understanding. The EMU Landscape Monitoring project was developed with pastoralists, for pastoralists. It complements recorded observations on a map overlay that is kept out and accessible all year. The monitoring makes pastoralists test their interpreted surveillance at the key places where they have chosen to "put their finger on the pulse". It also makes them focus on tracking any changes in ecosystem function, thus enabling adaptive and improved management responses.

What is most important about the EMU approach for pastoralists is that it is a journey, there is no "end point" – learning is continuous, situations change and improvement is always possible. EMU is an innovative process that can enhance the quality of life for all ecosystem managers.

[A] Appreciating What Pastoralists Have to Deal With

(1) Stewardship of the Rangelands

The island continent of Australia covers some 7 682 300 square kilometres, of which nearly three quarters (5 761 725 sq.km) is used as pastoral rangelands. This represents probably one of the largest areas on Earth in which the production of protein is based on wild vegetation from pollution-free pastures. In other words stock production is not based on feedlots dependent on grains and legumes, that are human staple foods, and which originate today from vast fertilizer-dependent monocrop fields often, in the case of soybeans, requiring the elimination of huge swathes of rainforest.

Ecologically sustainable rangeland management, which maintains or enhances the variety of habitats, vegetation and natural processes on a station, is the fundamental basis to the conservation of biodiversity. A high diversity imparts adaptive resilience to a system, unlike a simplified system that is vulnerable to change. Enhancing resilience of station landscapes, in particular the run-on areas, is critical for adapting to climate change (Friedel et al.1990; Nix 2004; Walker & Salt 2006; Pearson 2008; NRM Ministerial Council, Canberra 2010)). For an early view of adaptation see **Figure 6**.

However, encouraging and enabling pastoralists to adapt and become ecologically adroit managers is not enough. Government agencies are also in need of adapting policies and guidelines that are real to the predicament in the Outback. Not least, the need for the land overseeing agencies to develop a more effective coordinated approach to the conservation of coasts, water, soil, native vegetation and wildlife (e.g. Westoby et al. 1989; Wilcox & Burnside 1994; Abel et al. 2000; Stafford Smith et al. 2000; Flannery 2012).

Pastoral stations are usually family run businesses on very large properties. With few staff to help run the station there is typically very little time to attend to much else except management of livestock and the supportive infrastructure. Pastoralists are generally multi-skilled and involved in dealing with a large variety of subjects and aspects as exemplified by a perusal of the WA Pastoral Memos and the Australian Rangelands Society Biennial Conference proceedings. But with few hands they are confined to the stock, infrastructure and income generating treadmill, and without the funds to hire more staff are trapped. Anything additional is viewed by some as a threat or slight to their ways of doing things. Just the word "conservation" for example can provoke the terse response "that's the governments' job they own the land – we have to survive. We are already overburdened and have no time for more impositions" **(Figure 7)**.

Due to the short-term outlook of the political election process, policies tend to be subservient to appeasing voters and elected parties are reluctant to apply or monitor the regulatory guidelines and legislation, for example the soil conservation act, to protect the land from unacceptable damage (Roberts 1989). There is also no government on Earth that has the sustainable financial capability for protecting large numbers of parks and reserves over vast landscapes as ecologically 'comprehensive, adequate and representative' (Hopkins et al. 1996) examples of a country's biodiversity and natural resources. Nor do they have the capability for continuity of control, management and research at this dimension due to the changeableness of politics, policies, markets and the economy. Conservation is typically one of the first government functions to be affected in times of economic downturn and personnel retrenchment (Wilcox & Burnside 1994; Walker & Janssen 2002).

That means, as elsewhere in the world, that the actual and potential stewards and conservators of the rangelands of the Australian continent are the pastoralists and their families who live on the stations. They are in the frontline, the day-to-day interface, with the 'wild nature' of the Outback rangelands.

To sum up: *A system of conservation based solely on economic self-interest is hopelessly lopsided. It tends to ignore, and thus eventually eliminate, many elements in the land community that lack commercial value, but that are (as far as we know) essential to its healthy functioning. It assumes, falsely, I think, that the economic parts of the biotic clock will function without the uneconomic parts. It tends to relegate to government many functions eventually too large, too complex, or too widely dispersed to be performed by government. An ethical obligation on the part of the private owner is the only visible remedy for these situations (Aldo Leopold, 1949).*

For the maintenance and recovery of effective health and integrity of ecological diversity on stations, the focus is on the main drivers of habitat change. These drivers, that are within the management capabilities of pastoralists are: (a) stock grazing strategies that maintain topsoil and ground cover, particularly of perennial grasses, (b) erosion control in core grazing habitats and their infringing influences, (c) reconnecting and recovery of riverine and run-on areas, and (d) fire, flood and drought preparedness (Le Houerou 2006).

For pastoralists to become effective land managers they need to learn more about the ecological functioning of their station and its relationships with the surrounding country. They also need to find ways to devise best-fit ecological strategies for the particularities of their station that will enhance conditions for their pastoral enterprise.

For this they do not have to acquire a university degree, rather, they need to develop a keen interest and curiosity in close observation, in interpretation, and in monitoring of natural processes and the make-up of their country so as to become competent naturalists, as exemplified by illiterate nomadic pastoralists on the southern margin of the Sahara **(Box 2)**.

Box 2: West African Nomadic Herders

West African nomadic herders knowledge of their stock and arid 100 – 300mm southern margin pastures of the Sahara Desert (Sahel Zone).

Systemic monitoring of environmental changes in climate, and quality and quantity of forage helps the herders take advantage of green flushes of forage, or to avoid overcrowded areas. Even from a distance the Wodaabe herder can judge the intensity and significance of greenness of a pasture. He will also monitor the faeces of livestock, milk yield, animal weight and the number of cows in heat, to tell him about how well animals eat, and therefore the quality and quantity of forage. A very thorough study of traditional environmental indicators has been done among the Fulani of Mauritania.

They evaluate the quantity of forage by looking at the density and height of grasses and herbs, the portion of land covered by each pasture type, and the tree cover, and compare all of this with the need of livestock on the pasture. They evaluate the quality of range through 1) soil type and capability for each type of pasture; 2) presence or absence of individual forage species, and their palatability to different livestock; 3) degree of greenness of forage; 4) presence or absence of wildlife, for example good pastures also support gazelles, hyenas, lions, wild boars, etc., while the ones that have elephants, giraffe, ostrich are good only in the dry season because of excessive humidity and disease, and 5) behaviour of domestic animals, e.g. a good pasture is indicated by cattle who eat with good appetites, are not restless at night, sleep on their right size (full stomach not pressed), breathe slow but deeply, have beautiful skin and hair, are not rushing to pasture in the morning, do not need to be forcefully restrained during the morning milking, increased number of females in heat, and faeces are wet, not friable, and have little undigested matter. When going into a new unknown pasture, the Fulani herder will take the animals to pasture for seven consecutive days in each of four major directions, and will compare the pastures by evaluating the effect on the animals. The Fulani know that vegetation changes can be caused by overgrazing, drought, bush fires etc., but say that droughts cause the greatest change. There are also many indicators for monitoring the degradation of pastures. The Maasai and Wodaabe look at milk yields, and the Samburu observe grass and browse availability. Among the Fulani of Mauritania, degraded pastures are indicated by Cassia occidentalis *and* Calotropis procera*, and the presence of vividly coloured lizards.*

M.Niamir 1990: page 30

The sustainable conservation of biodiversity has become 'one-eyed' and habitually overlooks the essential other eye for its realisation, and that is the human component – human diversity (Krockenberger 2000). An enabling environment needs to be developed in the rangelands that addresses how livelihood and social issues can begin to support the expression of human interests, skills, talents, creativity and innovation in relation to the many natural resources of the rangelands. In other words the need is for human expertise diversification, more enterprises by more people, which supports and enhances ecologically sustainable pastoralism in the Outback.

It is not the emptying of the outback that is going to conserve its biodiversity, but rather its revitalisation through having more families with different suitable talents and skills living on the stations and in country towns who have the potential towards helping recover land health through 'incentive driven' conservation (Milton et al. 2003; du Toit et al. 2004; Hutton & Leader-Williams 2005).

Enterprise diversification within the communities, whether it be more motor mechanics, animal handlers, bookkeepers, teachers, naturalists, camel harvesters and rehydration teams would enable pastoralists to have time for their own wellbeing and to learn new creative approaches or strategies. Young people growing up on stations of course have a variety of interests and talents that they think can only be realised in the city – they do not necessarily want to go back after high school or university to do the same things that Dad and Gramps did. However, nature based income-generating enterprises, including facilitation of ecological management and rehabilitation, could provide exciting and lifetime interests as well as helping to recover and manage the rangelands.

(2) Conversation with a Pastoralist

Ken called in to visit David on his sheep station in the mulga country. David had earlier taken part in the EMU exercise and completed ground and air traverses of his station.

D: "After you fellas went off to run the EMU exercise on another station, I was left in a quandary; where to start to get away from the degradation trap of continuous grazing. It's going to need re-arranging water points and paddock connections…

I am running relatively low numbers of sheep compared to my neighbours, but I was devastated by the size and number of bare, sheet-eroded areas shown up by our air traverse. On our ground visits, you will remember, there is still a good variety of bluebush and saltbush in different areas, but the station obviously needs a rest to recover.

Anyway, let's take a walk. I need to check on the piles of dry sandalwood I have been collecting to increase my income; it has to be ready for trucking tomorrow. If I don't do it myself, some stranger gets a permit from the Forest Products Commission to harvest my station's sandalwood, and they pull out living trees as well as taking the dead wood! Where is the regrowth supposed to come from?

It makes me snake mad! Sandalwood is really still a colonial crop, now owned by the State, and from which WestCorp earns between $8000 and $12000 per tonne from Asian markets. Out of this I get $1100 per tonne! You would think the State is earning more than enough from all the mining, to have to scrimp and scrape what is actually part of a station's resources. Sandalwood is quite common on my station but young plants are as rare as…."

K: "That's right, David. From my field observations over the last six years across the Gascoyne/Murchison and northeast Goldfields there is a dearth of different age replacement of sandalwood. Together with over abstraction since pioneer times and the high palatability of the young plants to all herbivores, from rabbits to camels, there is also the extinction of the burrowing bettong that used to cache the seeds, and the killing of emu by some pastoralists because they break fences. Sandalwood needs help in order to become re-established."

D: "I tell you what, if sandalwood was a station-owned resource and I could sell the dry wood for the kinds of earning the State is getting, I would sell off all my stock, except for a small herd for our home consumption, and plant back sandalwood in all the bushclumps where they like to grow. This station also has a good lot of emu that you know are important for spreading the seeds. That would be my answer to giving this country of mine a rest to heal itself."

K: "David, do you know anything about the value of emu as a resource?"

D: "Well, I know that in earlier times their skins made the very best leather jackets, their meat is good, and their oil is valuable, used in sports therapy and injury treatment, also in veterinary work especially with horses." (See Frapple & Hagan 1992).

K: "Do you know what emu oil sells for these days, and how much oil is produced by one healthy adult emu? No, well, listen to this – a litre of oil now sells for $154, and the fat from a fit adult can be rendered down to around 7 litres of oil, that means…"

D: "My God, don't tell me – that one adult emu is worth about a grand!!! And they die in thousands along the vermin fence in a drought – what a tragic waste, bloody hell." **(Figure 1)**

K: "Yep David, but the law is that you can only farm emu in paddocks where they trample the place out, are fed on turkey pellets, and I'm told are prone to worm infestations. You are not permitted to harvest free-range emus where they feed themselves on a large variety of foods and disperse seeds. Free range they would be easy to cull humanely using a corral with plastic wings to direct them into, like they do with ostrich. There would of course be 'bag limits' so as to protect the viability of the populations, which are typically nomadic. Think of changing the bias in the mulga country from stock to native plant resources, emu and roo harvesting! This could have an enormous multi-layered healing response toward the recovery of country. For example in the West Australian of 25 August 2007 the news headline was 'Roos turn from pest to $230m industry in SA."

D: "That's impressive. But here in the mulga country for that to happen many people will have to overcome habitual hates against emus and roos they call rubbish animals because they break fences and eat the pasture. Now they are more worried about the feral dogs. What can be done about the increase in woody weeds, maybe only goats and camels will eat them? Anyway, these days with the increase of cattle replacing sheep they may take grasses and the scrub as well?"

K: There's an old saying that a weed or rubbish plant or animal is 'one whose value has not yet been realized' **(Figure 2)**. What is of concern regarding roos and emus is that the fencing for cattle includes an electric and barbwire strand which traps the animals and reduces them to a pulp. Sheep fencing still allowed them to be nomadic, now they are trapped, and their populations could decline, I am not sure there is any monitoring of emu populations, for example.

D: Listen, most pastoralists are strapped for time, fully involved in maintaining infrastructure and dealing with stock. Anything like broken fences or gates left open, especially in the summer heat, that forces us to do any additional work means our responses are on a short fuse – what you would call bloody irrational.

K: What the rangelands really need are more people living in the outback with a diversity of training and skills, and enterprises compatible and supportive of pastoralism. People like Rangelands NRM who can help apply ecological management approaches to conserve biodiversity on which stock production is dependent.

D: But, mate, the legislation for leasehold is that we may only use the station for the purposes of grazing, and can be fined if we do anything else. The whole situation is quite ridiculous. I'll give you a small example. My wife made repeated requests to the Pastoral Lands Board (PLB) to run a station-stay facility as we have suitable quarters. When eventually she was given permission, you know what their bottom-line was? That she was not permitted to earn more from the station-stay than from sheep! And, I can tell you, we are earning bloody little from sheep at the moment, more from goats actually.

How about that? It's like there's a hidden agenda to ensure the failure of pastoralists – to force us off the land and become supermarket junkies in Perth. I know that the Department of Environment and Conservation (DEC) have long been keen to empty the rangelands to protect their version of biodiversity."

K: Well, its way too late for that wish. What with feral stock and predators, weed plants, out-of-control fires, and eroding lands, particularly all the run-on areas, there is going to be a very skewed biodiversity without ecological management.

What we've actually been on about while piling your sandalwood is how to fit, not fight the land. More of the same is ruin all round. The big learning responsibility for people everywhere is to adapt and care for the land – that's what conservation ecology is all about. A government's job is to enable, oversee, and learn the wisdom to guide – there is no way they can physically manage land health problems across vast landscapes. We have to come up with innovative ideas and approaches learning from each other and the land specialists as the basis to ensuring sustainable environments, communities and families. David remember that other old saying, "We were not put on Earth to see through each other, but to see each other through!" (Peter de Vries). Let's get on with it.

Figure 1: Emu massed in drought along the Western Australia State barrier fence.

Between the wheatbelt farmlands (left of fence) and the rangelands in the drought of 2002 (Photo: Barry Davies in Pastoral Memo 2003).

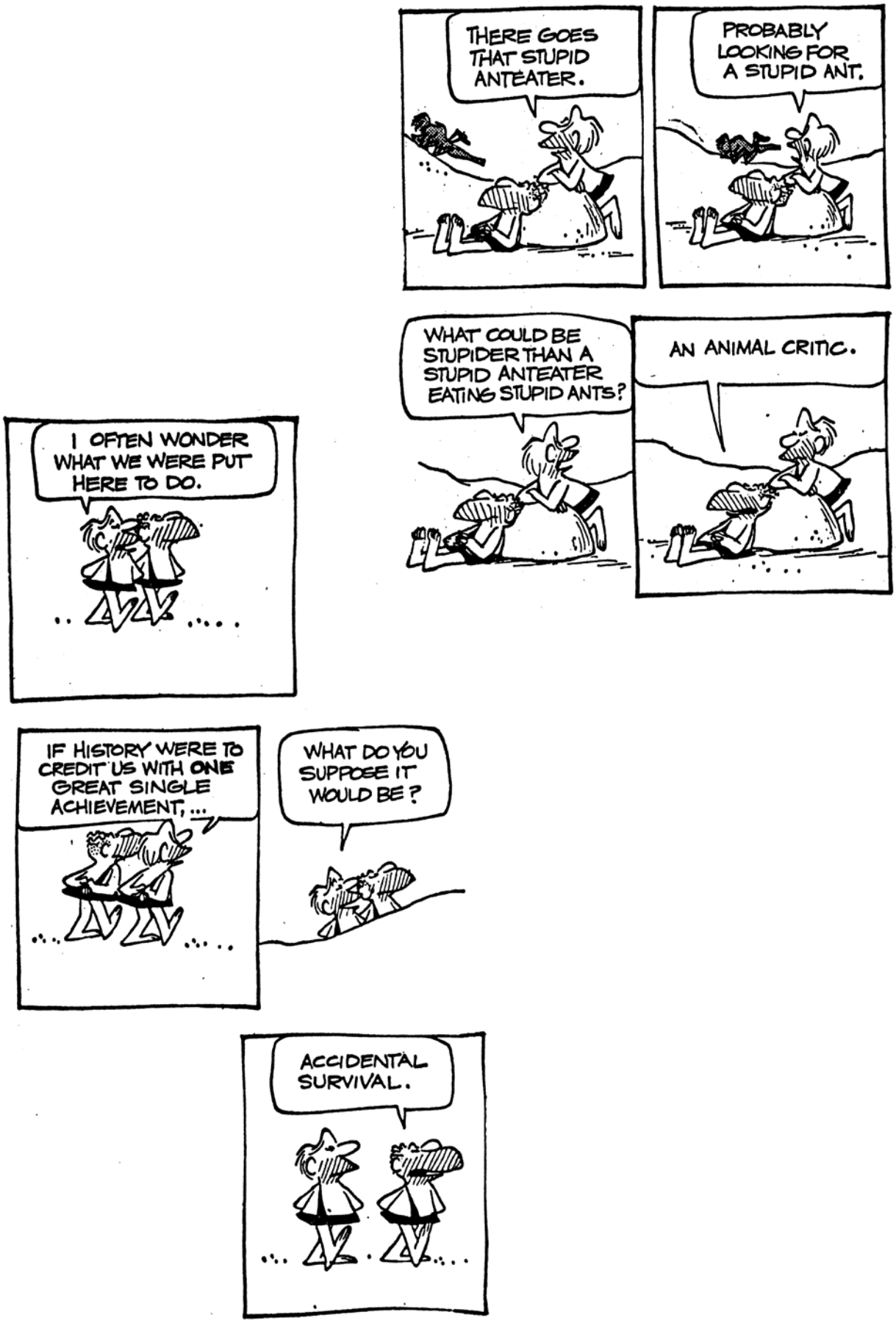


Figure 2: Cartoon insights from B.C. by Johnny Hart. (1966 Coronet Books, Hodder Fawcett, London).

[B] The EMU Approach

(1) Origin and Development of EMU

The overlay mapping basis for synoptic ecological analysis originated by McHarg (1969) was used by Ken Tinley in Mozambique in the late 60s and early 70s for landscape, wildlife and natural resources conservation. Ken's program comprised of survey, planning, research, air census and management of big game, and monitoring based on aerial surveys with ground validation and map recording. It also included identifying new areas for proclaiming national parks and a low-level air survey of the entire 2500 km coastline and its islands.

The same mapping method formed the basis to the EMU extension program in Western Australia (WA), developed by the authors to introduce ecological management and biodiversity conservation to pastoralists on their stations as part of the Gascoyne-Murchison Strategy rural reconstruction initiative. This extension method was initiated by the senior author in January 2000 and was joined later in that year by Hugh Pringle seconded from WA Agriculture Department Rangelands Section. In this form, the EMU program lasted almost 6 years.

The first station extension area was mainly in the Yalgoo-Murchison where it was well received, helping the voluntary extension program to spread by word of mouth. As interest grew we could eventually not meet the demand but fortunately federal funding enabled us to enlarge the team to five. We were then able to cover more stations on request by working as two teams each led by one or other of the present authors. The new members were PJ Waddell, Annabelle Bushell and Sally Black, all of whom were enthusiastic, worked well with the pastoral families, and contributed hugely to the refining of the program. By the fifth year EMU extension had involved a total of 120 stations (including those acquired by the Dept. Parks and Wildlife) from the Carnarvon Coastal Plain and Gascoyne, Murchison, and NE Goldfields to the Nullarbor.

Towards the end of the EMU extension program it was judged by two independent project assessors to be one of the most effective rangeland extension programs so far in the history of WA. With the termination of federal funding in 2006 a three-year hiatus in this extension work resulted. It was then resurrected by the WA Agriculture Department at the beginning of 2009 as ESRM (Ecologically Sustainable Rangeland Management). The new extension team was led initially by Luke Bailey for a short time, the field work on stations done by Richard Glover and the late Kaz Johnson (nee Collins) and ran for 4 years in the Gascoyne, Carnarvon Coastal Plain and Pilbara, covering 40 stations. The foundation to ESRM's extension was also based on the same synoptic ecological approach as EMU, facilitated by Ken Tinley.

Since the termination of the EMU program in WA, Hugh Pringle has taken EMU overseas to the stock and game ranches of Namibia, and locally to stations and Aboriginal lands in the Northern Territory (NT), northern Queensland (Q) and South Australia (SA). In the latter he has been working together with NRM field officer Janet Walton. Their success can be judged by the fact that they are unable to meet the demand from pastoralists. Ecosystem Management Understanding (EMU)™ is now trademarked by Ken Tinley and Hugh Pringle as a not-for-profit extension program.

(2) Synoptic Ecology by means of Salient Factor Analysis

Salient factors are the keystone elements that make-up and tie an ecosystem together as a functional dynamic system. The loss or modification of any one of the salient factors would cause perturbations - multidirectional shifts in form, composition and successional tendencies. This would result in the eventual replacement of the system or its component parts as well exemplified by the breaching of a ponding sill resulting in the drying out of the wetland.

Ecosystems are of inordinate complexity. This feature is emphasised repeatedly in the literature, in the training process, and by field experience. It is well known that disturbance to one part of an ecosystem can set up a chain reaction affecting many other components, the results of which are often hard to imagine or predict. However, many ecosystems are in fact governed by a few relatively simple key factors, a feature rarely mentioned anywhere.

Either the maximum condition or the minimum can be the most important for different systems. A forest for example may require high soil moisture but with good drainage, a wetland also requires high soil moisture but with poor drainage and for the latter there is a single critical determinant – an intact ponding sill. The key factors at any one time, can be replaced by others over time through changes imposed by natural processes and human influences (as recorded in Section C 2).

In each ecosystem there is a hierarchy of salience that forms a pyramid composed of five levels of increasing importance from bottom to top, and increasing complexity from top to bottom **(Figure 3)**. The gradient of importance is based on the precept that if the ecosystem as a whole is maintained survival of its components is ensured, at least in a human time scale. The ecosystem process units on land are drainage or fluvial ecosystem bound into functional compartments by their watershed divides (Section B6).

It is the 1st Level regional or local ecosystem process unit, such as a tributary catchment, that forms the functional contextual basis to all its components parts. The 1st Level provides the comprehensive view and frame of reference for shifting to and fro between the holistic top-down perspective and assessment and bottom-up verification and action. In certain circumstances fifth level microbiotic components such as malaria mosquito or other diseases are moved up to the second level of major components because of their impact. But the ecosystem always remains in first place as the foundational determinant to which all components relate.

The ecological study thus passes through the following cycle of interaction **(Figure 4)**: (1) Synopsis (SFA), (2) correlation and data integration, (3) synthesis, (4) application, (5) response monitoring, (6) re-assessment, and back to (1). With sufficient information, thereafter most situations can be adequately handled by going from (1) to (4) to (6) and back to (1) again. As most management programs are biologically biased (e.g. stock and pastures) they typically start and stop at (2) or leap to (4) setting in train a bewildering new series of interactions superimposed over the salient features that typically have neither been realised or identified. Together **Figure 3** and **Figure 4** provide guidelines for developing a rational, explicit and replicate management method from which to work out from and back to. Another value of the method is that it enables any study or investigation to get to root causes rather than attempting conservation and control by dealing with effects.

In synoptic ecology the salient factors that distinguish and determine the functioning of a particular system are identified by means of the map overlay technique. Base maps (all at the same scale) of topography, geology, soils and vegetation are analysed on separate transparent overlay sheets (today facilitated by GIS). However, these base landscape parameters are also available as colour-coded catena composite landsystem maps that accompany most of the Department of Agriculture WA rangeland surveys publications, hence their value as the base maps for overlay mapping.

The catena landsystem method of classifying, describing and interpreting terrain features using aerial photographs together with ground validation traverses (Christian & Stewart 1953) has been used to record almost all pastoral regions in WA. As landsystem maps are composites of the base maps listed above, except for topographic contours and drainage details, they are used together with a suitably enlarged Landsat TM /Google Earth print at the same scale as valuable discriminating tools for management and recognising landscape features from the air.

The map overlay method has been used by the earth sciences since the advent of tracing paper. The use of salient factors as the means of analysing synoptic ecology using series of overlays was perfected by Professor Ian McHarg and his school of Landscape Planning and Architecture at the University of Pennsylvania, USA. Their approach is enunciated by McHarg (1969) in his landmark book Design with Nature, particularly the chapter titled 'Processes as Values' which remains a classic of its kind.

Depending on the field of interest and the information required, the overlay method with landsystem maps provides the basis for interpreting and evaluating the intrinsic suitability for any land uses and management requirements, including conservation of natural resources or positioning of roads and settlement. With the focus here on rangelands and the facilitation of pastoralists' understanding of landscape management, the hands-on map overlay method is foundational both as a learning tool and for recording monitored information (see Section **B 4; Table 1**).

Using the map overlay process, both for establishing baseline information and as a monitoring means of tracking change, provides the pastoralist with a rational, explicit and replicate method in a whole-station drainage context, from which to work out from and back to. This process makes it possible to shift perspective from the study area to the broad surrounding context and influences and back in again. Zooming out for context and in for process detail.

The ecological researcher or station manager thus passes through a learning cycle, each stage a reminder of where he or she is at. Have I enough information? Where do I need to double check, particularly the critical issues? What about the impinging factors? What have I learnt and recorded from extreme events? What are the climatic predictions?

Box 3: 'The Whole Pattern' (Charles Elton 1966)

" …ecologists … have embarked on various quantitative investigations without fully taking into account the WHOLE CONTEXT in which their populations live in Nature.

…the large number of species of plants and animals and micro-organisms, and a good many problems in taxonomy, have made animal ecologists hesitant to investigate whole ecosystems – plant, animal and environment. I believe that at every level in science this sort of view is natural, and that one has to make a considerable effort to break through from one level of study to another above it, and while doing so to forge through the apparent complexities to a higher level of integration and arrive at simple ideas applicable to that higher level but invisible from the jungle below.

At each stage the synoptic view will appear superficial and incomplete to the person working at a less synoptic level. The only way, however, to decide whether or not a particular method of ecological survey is rewarding in this way is to show whether it has produced some new concepts of the structure (and function) of natural systems…. The conclusions can best be traced through a series of propositions, some of which are perhaps self-evident once pointed out, … while all can be tied together in a logical whole."

Elton CS 1966. The Pattern of Animal Communities. (1st edn.) Methuen, London. (Ch.19, page 374).

HIERARCHY OF SALIENCE
(OR OF KEY AND MASTER FACTORS)

1st Level: REGIONAL ECOSYSTEM
e.g. ocean, continent, island, desert, mountain, river basin, biome.
Natural processes of landscape evolution, climate, hydrography, geomorphic and edaphic controls, plant formations and succession. The regional ecosystem as a whole remains primary no matter how important one or more of its components may be; it is the contextual setting or process arena in which everything interrelates.

2nd Level: MAJOR ELEMENTS
Elements or components with the greatest impact, most importance or largest space requirements; one or more of these are derived from the other levels e.g. malaria mosquito.
Examples:

1. Man (hunter-gather. fisherman, pastoralist, cultivator, beekeeper, industrial man).
2. Large mammals (migration, overgrazing etc).
3. Representation of the full spectrum of ecosystems.
4. Unique elements (e.g. scenery, aquifers, endemics, rare of endangered species).
5. Dominants and prime mover components.

3rd Level: INDIVIDUAL ECOSYSTEMS
(and communities)

4th Level: MACRO-COMPONENTS
e.g. ungulates, flora and fauna

5th Level: MICRO-COMPONENTS
e.g. insects, fungi micro-organisms, chemicals

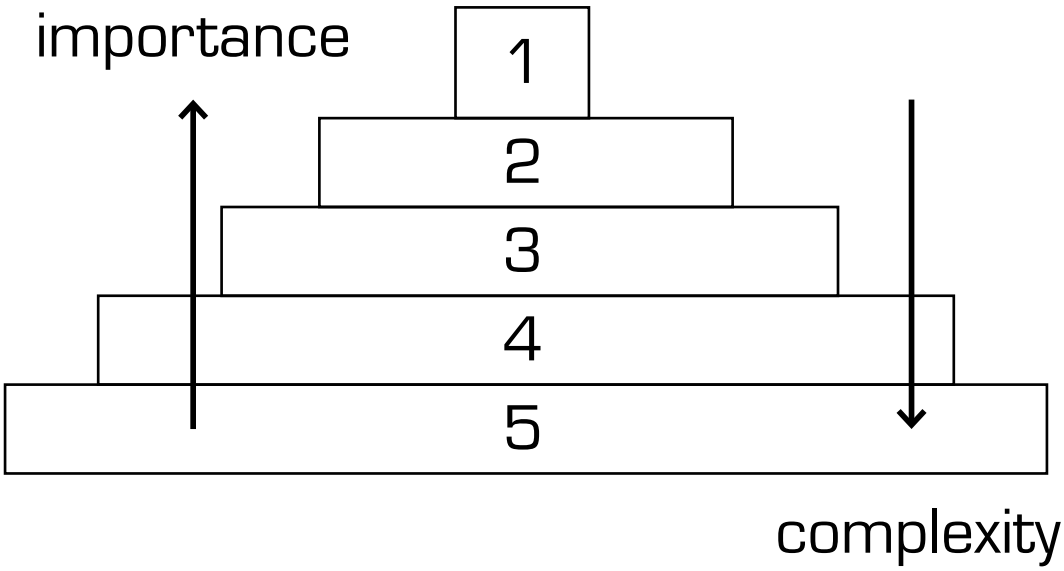


Figure 3: Hierarchy of Salience (Tinley 1977).

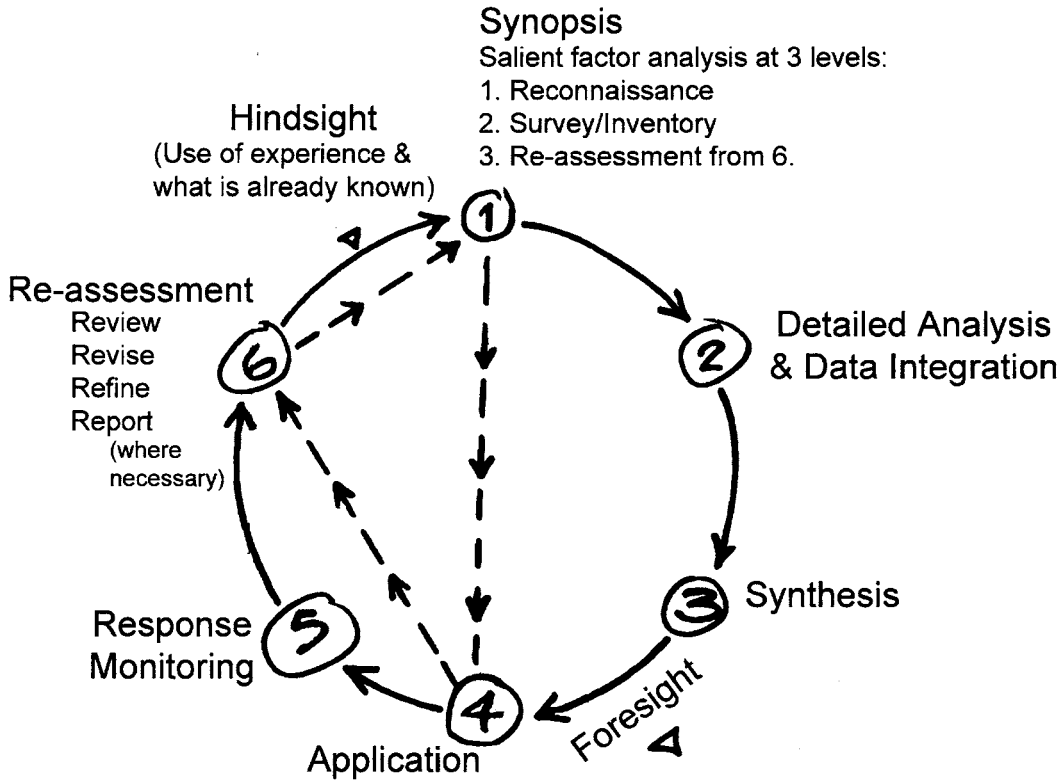


Figure 4. The Continuum of Ecological Management Practice.
Once one round has been completed many situations can be effectively handled by going directly from 1 to 4 to 6 and back to 1 again. The latter will indicate any gaps or needs and hence which circuit to follow (Tinley 1987).

Box 4: Why Monitor?

1. To identify and assess changes.
2. Visual annotated record made at seasonal intervals or after exceptional events, e.g. flood, drought, fire.
3. Releases reliance on memory.
4. Picks up 'creeping' incremental change.
5. The best means of recording and passing on knowledge and information – continuity.
6. Sharpens analytical observation and factual recording.
7. Sharpens observational acuity (changes looking to seeing). Familiarity breeds bluntness.
8. Capacity for older generations to pass on their knowledge and experience to following generations.
9. Incremental learning and refining process with feedback of interrogation – double checking. Tests preconceptions.
10. Provides a 'moving picture' visual context of the whole station and its parts.
11. Documents disturbances and recoveries.
12. Being versatile and on-the-mark in response to the changes in management required.
13. Benchmarking: reading the landscape – indicators or early warning of change by recording differences between overgrazed and least grazed areas of the **same** habitat. Key role of the Benchmark Paddock exclosure.
14. Accreditation (needs facts and figures).
15. Potent means of tracking trend and hence management success – whether improving, staying the same or worsening.

(3) How to Run the EMU Exercise

Introduction: EMU workshops require both the pastoralist and partner to participate in the exercises. It is important for both the man and the woman to take part as they bring different views, experiences, understanding and ways of thinking to the process.

The most effective way to run an EMU workshop is by two facilitators. Then they can work as a duo, interchangeably. While one talks, the other lays out the mapping tools, or when one stops talking, the other fills in gaps, expands on some keypoint that has been left out or fields questions. Or when one is fatigued the other takes over.

1. The initial introductory exchanges should be informal, getting to know about each other's backgrounds, interests and present tasks. Ask the pastoralists to outline a brief history of their station's use.
2. Outline what the facilitator's approach is. Explain the sequence of exercises including the pastoralists' map-recording of their local knowledge **(Table 1)**, the aerial view and the field excursions.
3. Focus on the workshop as a team building exercise through the participatory process of learning from each other. The facilitator learning about the station; both learning by doing. It is fine to disagree with pastoralists, and you will gain respect if you do so gently but firmly. But it is never productive to tell them they are wrong and by implication you are right. There is a chance you may not be right and that you have something to learn by listening and questioning.
4. Explain that the initial workshop mapping is always hand-drawn. The information so derived is of course amenable to transfer to a computer. (However, ideally, the map overlays should be laid out on a small table so they are open and easily accessible at all times for adding notes from field observations. They should not be stored rolled up nor hung on a wall).
5. Over the course of the several days banter, jokes and exchanges about adventures are helpful for developing an atmosphere of trust and acceptance.
6. Ask a series of questions at appropriate times:
   (a) If you were permitted to do anything you like on this station beyond just grazing what would it be?
   (b) What would help make landcare groups work more effectively i.e. to better aid self-help through mutual help?
   (c) What was the most interesting or critical experience you've ever had?
   (d) Identify the pastoralists' interests, and their views on landscape changes occurring on the station and what their take is on climate change, for example. What are their ideas or strategies to adapt to change (e.g. monitoring, evaluating and managing adaptively)?
   (e) What problems are they most concerned about and what specifically they aim to do?
   (f) What common concerns do pastoralists have in their district landcare groups? What do they disagree about? What critical behaviours affect their station function and lifestyle?
   (g) How can we develop a vision for a sustainable future?
7. A cautionary note: It is important to point out that the sequence of exercises that the pastoralists takes part in is not a test or trick, nor intended to expose what they do not know. It is a participatory learning process between the resident pastoralists and the visiting ecological facilitator who at this first visit knows little about their station.
8. Of course the pastoralists will be hearing and doing things in the exercises that they may already be well informed about. Ask that they just go with the process, relax into it, think sideways, and see their everyday knowledge in other ways.
9. Operationally, clarity is critical. Every participant must understand the process, where they are at in that process, why they are doing something, and what exactly is required. Dealing with groups of four or more is quite challenging because some will really get into it, others will be confused and some will just naturally be slower than others. You always need to be reading the subliminal messages they put out.

All information involved in this process is confidential and the sole property of the participant. It is very important that this confidentiality is demonstrated in several possible ways:

- Repeating the confidentiality of the process while doing it,
- Demonstrating it by leaving everything on the property unless requested otherwise by the participant,
- Never speak about other people and properties without their permission.

Table 1: Station Map-overlay Exercise: Baseline Graphic Record

Key factors to be drawn on tracing film by the pastoralist and partner over enlarged landsystem base map of the station. Locate the numbered annotations for each overlay in a different position so that they can be read when superimposed.

Overlay A:

1. Best pasture areas. Where and why (green pen outline).
2. Poorest pasture areas (brown pen outline).
3. Longest lasting natural potable surface water (blue pen oval).
4. Artificial water points (windpumps and endpoints of piped water) (blue pen cross).
5. Draw in circles around each artificial water point, 3km for small stock, 5km for large (use pencil compass).

Overlay B:

6. Areas susceptible to fire (red broad cross-hatch).
7. Areas susceptible to flooding. Include outline of salt lakes and pans (blue broad parallel lines).
8. Eroded areas (identify whether sheet or gully types (purple)
9. Areas favoured by feral animals (e.g. goats, camels, donkeys, horses, cattle, rabbits). Large capital letters for each where they occur.

Overlay C:

10. Landscape linkage patterns.
    (a) Drainage patterns (blue lines)
    (b) Scarps (brown lines with teeth along one-side), and ridgelines (brown pen lines with cross-ties like a railway).
    (c) Dune ridge lines and contour grove stripes.
    (d) Width of coast dune zone.
    (e) Mangrove occurrence.
11. Ecojunctions: confluence area of largest number of ecosystems within a 5km radius (red circle).
12. Vista points or areas of scenic value (e.g. ecotourism) (green triangles).
13. Unique features/elements (e.g. unusual rock types, formations, fossils, glacial striations. Unusual, endemic or rare plants and animals (e.g. mallee fowl, rock wallaby, also nesting or breeding areas) (brown numbered squares).

Overlay D:

14. Outside interference on stations: e.g. major roads, railways, powerlines, pipelines, canals, mineral exploration, mining (and haul roads), fishermen access damage to riverbanks (black pen).
15. Other negative impacts or intrusions: e.g. areas damaged by hail, areas invaded by declared weeds, areas cleared for crops or by timber extraction.

Materials required:

(a) Coloured landsystem map and matching satellite image of the station enlarged to 1cm = 1km (or, map sheet of about 80 x 110 cm size).

(b) Five sheets of tracing film (one-sided and clearest available), the same size as the base map.

(c) Two sets of coloured permanent marker pens, fine and medium thickness.

(d) One roll of masking tape.

(e) Pencil 'B' and eraser for some preliminary line drawing.

(f) Scissors for cutting tracing film.

(4) The Mapping Exercise: Premise of the Graphic Approach

It was working with local tribal leaders in late1968 on the boundary of Gorongosa National Park in central Mozambique where KT discovered the power of the graphic approach for himself as expressed by illiterate people. On request the tribal elders drew their country on the ground with soil, stones and sticks. When my coloured-in topographic map was laid down next to theirs, I learnt for the first time that they could clearly relate the two pictures. The issue at the time was to try and resolve a longstanding and bitter standoff between the tribe and the administration regarding the dangerous dry season clashes between people, mainly women and children, and elephant for available water. Using the locals' map in the sand and the topographic map lying alongside, together with their intimate local knowledge and some help from their medicine man, it was the locals and not myself who solved the impasse.

A similar circumstance was experienced in Saudi Arabia with the Bedouin nomadic pastoralists where I was on a six-month survey of the regions desert wetlands. More recently HP has had similar personal experiences with rural Aborigines in central Australia and with illiterate tribal pastoralists in NW Namibia.

To **look** only requires opening your eyes, but the familiar and obvious are easily overlooked. The first rule of attention is this: we don't see what we **look at**, we see what we **look for** – we see what we expect to see. People, including land users, do not see alike because they look for different things depending on their interest, education or habit. As an example the first time pastoralists are taken up in the air to learn how to read the land, its condition and processes, they immediately start searching for stock. That is their entire focus.

To learn how to see different things requires a different perspective, a different way of viewing the station's natural environment as an ever-changing life support system – a web of interactions and interrelations on which the pastoral enterprise is totally dependent.

Born and bred in a place, or staying there for decades, the human typically becomes accustomed to and grows with the changes, as evinced by the oft repeated phrase when encountering stripped and scalded country "it's always been like this". Drawing is a way to escape the trap of familiarity or the seemingly obvious where things are taken for granted and have merely become a background presence until the advent of an extreme event.

To really see what is there requires a discipline. The EMU sequential process of identifying the key factors is a 'learning to see' discipline based on graphically recording, on transparent map overlays, the pastoralists' local knowledge and the key features they have learnt to recognise from the air and ground traverses.

The drawing of observed information onto overlays is an exercise that imprints landscape knowledge and relationships within the context of the whole station system and its surroundings on the drawer.

Drawing information onto overlays is the organising principle enabling a shift from only looking at stock and feed to the special relationships of landsystems and drainage. Drawing features of what makes up a station's environment enables a deeper more profound insight into its workings. There is a cognitive shift from what it is 'thought to' or 'ought' to look like to how it really is. This process offers a simple yet profound tool for landscape analysis and management of all kinds that can be organised into a time sequence using date recorded information on the map overlays. For example the space occupied by scrub invasion on an eroded area, can be outlined on the map using drainage and infrastructure to plot the exact area. In several years observations are made to see whether the affected areas are the same, expanding or decreasing (improving) in extent. This graphic form of monitoring is used together with fixed-point photo records, without quantitative methods apart from listing the kinds of plants involved.

The map-overlay method is the pre-eminent means of recording one's knowledge and observations in graphic form so that the whole station context is present at all times – the position of a particular bend in the creek, rocky isolates, springs or soaks, or rare plants plotted as part of the baseline exercise hugely facilitates the addition of notes, photo references, new information, refinements or enlargements etc.

Writing field observations as marginal annotations with arrows to the specific sites or areas enables planning, management, monitoring and revision, always learning something new as a means of discerning how to work or track towards the ecological best-fit strategy to that station's landscape make-up.

To achieve this continuity of 'reading the land' the manager builds on the overlay baseline record with new overlays in a constant dialogue over the years. Hence these map records should at all times be lying open on their own little corner table waiting for information and updating. To roll them up or hang them on the wall negates the exercise and hides their incredible value as a simple, progressive, hands-on tool for land management.

Of course map overlay data are amenable to GIS treatment, but it is important that the first EMU baseline exercise should be done by hand. Drawing one's knowledge, every dot, every line, on the tracing film over the visible colours and patterns of the landsystem map or satellite photo subconsciously leaves an indelible imprinting on the individual not matched by computers or writing. Findings from learning-related research show that as super learning takes place with the aid of music with a 4 cycle beat so too does drawing greatly facilitate the imprinting of data on the brain. As sculptor Henry Moore said – "you have not SEEN it until you have DRAWN it".

At the end of the mapping exercise the pastoralist and partner or manager present their findings to the facilitator(s) first as a single overlay, over a blank surface, and then all of the transparencies one on top of another as a suite. Where the greatest density of drawn lines overlap typically indicates 'best country' hence where most focused management attention is required. Of course those individuals or couples who have a more comprehensive local knowledge of their station country are not going to be surprised at the conclusion of the map overlay exercise because the outcome is a graphic expression of their own knowledge. But, maybe for the very first time, they will have their knowledge embedded in a whole system context.

Table 2: Landscape Monitoring Tick-Box

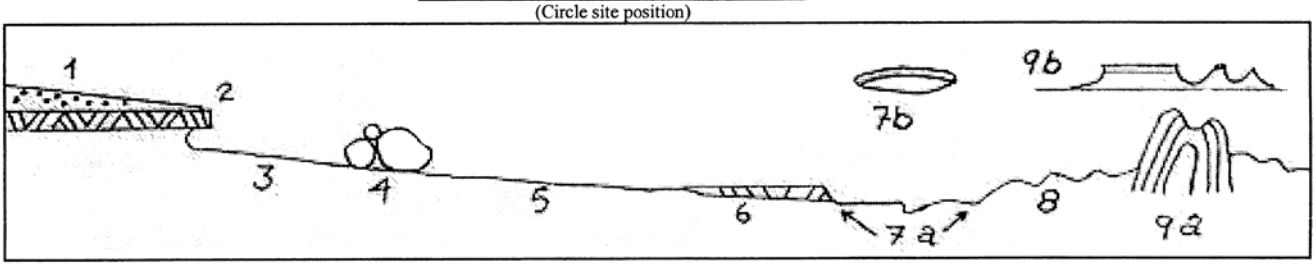
STATION_____ DATE_____

SITE NO:/NAME		PADDOCK		LAND SYSTEM	
NEAREST WATERING POINT	KM	WATERING POINT NAME	PHOTO	DATE	NO
			GROUND		
			AIR		

SPECIFIC MANAGEMENT ISSUES (Reasons for monitoring this area)

MANAGEMENT HISTORY

PROFILE OF PREVALENT LANDSCAPE CATENA SEQUENCE IN THE GASCOYNE-MURCHISON REGION
(Circle site position)



1. OLD PLATEAU SURFACE Red sand over laterite duricrust. (Run-in)	**2. LATERITE BREAKAWAY** Scarp retreat & exposure of saline kaolin (Run-in, -off)	**3. UPPER STRIPPED WASHSLOPE** Saline duplex soil over hardpan. Shallow brittle topsoil (Run-off, -through)	**4. GRANITE OUTCROP** Domes, tors, ridges, hills (Run-in, -off)	**5. MIDSLOPE WASHPLAINS** "hardpan plains" "hard mulga country" (Run-on, -off, -through)
6.LOWER SLOPE SAND DEPOSITION Wanderrie banks, (Run-on,-in,-off, -through)	**7. BOTTOMLANDS**		**8. UNDULATING TERRAIN** eg. Calcrete country, rolling plains, low rises (Run –in,-off, -through)	**9. RIDGES & RANGES** **(a) FOLD RANGES** Rocky outcrops of tilted strata **(b) TABLELAND RESIDUALS of** Horizontal strata (all Run –in,-off)
	(a) CREEK, FLOODPLAIN & BILLABONGS (Run-on, -in,-off, -through)	**(b) CLAYPAN OR SALTLAKE** (Run-on)		

LAND SURFACE/SOIL TYPE & COLOUR (Tick)

ROCK TYPE	**Laterite Duricrust**	**Banded Ironstone**	**Granite Gneiss**	**Basalt Dolerite Gabbro**	**Sandstone Quartzite**	**Shale Siltstone Mudstone**	**Silica Hardpan**	**Calcrete Limestone Dolomite**
SOIL SURFACE	**Stony**	**Gravelly**	**Earthy Loam**	**Sandy**	**Silty**	**Clayey**	**Litter cover**	**Bare**	**Algal Mat**
SOIL PROFILE	**Uniform (same throughout)**		**Gradational (increasing texture with depth)**		**Duplex (texture contrast between top & subsoil)**		**Crabhole Cracking Clays**	

Table 2 continued: Landscape Monitoring Tick-Box

SITE NO	PADDOCK				UPDATED PHOTO GROUND	DATE	NO
SEASONAL CONDITION	EXCELLENT AVERAGE	VERY GOOD BELOW AVERAGE	GOOD DROUGHT		AIR		
RAINFALL Quarterly amounts: Total mm	J.F.M	A.M.J.	J.A.S	O.N.D	STOCK HISTORY THIS YEAR		
COMMENTS							

LANDSCAPE PROCESSES

Water in the Landscape (recharge & erosion or deposition)

Is the landscape trapping water effectively				YES	NO
Is there active soil erosion or siltation (sanding -up)?				YES	NO
What kind of erosion?	Sheet/wash	Gullying	Pedestalling/mounding		
What proportion of the sample area is unstable				%	
Is the unstable area	Contracting?	Stabilized?	Expanding?	Incising?	
In the bare areas is the soil covered by an algal crust and / or stone pavement (gibber)?				YES	NO
Other Impacts/Influences	Wind erosion	Fire	Hail	Frosted vegetation	

VEGETATION:

Layering of Vegetation (tick one or more)

❑ Top Layer	❑ Middle Layer	❑ Lower Layer	❑ Ground Layer

Bush Clumps Beneath Trees and Large Shrubs

❑ None	❑ Few	❑ Many

Is There Effective Recruitment Of The Key Plants (insert plant's name)

Flowering	Fruiting/Seed Set	Recent recruits	Recently dead or dying

Plant Kind &/Or Cover Change Plus Browsing & Grazing Influences

Is the overall perennial plant cover	Increasing	Stable	Decreasing	
If increasing, does this involve mainly undesirable plants? E.g. needle-bush, camel thorn			YES	NO
Name undesirable plants				
Why undesirable?	Taking over good pasture	Unpalatable	Toxic	Burrs	Other
If increasing, do the invading scrub or weed plants have useful fodder plants growing beneath them?			YES	NO
Name plants growing beneath:				
Do the trees & large shrubs have an upper feeding reach browse line?	YES	NO	PART OF	THROUGHOUT
What is forming this browse line?	Sheep	Goats	Cattle	Camels
To what degree are the lower & ground layer plants eaten?	V. heavy	Heavy	Medium	Light
To what degree are the bush clump plants browsed	V. heavy	Heavy	Medium	Light

CONCLUSION:

Comparison With Previous Years Monitoring Record

Is the area?	❑ Improved	❑ The same	❑ Deteriorated

(5) The Indispensable Air Perspective

Only from the air at about 122m (400ft) above ground level (a.g.l.) is there the comprehensive view that scans the entire panorama – the totality of the landscape context. Only from the aerial view can landscape patterns, relationships, dimensions or scale of phenomena, and linkages be perceived. Also, the degree of change and trend in a drainage process and whole station context can only be appreciated from the air. Trying to judge land and pasture condition only from the ground is 'one-eyed'.

Only by combining the bird's eye view with the ground evidence is it possible to shift ones perspective between the top-down holistic context and the bottom-up verified information for insightful management practices. Such an approach enables cross-level comparisons and access into understanding landscape function and trend.

(6) Drainage/Fluvial Ecosystem Units and Sub-units

Surface drainage catchment unit areas, at all scales, contain all ecological process and response relationships between physical, biotic and human land uses within each drainage compartment (Leopold et al. 1964; Odum 1971; Lotspeitch 1980; Tinley 1977, 1986, 1991). A drainage catchment ecosystem involves the full surface area bounded by its watershed divides, containing a branching hierarchy of diminishing sized tributary sub-unit compartments each in turn partially enclosed by divides.

There are three major types of drainage system, those that reach the sea (exoreic), those reaching landlocked endpoints (endoreic) such as saltlakes or dunefields, and those with little to no surface flow (areic), such as sandplains, dunes and limestone karst **(Figure 5)**.

In areic areas the process units are identified by surface features such as sands (sheets and dunefields), gravels or gibber, or limestone. Each is often easily identifiable by having a particular natural vegetation cover. On desert sands there is often and typically a seepline at the base of bare dunes or the edge of a sandsheet is indicated by a line of plant growth. On vegetated coastal dunes denser and taller vegetation occurs on basal lee slopes and in dune hollows (e.g. coast plain tract of Wooramel River along the south bank and Shark Bay to NW Cape dunes).

Under the force of gravity land surfaces are continually being worn down by water moving towards lower levels. The lowest that erosion can cut down to is sea level (or a saltlake or dunefield for internal drainage), this is called the primary base level. There are many local temporary base levels located throughout a drainage system that hold up downcutting. These are called erosion base levels. Some are longer lasting like a rockbar, but the majority are less durable, such as ponding sills formed by a convex deposit of soil fixed by vegetation. The converse is a deposition base level which is the highest level to which a sedimentary deposit can be built (e.g. up to the lip of a rockbar, a weir or dam wall).

Due to the natural processes of water moving across the land under the force of gravity coupled with disturbances initiated and accelerated by human and stock activities, drainage dissection increases runoff and the upslope migration of headcutting erosion. This drains the land of water and leaves the surroundings perched above the drainage channels.

The natural wearing down or lowering of land surfaces is an inevitable and inexorable long-term geomorphic denudation process. Hence the fundamental focus of land management is to slow these processes down to retain soil moisture by rainwater harvesting and spreading, and not allow them to develop into accelerated erosion.

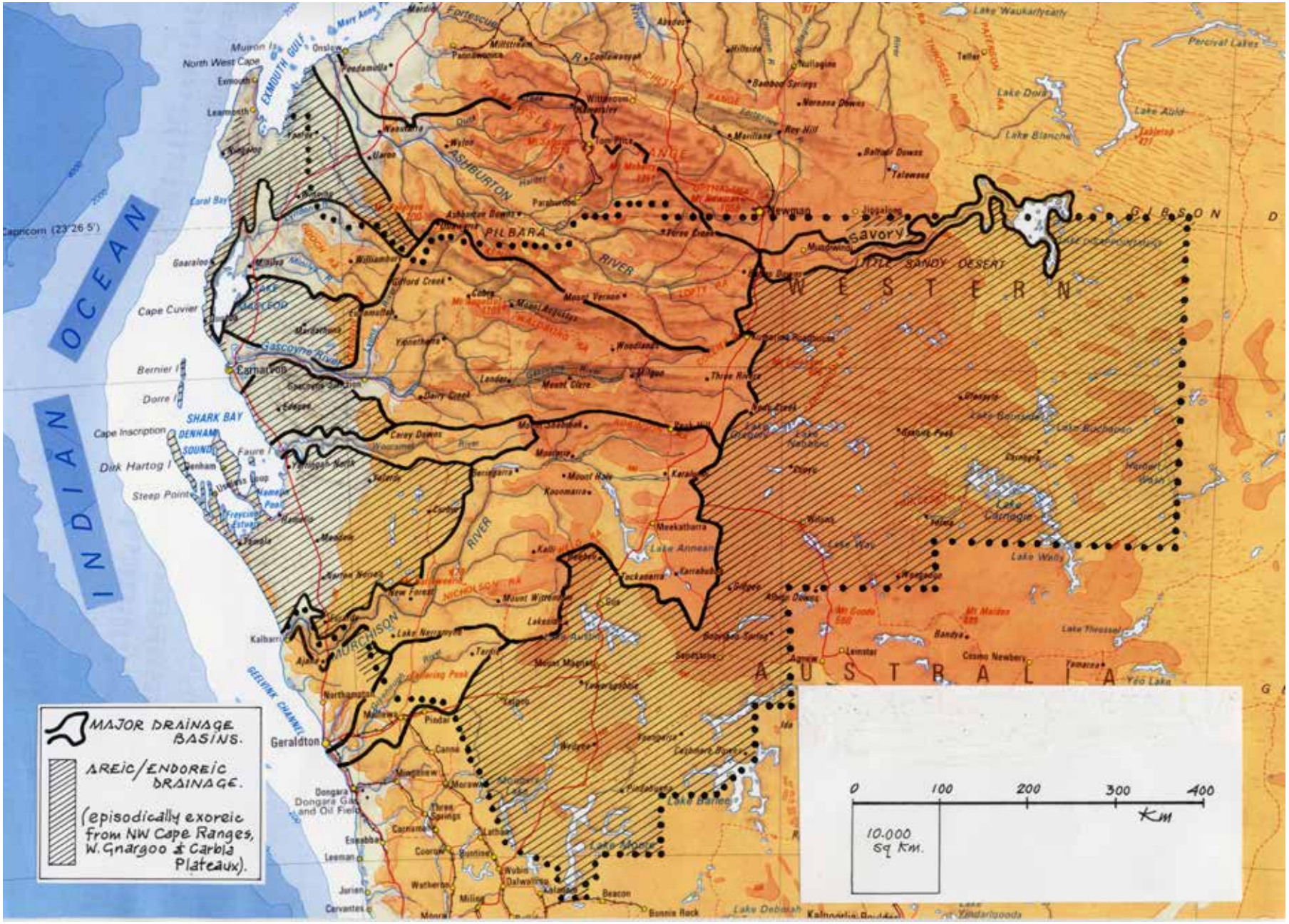


Figure 5. An Example of Surface Drainage Systems. The Gascoyne-Murchison Strategy Area, Western Australia.

(7) Indicative Monitoring

The Landscape Monitoring Tick-box **(Table 2)** approach was developed and fine-tuned with pastoralists through the EMU Project, most notably those around Mt Magnet. It is based around a core set of questions that together we thought would leave no doubt as to the condition and recent trend of a site once answered. Pastoralists wanted something quick to use once installed, but structured so that the observer had to take a really good look at what the signs were saying about the landscape. Thus there is purposely no counting or measuring. Pastoralists are encouraged to walk over about a hectare doing assessments so that local idiosyncracies are recognised but do not overwhelm the assessment. This broad assessment area also allows for broader patterns and processes to be included than at say a typical Pastoral Monitoring Site.

This approach is not intended to replace any existing monitoring on a property. Certainly not; the longer the data trail for a site the more valuable it gets. This approach complements whatever exists beforehand.

The key to successful implementation is to locate the sites in areas that matter most to management and this should be guided by the implications of the overlay mapping process. It is likely that the sites will not be near the existing Government sites (as a rule, about 20% of the latter are near selected sites). This is to be expected as the selection criteria are quite different and are often complementary (Pringle et al. 2006).

Having a few reference sites within main ecojunctions is a good way to focus some of the landscape learning in a relatively small area in terms of issues such as terrain processes, key species, habitat preferences by stock, feral animals, wildlife and in terms of recognising the indicators of change. Other sites might focus on a particular concern or issue, and others simply be located in sensitive parts of best country as an early warning system.

One does not need scientific monitoring sites and data to judge how a place has changed and how it is changing now. The landscape contains all the indicators of change - when you have learnt to recognise them and keep track with fixed-point photo records. To really see 'what is' requires developing the habit of acute observation and interpretation. For example, where spinifex or scrub is invading downslope into bottomland clay tussock grassland there will be an uneven age/size of plants with the youngest/smallest at the encroaching front. They are indicators of the landscape changing towards drying out - likely unplugged by drainage incision. An indication of topsoil stripping is dead mature plants or temporary survivors on remnant patches of topsoil.

Conventional landscape ecology tends to view problems, symptoms and solutions as being spatially congruent. However, problems often indicate system dysfunction at key drainage control points some distance up or down slope.

(8) Preparedness for Adaptive Management

It is critical to integrate anticipatory (predictive) and adaptive (reflective) management to get best value from strategic decisions. Anticipatory management involves predicting most likely changes to occur during the next cycle of management. For example, is the 'best country' approaching a threshold or tipping point of change? "What management actions need to be taken to avoid such a threshold? What are the key variables driving them?" (Walker & Salt 2006). Overlay mapping is the way to track change together with fixed-point photo records. Rainfall is an obvious example of an issue that is critical due to its highly variable occurrence in space, time, quantity and intensity – in tandem with its converse, variations in severity and duration of dry periods and drought. Fuel loads indicate the likelihood of fire, in particular where rank growth follows on high rainfall events resulting in massive landscape-scale wildfires of the spinifex country. What is the status and condition of the station's water resources? Are bore water levels staying the same or dropping, and/or are they becoming saline?

A key part of adopting adaptive strategies, including exploring new enterprises, is to apply mitigative management measures in the meantime in order to heal/recover best country from erosion and overgrazing. Adaptive Management refers to assessing systematically whether the observed outcomes match the expected

and desired outcomes, and if not, why not. Thus strategic pastoral management is the art of integrating possible future changes and issues (and the skill or reliability of predictions) with reflections on what happened in the last management cycle (usually a calendar year, but possibly by seasons). Always looking forward for opportunities and risks, always looking backward to check and learn (Botterill & Fisher 2003). Contacts include:
www.bom.gov.au/climate/change or drought or cyclone
helpdesk.climate@bom.gov.au for tracking rainfall deficiencies
www.csiro.au/outcomes/climate/understanding

Figure 14: "A drought-resisting stock. Vol. 24 - No. 1243
The Australian of the future who will only carry a billy through force of habit."

Figure 6. An Early take on Adaptation (from The Bulletin 10 Dec.1903:Vol. 24:1243).

Figure 7. The Pastoralists' Burden (with additions by the authors) (from The 1900 NSW Royal Commission – A critical Re-evaluation).

[C] Key Landscape Features and Processes

(1) Catena Series

(a) Landsystems

The landsystem approach was initiated first in the late 1940s by Australian CSIRO scientists Christian & Stewart (1953). A landsystem was defined as: "an area or group of areas with a recurring pattern of topography, soils and vegetation." These recurring landscape patterns, discernable on aerial photographs and other remotely sensed imagery, are mapped and verified by ground survey traverses with notes on their drainage, geology, geomorphology and vegetation plus detailed soil profile analyses.

If not a world first, this approach is a unique terrain analysis method of far reaching importance and value for all land-use mapping, planning, management and monitoring. It should also be a basis for the positioning of roads, tracks and other infrastructure and the basis for conservation of soils, water, forestry and biodiversity. Landsystem surveys of most of the pastoral lands across WA have nearly been completed and published by the WA Department of Agriculture and Food.

Not using this valuable and freely available wealth of field recorded information (which includes susceptibility to erosion or water starvation) means ongoing consolidation of damage and degradation of land and resources from wrongly positioned developments or mal-practices due to estate agent, political or engineering decisions.

Landsystem survey maps are colour coded from moist (bottomlands) blues in an upslope direction through greens, yellows (sands), to rocky systems in dark brown. Once the significance of the colour code is understood, one glance can summarise the terrain make-up and the attributes of the individual or groups of landsystems of a station (for examples refer to: Payne et al. 1987, 1988, 1998; Van Vreeswyk et al. 2004a; Waddell et al. 2010).

Catenas are linked repeat series of landform, soils and their biotic components. There are three kinds of terrain catena:

I. Topo-catena series represented by a profile from hill-top to valley bottom (**Frontispiece; Figures 8**a and **8b**).
II. Alluvio-catena is a horizontal or faint slope series of differently sorted sediments on sheetwash plains, floodplains, fans and deltas.
III. Drainage catena is a repeat pattern with dendritic head and distributary pediment fans typical of local valley side tributaries (e.g. Murchison region, see **Figure 18 in the Field Guide)**, and of paired scarps and dipslopes of fold ranges (e.g. Bangemall fold ranges of the Gascoyne).

Left to themselves wild ungulates and stock exhibit a seasonal up and down slope catena grazing strategy. In the rains they feed upslope allowing rest and regrowth of the bottomlands, and return to focus on the bottomlands in the dry season. This is a grazing strategy worth considering when planning the layout of paddocks.

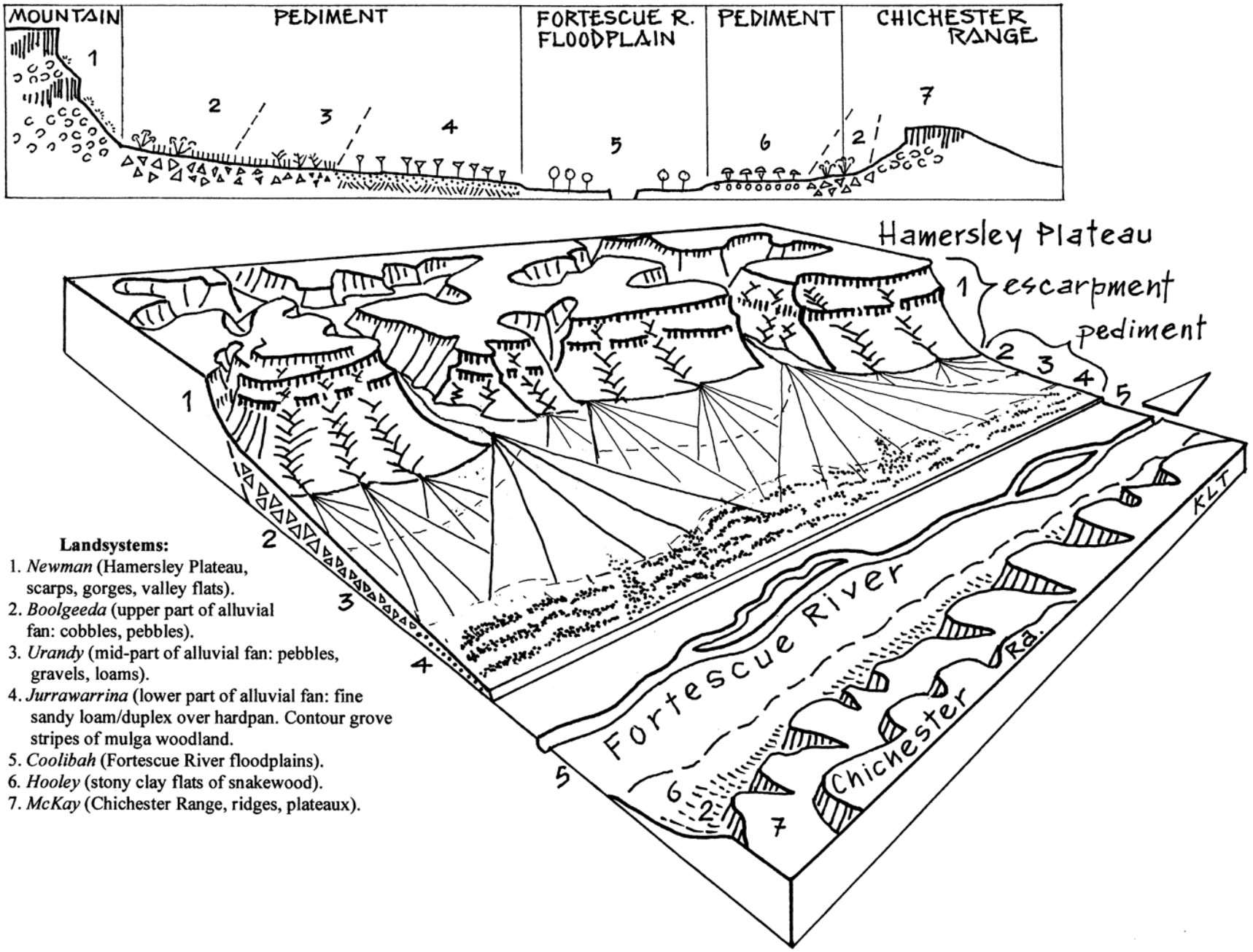


Figure 8a. Pilbara example of a topo-catena series. (Hamersley Plateau and Fortescue River Valley).

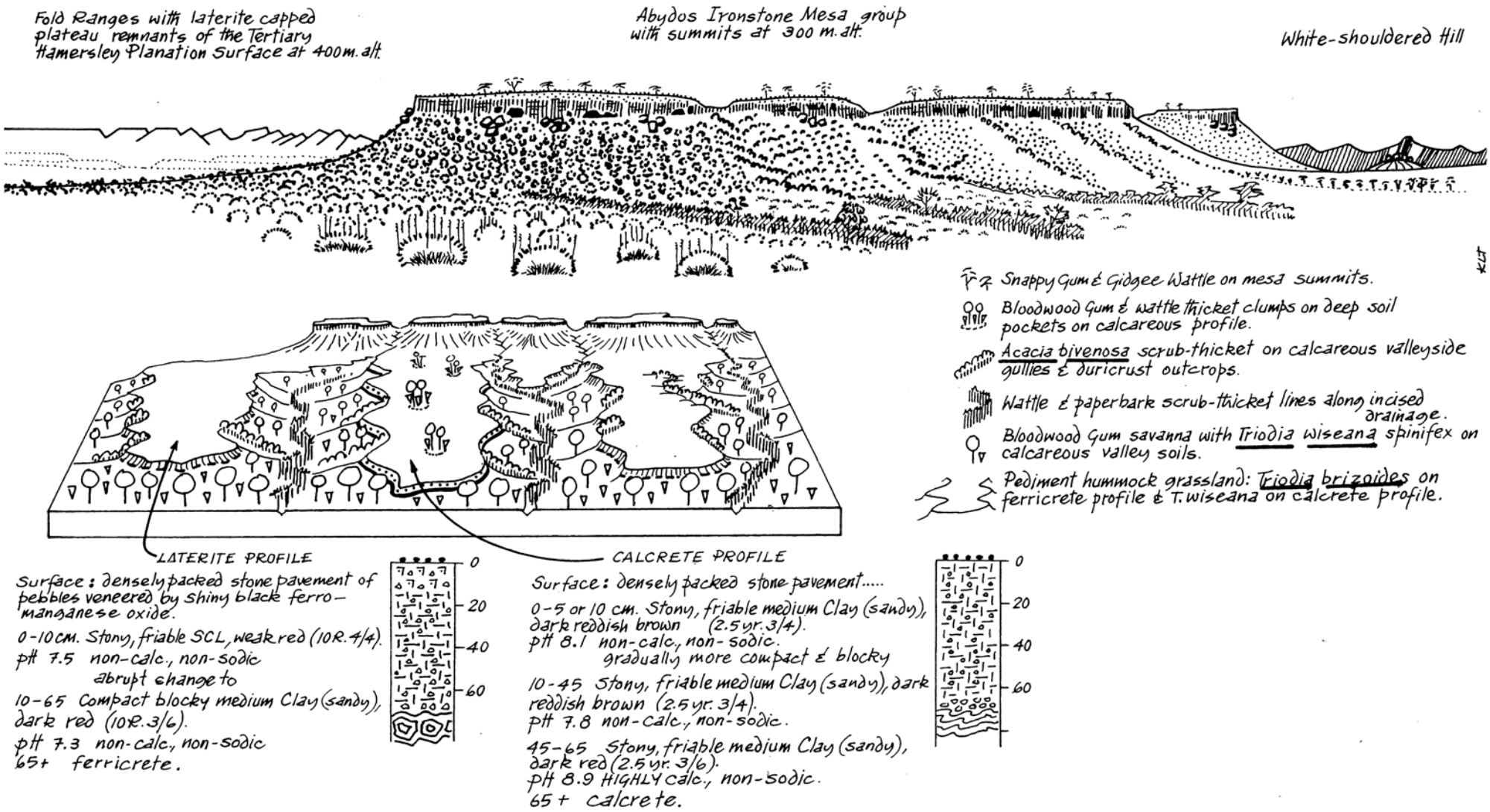


Figure 8b. The Abydos mesas in the source area of the Turner River, eastern Pilbara.

Inselberg remnants of dissected Tertiary planation surfaces surrounded by broad incised pediments abutting fold ranges and granite plains with their dome and tor residuals (Tinley 1991).

(b) Soils

As can be expected there are a great diversity of possible soil profile permutations in catena sequences dependent on topography, terrain position, parent material, geomorphic processes and moisture conditions. However, fundamentally Australian soils are classified into four major divisions based on the textural and horizon properties of the soil profile as observed in the field. Profile assessment is made from the surface down to the rock weathering front (saprolite) or to 2m depth in deep soils.

These primary profile forms are:

I. Organic soils - O.
II. Uniform textured profiles - U.
III. Gradational textured profiles - G.
IV. Duplex (contrasting textured profiles) - D

The main subdivisions of these are based on pH in organic soils, texture in uniform soils, presence or absence of calcium carbonate in gradational soils, and colour (mottling red to grey, blue, gley) in duplex soils (Northcote 1960; McDonald et al. 1984). For WA soil type details see Tille (2006) and the Department of Agriculture technical bulletin series of rangeland inventory and condition surveys (e.g. Van Vreeswyk et al. 2004 a).

In dry regions the quantity of rain is only of indirect or partial importance to plants. The amount of available moisture remaining in the soils is of far greater importance (Walter 1973). This is directly related to three coactive influences (a) slope/runoff, (b) soil profile properties (particularly topsoil porosity) and (c) density of groundcover (particularly perennial grasses).

The soils which have the best available moisture for plants in the aridlands are sandy duplex (sand over clayey or strongly compacted subsoil within reach of the annual rainfall); gradational sandy loams more compact with depth and stony or gravel varieties, particularly calcareous forms. In contrast clay soils such as those supporting the Mitchell and Roebourne type grasslands in the aridlands exhibit soil moisture extremes. In the Murchison Shield and other sand covered areas the total annual rainfall is trapped down to the laterite kaolin horizon (which produces seeps in good years).

The best country for cattle, as in most of northern and arid Australia, are the tufted (tussock) grasslands on the heavier textured and duplex soils of alluvial plains that are seasonally or irregularly flooded or waterlogged. In healthy ecological condition these grassland types are characteristically treeless – without woody plants of any kind. The condition is well exemplified by the Pullgarah Land System and Horseflat Land System on the Pilbara coastal plains. This is due to their high water holding capacity under a dense grass cover that inhibits the establishment of woody seedlings. The high soil moisture period is followed by the opposite condition of desiccation in the dry season, again inimical to the establishment of woody plants, as the clay soils become impacted making any soil moisture unavailable, and the gilgai clays become deeply fissured (Tinley 2001).

Too deep and long duration of floodwater can drown both perennial grasses and woody plants. This is another reason for using sieve structures in erosion control **(see Section D in the Rangeland Rehydration Field Guide)**. As recently reported by Graham Forsyth of Three Rivers station in the headwaters of the Gascoyne River, the two year sequence of exceptional rains and flooding in 2010-2011 resulted in some floodplain depressions being long inundated, killing the perennial grasses typical of clayey alluvia: e.g. Neverfail *(Eragrostis setifolia),* Roebourne Plains Grass *(E. xerophila)*, Swamp Grass *(Eriachne benthamii)*, and Claypan Grass *(Eriachne flaccida).* Subsequent floods in February 2011 encountered bare floodplain soils dried out and cracked as they are at the end of a dry spell, which ripped out large areas of alluvia almost to an underlying hardpan horizon.

As grasses use only the topsoil and upper subsoil horizons, it is only under grassland that a high field capacity can be attained. Field capacity refers to the amount of water remaining in the soil after the excess has drained off. In addition it is only with a dense grass cover that effective infiltration can occur to wet the soil profile adequately for maintenance of the pure grassland habitat on textured soils. Sandy soils of course absorb all rainfall whether bare or vegetated (unless they are of water repellent type).

Any factor that lessens the periodic high soil moisture waterlogged condition enables scrub to become established. Their typical paths of encroachment are on the drier, better drained disturbed areas, as of erosion, stock pads, tracks, fence lines or any convexities **(Figures 6 and 7 in Field Guide)**.

The amount of available water remaining in the soil for plants is determined by the topsoil and subsoil textures. In humid regions the sand and loam soils are dry and clays are wet. In arid regions it is the opposite, where lighter porous soils absorb rain with little runoff and have high moisture availability for plants. In contrast heavy clays, though having a higher field capacity, the moisture is bound in the dry and unavailable to plants. The two main kinds of clays in the region have quite different soil moisture balance. The non-cracking clays only absorb moisture well where they are well covered by grassland and have loamier topsoils. When bared by fire or overgrazing followed by rainstorms their surface can become sealed and water shedding, subject to sheet erosion. The gilgai cracking clays (crabhole soils) absorb a large amount of water down the deep cracks before swelling and sealing-off thus the entire profile is wetted. However, this deeper groundwater acquisition can result in underground pipe erosion where the clays overlie an impervious layer on sloping ground.

Water absorption is also enhanced where gilgai have crumbly self-mulching surfaces or have a high content of gravel, pebbles or large stones. Typically a more open grass cover occurs on the non-cracking clays and a denser one on the gilgai is likely to be an expression of their differences in water availability. Where a clay grassland cover begins to fragment the bare openings become sites of topsoil stripping, surface sealing and scrub establishment.

Hence the crucial factor in pasture management of clay soils is the maintenance of a continuous grass cover that enables a high field capacity to be attained when wetted. This means stock grazing pressure should be on an effective rotation basis, and be free of stock after a fire for the full recovery of the grassland to the seed set stage.

(c) Soil Moisture Balance

Soil moisture balance is the amount of moisture required to support and maintain a particular kind of plant community in a state of dynamic equilibrium or balance. Anything that shifts this balance towards drier or wetter conditions sets in train inexorable changes in the plant cover's physiognomy and species make-up as adjustments to the altered edaphic condition develop, i.e. climate, in a vegetation context is expressed through its translation by the edaphic medium.

The factors responsible for such changes in soil moisture are due primarily to the natural landscape surface cut and fill successional processes (at all dimensions from the micro to the macro) that occur under unchanging rainfall regimes, let alone with climatic change. This geomorphic succession is either a spatial replacement of land surfaces by erosion (sheet and gully) and/or in-situ edaphic change due to increased runoff from incised local base levels and headward migration of nickpoints. In rangelands these erosive changes are largely initiated and accelerated by human and stock impacts, with major damage caused by the extreme rainfall events such as a thunderstorm or tropical cyclone deluge.

Conversely, factors causing intensified waterlogging include removal of woodlands and their evapo-transpiring pump action, or blockages in drainage from deposition or damming. Superimposed factors that obviously alter soil moisture balance include baring of the ground from overgrazing, lack or excess of fire, stock and wildlife pads, human footpaths, tracks and roads, draining of wetlands or damming drainage. All of these can act as initial causes of edaphic change as well as accelerator factors that sharply increase the velocity, intensity and dimension at which landscapes become modified.

Earlier studies from Namibia and Kalahari (biome equivalent to the Australian arid zone <600mm isohyet), found that, due to their contrasting root systems and physiology, woody and grass strata have different water economies and hence occur together in a moisture tension state (Walter 1964, 1973).

Savannas both of the arid and moist biomes thus occur as antagonistic strata, exacerbated by the fire factor in what Walter (1973) calls a 'labile equilibrium'. Anything that disturbs or changes the soil moisture balance results in a change of predominance between the woody and herbaceous layers and also in their species composition.

Grasses use only the topsoil and upper subsoil horizons, it is thus only under grassland that a high field capacity can be attained and maintained. Woody plants with their deeper reaching root systems 'pump' the soil profile dry. Conditions required to maintain the pure grassland habitat, i.e. seasonally high soil moisture balance, actually preclude woody seedlings. These are killed in the wet season by excessive soil moisture and again in the dry by soil desiccation when the soils become fissured or the subsoils indurated.

Any factor that decreases the high or adequate soil moisture condition, such as baring of the soils and increased runoff along paths or other incisions, results in inadequate waterlogging to maintain the grassland and keep woody plants at bay. Of all the insidious factors at play the most easily overlooked key factor is the development of a gutter or gully incision, often initially hidden by the grass cover. The incision nickpoints migrate headwards and literally 'pull the plug' out of the system so that it loses rain or floodwater down the drain and thus initiates and drives the dehydrating change of an entire ecosystem **(Figures 14, 28, 40 in Field Guide)**.

On any slight, now drier, convexities in the grassland terrain, such as the faint level edges of the drain or gully, fan outwash of the gullies, micro-ridges of gilgai or micro-pediment of a termite mound, woody seedlings are able to become established as exemplified by floodplains of the east Kimberley and adjacent NT **(Figure 7 in Field Guide)**. Typical examples of the woody invaders of floodplains in this area are: bauhenia *(Bauhenia cunninghamii),* gutta-percha *(Exoecaria parvifolia),* conkerberry *(Carissa lanceolata),* silver box *(Eucalyptus pruinosa),* rough-leaf cabbage gum *(E. confertiflora)* and rosewood *(Terminalia volucris).*

The typical give-away growth pattern exhibited by scrub encroachment is the different size/age cohorts, oldest and tallest on the first drying surfaces and youngest and smallest groups reaching out from each convexity as the flats and faint depressions become increasingly drier. Once established, exceptional flooding rarely kills mature scrub as the ebb is faster due to either increasing size of the erosion incision and/or the woody plants pumping the soils free of excessive waterlogging. With further spread and maturation the woody plants occlude what was once an island of treeless grasslands, homogenising the vegetation structure across the landscape to a woodland system (**Figure 6b** and **40 in Field Guide**).

Without blocking off the incision(s) that breach and overdrain planar or faintly convex terrain, effective waterlogging of the perennial grasslands is lost and all other means of combating scrub encroachment are eventually in vain (e.g. Radford et al. 1999, 2001). In our experience merely blocking off the drains and restoring effective waterlogging is often sufficient to kill the scrub initials.

Summary

Landscape processes both natural and those superimposed by human actions, change soil moisture balance, initiating and entraining land surface and vegetation successional changes. Though erosion changes over the long term are inexorable they are slowed down by the occurrence of rock bars, alluvial plugs, highly cohesive clays and dense plant cover. By reinstating plugs or sills at key points in the landscape it is possible to prolong the survival and productivity of perennial productive grasslands and of wetlands that are the drought buffering habitats. Improved profitability thus needs perceptive management responses that include simple and subtle water harvesting and spreading, retention or drainage techniques (i.e. the role of water management in a particular terrain setting). In management for ecologically sustainable productivity it is not enough to manipulate vegetation and fauna alone. This approach forever misses the point – the nickpoint – a primary causal and orchestrating process in landscape change.

Field observations and soil profile recording from across southern Africa, Saudi Arabia and central and western Australia indicate that soil moisture balance is the most significant edaphic feature as it overrides all other properties or influences their effects (Tinley 1977,1982).

(2) Drainage Dynamics

The dynamics to tap into for successful rehydration are at the critical drainage control points **(Figure 18 in Field Guide).** These vary from subtle and small scale in terrain of low relief to prominent features requiring stronger interventions in rugged country with higher runoff velocities (particularly where subject to tropical cyclone flood events). Working at the control points, the endeavour is to entrain the natural processes to do most of the recovery work. Hence the initial focus is on recognising 'where to tap', what the implications are, and only then - how to and what tools to use **(Table 2 in Field Guide)**.

When water flows across the ground it accomplishes three processes simultaneously – erosion, transport and deposition. Erosion cuts down, sideways and back upslope in the opposite direction to the flow. The cutting back is led by a nickpoint (or headcut) at the exposed vertical soil face the progression of which is driven by water tumbling over the fall, undermining the base and causing slumping **(see Figure 27 in Field Guide)**. This cavitation process occurs at all scales from micro-scarps of sheet erosion to major gullies, waterfalls and escarpments such as the laterite breakaways of the Murchison region **(Frontispiece)**.

Apart from some of the upland source tributaries in the Kimberley and the Hamersley Range, that are incised along joints or fault lines, the major rivers in the arid originate from upland plateau soaks or seasonally moist flats below converging alluvial fans off pediments. The drainage throughout these rivers' courses is mostly of braided channels traversing hugely varying widths of floodplains. Where these rivers have cut down deep (>10m in some stretches of the Murchison River), the course of the river flow is trapped within its channel and rarely inundates adjacent floodplains. True meanders with billabongs are rare in most WA river and creek systems, although long river pools, common in the Kimberley, may occur in flood channels blocked by rock bars or gravel and sand deposits stabilised by plants. Tightly meandering river courses are typical where creeks traverse coastal plains and estuaries as in the Kimberly and Top End. For more comprehensive information refer to the geomorphic textbooks by: Twidale 1973; Mabbutt 1977; Twidale & Campbell 1993.

Critical control points in various parts of a drainage system: **(see Figure 18 in Field Guide)**

(a) Baselevels,
(b) Erosion and gravity slumps,
(c) Channel necks and tributary junctions,
(d) Floodplains,
(e) Valley-side tributaries,
(f) Stream capture.

(a) Base-levels

At all scales base-levels are critical controls of drainage function as they determine either the limits of downcutting or conversely the level up to which sediment can be deposited. Where an erosion base-level such as a rockbar or ponding sill is breached (unplugged) this results in a new phase of headward erosion and incision leaving the adjacent and upslope terrain in a perched and drying soil moisture trend. On gently sloping terrain gully nickpoints act as temporary base-levels for everything upslope of them, shifting in an upslope direction as gullying proceeds (i.e. they are migratory baselevels). Where a depositional base-level is incised this results in the erosion of the sediments that had been deposited.

As changes in base-level results in either erosional or depositional responses, they are fundamental determinants affecting changes in vegetation through the influence exerted on soil moisture balance. Essentially intact base-levels slow the free flow of surface water on vegetated flats or pediments where it spreads out and infiltrates the soils if these are porous and grass covered. In any catchment or drainage situation the local base-level to every tributary is formed by the floor of the larger channel it adjoins.

(b) Erosion and Gravity Slumps

Of the many kinds of erosion five kinds are encountered in the rangelands that are important for identifying the processes occurring in a potential rehydration situation: (I) sheet, (II) rill, (III) gully, (IV) pipe erosion, and (V) gravity slumps.

I. **Sheet erosion:** topsoils stripped over wide areas by sheetflow run-off **(Figure 6c in Field Guide)**.

II. **Rill erosion:** small scale shallow and narrow channels such as stock pads or footpaths. When these are deepened by run-off they are transformed into gullies i.e. they are indicators of potential escalating problems **(Figure 8 in Field Guide)**.

III. **Gully erosion:** soil profile incision by running water down slopes forming a steep sided erosion gash led by an upslope cutting nickpoint or headcut **(Figures 26, 27, 36a, 40 b, c in Field Guide)**.

IV. **Pipe erosion:** initially a subtle hidden process where the land surface or soil profile is eroded from below by the underground flow of water along a sloped impervious horizon. This process results in various degrees of surface collapse, with sinkholes of different sizes often occurring in a line that indicates the direction and expansion of excavation. Pipe erosion occurs in certain areas of cracking clay soils, in kaolin clays of laterites, and in limestones where overlain by regolith. Though of minor or local importance in arid areas, it can become significant in high rainfall humid areas.

V. **Gravity Slumps (mass movement/wasting):** This includes a large variety of processes including rockfalls, bedrock slump, rockslide, scree creep, soil creep and earth flow. Slumps occur most frequently along escarpments at all scales **(Frontispiece and Figure 13)**. They also occur where steep-sided valleys are orientated east-west with poleward facing steeper, moister slopes that are susceptible to mass movement, and less steep, more stable drier slopes on the opposite valley side susceptible only to soil creep. Examples of such valleys occur in the Hamersley Range near Wittenoom. In the Murchison breakaway gravity slumps occur from basal sapping by springs or seeps and pipe drainage that hollows out in the kaolin zone beneath the laterite resulting in blocks breaking off the scarp faces. In ravine drainage gravity slumps are important for partially blocking flow into a series of pools.

(c) Channel Necks and Tributary Junctions

Channels are usually irregularly sinuous in form which results in alternating sets of undercut and slumped bends. The undercut slope is steeper with faster water flows, the slip-off slope opposite is flatter and veneered by sediment. Between the pairs of undercut and slip-off slopes are nodes of least change or cross-over - the safest positioning for vehicle crossings such as causeways **(Figure 36c in Field Guide)**.

The importance of these processes is reflected in the contrasting responses of a tributary or flood exit/entry point connecting at either curve. Laterals joining at the undercut slope results in ongoing lowering of the local base-level which engenders repeated down cutting and headward erosion, threatening any floodplain or wetlands. Entering at the slip-off slope side such laterals add to the sediment build up and are thus self-protecting and relatively stable by comparison.

Tributaries that rise on steeper more erodable terrain than a main river channel can have far reaching creative consequences in rainwater harvesting and spreading. In these circumstances gravel and other alluvia dumped at the confluences backs up the flow in the main river resulting in its effective overbank flooding, thus helping establish and maintain a floodplain or wetland **(Figure 36 b in Field Guide)**.

Where such tributaries occur in series the main river channel can become partitioned into long pools which may survive the duration of each dry season – particularly if shaded by riparian woodlands. Partitioned channels also buffer extreme flood events by reducing the erosive velocity of the water and spreading it widely. Any narrows or necks in channels are important sites for establishing water calming structures **(Figures 31, 37 in Field Guide)**.

If judged to be important, reinforcing of such confluence alluvial plugs can be supported by means of a hanging mesh fence or a weir, and planting reeds and riparian trees immediately down-stream of the confluence.

(d) Floodplains

Rivers that traverse floodplains often have embankments of alluvium parallel to the channel along each bank. These are called levees and are deposited by overbank flooding. Levees are interrupted at various intervals by flood exit/entry gaps or troughs. Typically, levees rise one to three metres above the level of the adjacent floodplain and support riparian woodland or forest.

The condition of the flood exit or entry gaps between the river and floodplain are critical control sites to assess whether, in order to maintain healthy floodplain function, they are in need of repair work or if the need is for merely slowing of water flow using mesh fence or roll. Levees, particularly at pool sites, can be cut through by livestock paths thus initiating floodplain incision and dehydration.

In their healthy state floodplains are typically treeless perennial grasslands, with perhaps island patches of specialised swamp woods or thickets as occur in the Top End (e.g. the legume tree *Cathormion umbellatum*). Where invaded by dryland scrub, wattles for example, this indicates desiccation of floodplain soils by lack of effective flooding and over-draining from unplugging by gully incisions. The causes of this being either the river cutting down its bed leaving the floodplain perched out of reach of normal flooding, and/or gutters and gullies cutting upstream from eroding creek drainage and from roads or cattle pads **(Figures 6b, 7b in Field Guide)**.

Another cause of over-draining is when a local valleyside tributary has cut a trench across the floodplain to join the main river channel instead of forming an alluvial fan at its junction with the floodplain. If the field evidence shows that the most important source of floodplain wetting is the runoff from adjacent uplands, rather than a main river channel which has become deeply incised, the healthy functioning of these laterals then becomes an important management focus (see (e) below).

The drainage condition of upland streams, particularly where they meet the alluvial flats, should ideally be in the form of a slow flowing water, not torrential. If the latter, then water calming measures are required upstream. At the same time the floodwater exits need scrutiny as they may require ponding sills where eroded – built to the same level as the flats. Not higher as this could result in too long lasting flooding and waterlogging that could drown perennial grasses.

(e) Local Valley-side Tributaries

These are local tributary systems as opposed to major tributaries each of which also have their own valley-side catena systems. As the major rivers and creeks of arid rangelands are mostly seasonal they are highly variable in flow and typically both flood and ebb are rapid, except in exceptional sequences of follow-up rains. In contrast the extensive, higher rainfall, Top End coastal flat wetlands are flooded deeply or waterlogged for prolonged periods of up to six to eight months (Perry 1960). Hence aridland stations are in a situation of all or nothing for bottomlands revitalisation. It is important therefore to identify the feasibility of enhancing rain recharge of station bottomland pastures by local drainage.

Depending on variations in geological structure and landform, valley-side tributary catenas occur in various patterns from single incised channels to more complex distributary fan forms **(Figure 8a)**. See also figures in Pringle & Tinley 2003, Pringle et al. 2006.

In steep uplands, as in parts of the Kimberley and Pilbara, valley-side tributaries exit from incised valleys or ravines to form triangular shaped alluvial fans **(Figure 8a)**. The apex of the fan lies at the mouth of the valley and the rock detritus is spread out downslope by fingers of braided drainage (distributaries) towards the bottomlands. The coarsest rock debris is deposited nearest the stream exit, at the apex of the fan, with decreasing size detritus downslope to the finest sediments along the fan foot. Where many creeks exit the uplands the alluvial fans become laterally confluent. Flash flood run-off from the uplands can result in one or more of the braided distributaries becoming deeply incised leaving the fan in a perched condition (many examples in the Kimberley and the Top End Victoria River catchment).

On the crystalline shield of the Murchison region the terrain is a gently undulating plainsland with isolated or grouped outcrops of granite or greenstones. The greater area is a more subdued landscape, capped by a sand mantled laterite duricrust, which is the remnant of the old Early Tertiary plateau. This has eroded back, irregularly, to form multitudes of low breakaway escarpments that typify the country. Being sand mantled there are no creeks running from off the top of the plateau remnants.

From off these laterite scarps and their footslopes are catena units of dendritic drainage which converge, then splay, to form alluvial fans that become laterally confluent across the broad faintly inclined pediments. This pattern can be imitated by crossing your hands, wrist on wrist, fingers aligned with the forearms and splayed wide apart. The pediment sheetwash plains typically slope at a very low angle between 1^0 and 7^0 (Twidale 1973; Thomas 1974) down towards the bottomlands of a river, its major tributaries or to saltlakes.

A typical landsystem sequence in the Murchison is: Sherwood/Challenge or Koonmarra from below the plateau edge or breakaways down across the upper to mid-pediment loam, duplex, or stony soils over hardpan, and further downslope the sand mantled fan (also over hardpan) comprising of Wanderrie, Belele, Woodline or Yanganoo landsystems, reaching to the junction with the river plains (e.g. Beringarra Land System). All of these landsystems when in medium to good condition support a high diversity of palatable shrubs (Curry et al. 1994). Hence, they would benefit from a catena grazing strategy that takes advantage of the up and down slope seasonal wetting and drying sequences.

Salt lakes are often surrounded in part by a rim of lunette dunes separating the hypersaline conditions from adjacent floodout alluvial grassland. However, where the rim is eroded by flash floods, stock or vehicle tracks, this provides a direct conduit for runoff loss from the productive terrain and its contamination by salt.

The shallow braided flowlines of intact pediment fans carry upland runoff through to the bottomlands indirectly, recharging any grass soaks and filtering through the lower wanderrie sand part of the fan. However, many fans have become eroded with incised channels so that the slope run-off has cut a gutter across the floodplain and flow is lost directly into the main river channel **(Figure 18 in Field Guide)**. Local knowledge or mapping from Google Earth together with flying and ground truthing can identify which valley slopes are the most favourable as floodplain 'irrigators' and whether they require repair.

(f) Ponding/ Run-on Surfaces

The present day preoccupation with climate change has made wetlands a focus of concern together with over extraction being the greatest threat to their survival (e.g. Rochier et al. 2001). Quite overlooked is that the major threat is from the breaching (unplugging) of the sill responsible for a wetland's existence (Tinley 1977, 1982, 2001; Pringle et al. 2006). Unless 're-plugged', wetlands become extinct and are replaced by dryland systems supporting scrub **(Figures 8a and 14 in Field Guide)**. This erosion process of incised nickpoints cutting upslope happens some where everytime it rains, particularly in the arid rangelands as the most superficial assessment of the field evidence shows.

By reinstating the plugs or sills at key points in the landscape it is possible to prolong the survival and productivity of perennial productive grasslands and wetlands that are not only the prime support for stock but are keystone habitats for wildlife and for the maintenance of biodiversity. What is required is first an understanding of the patterns and processes of drainage in a particular station setting, then the planning of water management that enhances ecologically sustainable productivity. It is not enough to manipulate the pastures and stock alone.

There are many kinds of ponding surfaces formed by a variety of processes in different geoecological settings. These include:

I. Pan-like depressions with flat floors that are round, oval or irregular in shape. Typically saltpans (salinas) and claypans and their successional pioneer plant colonisation stages of chenopods or grasses towards mature stages of bushclumps or thickets **(Figure 18)**.

II. Drainage channels: (a) main channel ponded by sediment blockages deposited by more active tributary channel or from landslides in steep sided valleys; (b) changing positions of delta or fan meandering distributaries leaving the slightly deeper undercut slope pools and interdistributary slack pools isolated. These are subsequently enlarged and rounded-off by swash action (when flooded) and/or deflation (when dry); (c) waterfall and rockbar plunge pools.

III. Dune trough pans, enlarged and rounded-off by swash action and/or deflation (e.g. panfields of Ashburton, Gascoyne and Wooramel river deltas and floodplains).

IV. Coastal barrier-dune pans, lakes and wetlands.

V. Littoral pans (birrida) originating from littoral sandspit enclosed lagoonal stages to isolated landlocked pans. Subsequently segmented by the composite growth of swash-banks and low lunette dunes growing transverse to the formative wind (e.g. southerly winds on Shark Bay's Peron Peninsula berridas).

VI. Solution depressions in calcretes, limestones and laterites.

VII. Gnamma holes and rock basins (e.g. on granite outcrops).

(g) Stream Capture

Stream capture, also known as river capture or river piracy, is a common phenomenon wherever stream and tributary heads on steeper slopes abut drainage on flatter slightly higher terrain. Due to their greater erosiveness, the streams on the steeper slopes cut back headwards (upslope), intercept and capture a drainage branch of the flat terrain on higher ground.

An example from the headwaters of the Gascoyne River is where a small tributary off the main river channel has cut back upslope from a lower level through a saddle between hill ranges aided by a dirt road used since ox-wagon times – to capture the seasonal floodway drainage that used to flow through a series of small seasonal wetlands to the Trenaman Swamp **(Figure 43 in Field Guide)**. When full the swamp overflows back into the Gascoyne River via the Coodewa Creek.

This example indicates what to look for when checking the condition of seasonal wetlands and floodplain areas. Search for signs of a relatively sharp change in direction of the feeder channels away from the outwash or flood area where a pirate channel has cut back from the side of the original flow. Another example of stream capture is that of the Upper Wooramel, which used to be a tributary of the Murchison River via the Muggon Lakes, by the lower Wooramel cutting back upslope (van de Graaff et al. 1977; Denman et al. 1985). Low level flights over the Gascoyne drainage and its upper Lyons tributary, and the upper Wooramel and Murchison rivers – along their watershed boundaries show many signs indicating actual and potential stream capture by the headward erosion of tributaries, as well as the shifting of divides by the active headward erosion of streams on steeper slopes.

The Big Picture: A classic example. From the hundreds of hours we have spent flying at low level to track landscape change across WA, NT and SA rangelands it's the productive run-on perennial tussock grasslands habitats of seasonally impeded drainage that are most under threat of conversion to scrublands, savannas or woodlands by drainage incision at all scales. These run-on habitats are comprised of floodplains, Mitchell/Bluegrass clayplains, alluvial fans, braided drainage, grassy depressions, outwash and sump areas.

While the drainage lines traversing run-on areas remain flat-floored the pure grassland condition is maintained by effective seasonal waterlogging that at the same time precludes woody plant invasion. However, when such drainage becomes incised (channels with banks) accelerating run-off, and hence drying the adjacent terrain, then woody plants are able to invade along the more aerobic banks and convexities.

At the very large scale, as viewed on Google Earth, the developmental stages of these edaphic patterns is clearly expressed by the woody plant succession occurring on the vast Mitchell/Bluegrass clayplains of the Barkly Tableland, Gulf and Channel country. These grasslands are being increasingly encroached by the spread of dendritic tributary heads cutting back upslope that are entraining a soil drying trend and attendant colonisation by woody plants. One example is in the eastern part of the Barkley Tableland where there is a 3-way convergence of incising tributary heads gradually encroaching on each other, with interesting potentials for stream capture, within a 20 km radius of a round lakelet 40 km WNW of Gallipoli Airport (19^0 03' S, 137^0 30' E). These are (a) westward draining creeks to the Tableland lakes, (b) the Lawn Hill and Gregory Rivers draining north-eastwards to the Gulf, and (c) southwards the Georgina River, an affluent of Lake Eyre.

An effective way to inhibit the ongoing spread of scrub is to establish sieve structures in series **(Figures 29b and 37 in Field Guide)**, planted with reeds, to slow incision and the velocity of run-off. Not to stop the flow, but to slow it down and maintain longer effective waterlogging which reinforces grassland dominance and inhibits scrub take–over.

Figure 9. Extinction of an outwash fan fed by run-off from hill ranges.
Eliminated by overgrazing and sheet erosion. Hard and stony water-shedding subsoil exposed at the surface. Note first pioneers of wattle saplings on the thin layer of topsoil still held by the floodplain coolabah gum *(Eucalyptus victrix)* and lone mulgas.

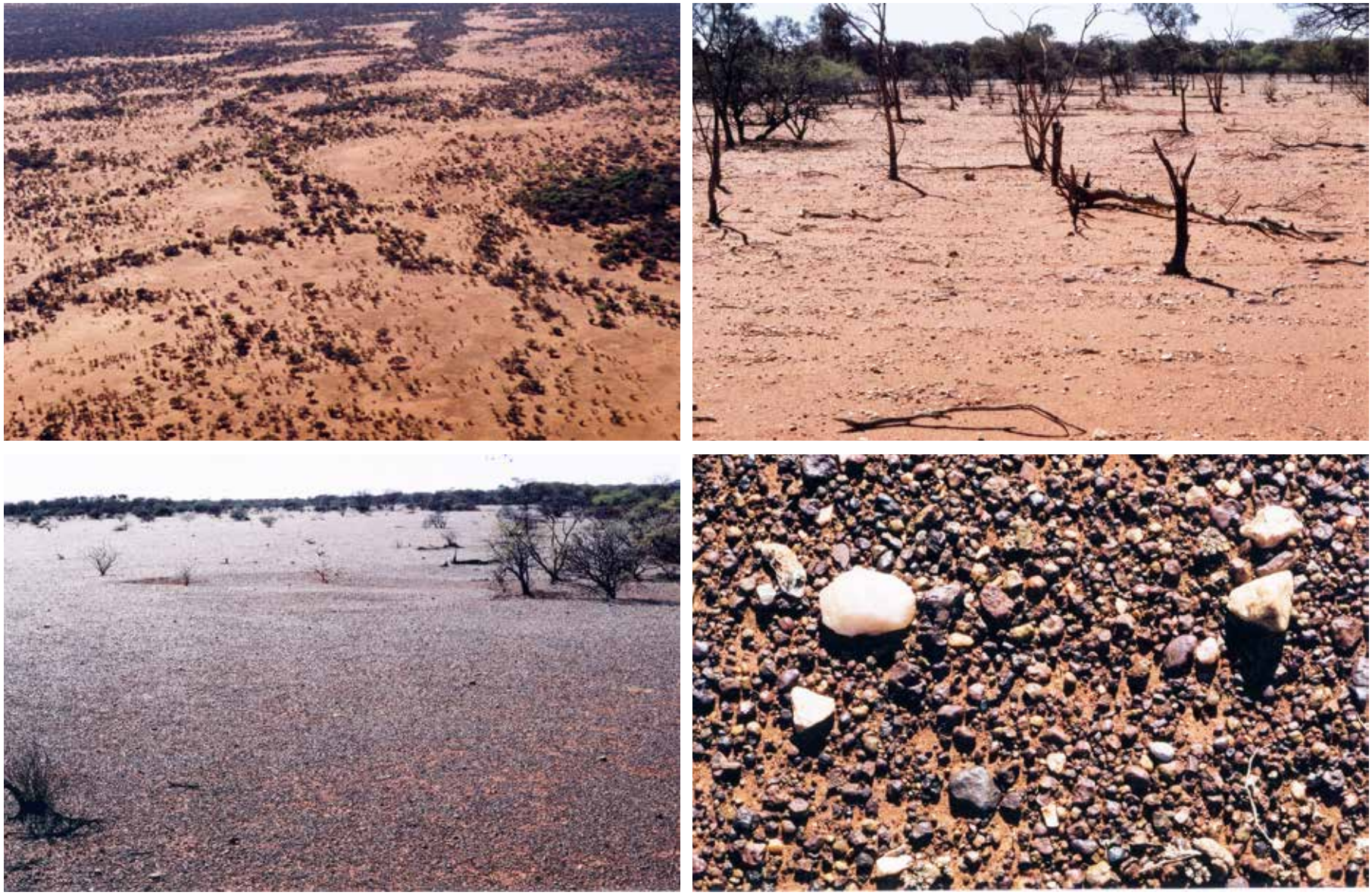


Figure 10. A creek system in the mulga country stripped to a subsoil gibber surface. Murchison Catchment, WA.

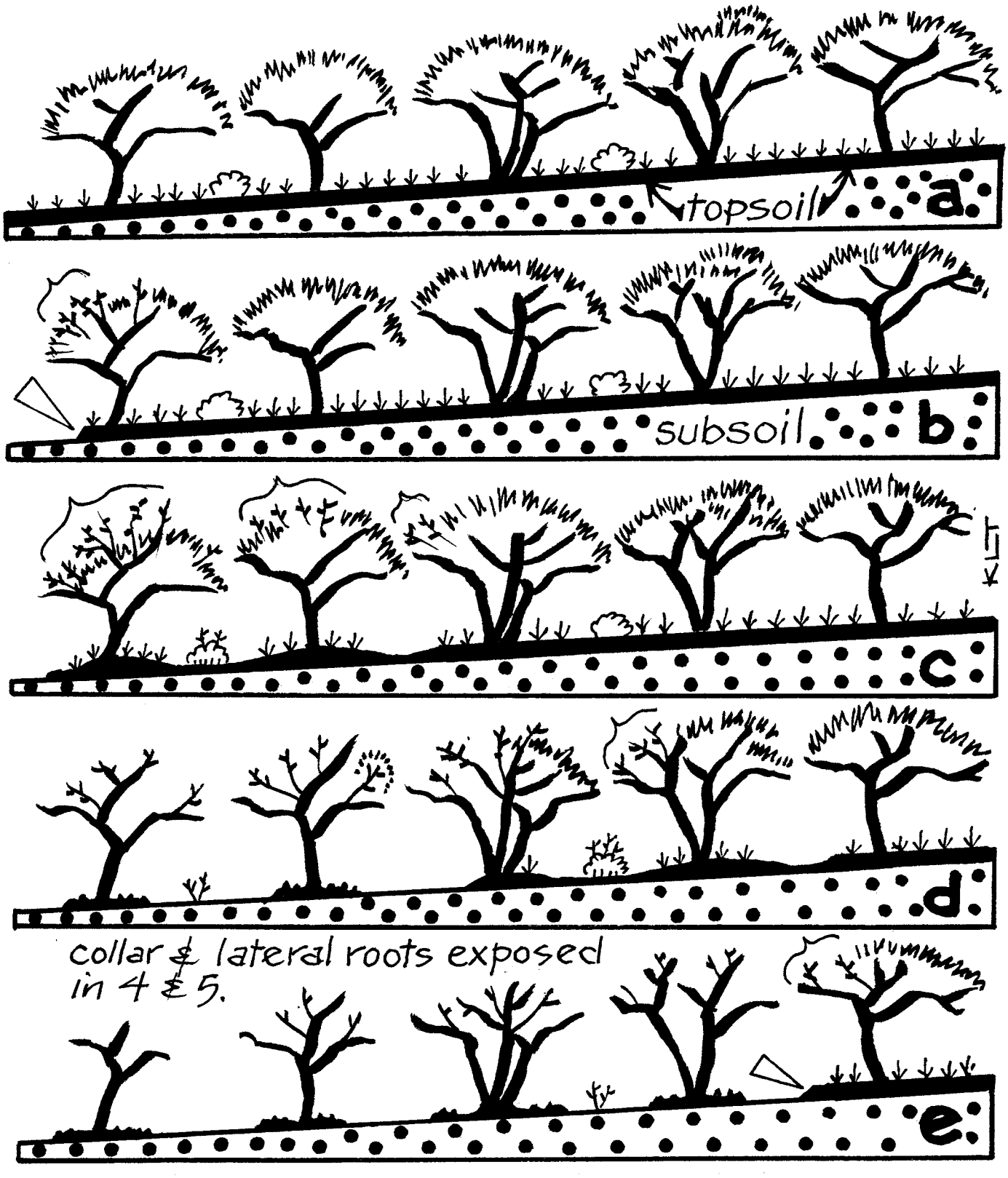


Figure 11. Topsoil stripping/ dieback of woodland and perennial grasses from water starvation.

(a) Intact sandy topsoil. Healthy trees of mulga or myall, shrubs and grasses.

(b) Sheet erosion cutting back upslope, stripping off sandy topsoil. Note crown branches starting to die-off.

(c) As sheet erosion cuts back upslope the topsoil and grasses beneath tree canopies remain longest.

(d) On lower part of slope topsoil stripped exposing tree roots and the compact subsoil. Ongoing die-off of canopy and grasses.

(e) Lower slope mostly dead and dying trees, bare subsoil, no grasses, erosion headcut continues upslope.

(3) Soft Coast Dynamics: Dunes, Deltas, Estuaries and Wetlands

Soft coasts are those composed of unconsolidated sediments, contrasting with hard coasts which are rock-defended. The three major properties which all soft coasts share are (1) their malleability, (2) their temporary stabilisation and protection by plant growth, and (3) their vulnerability to disturbance (seemingly trivial features such as a wrongly sited footpath can have far reaching and large scale erosive effects).

A characteristic feature of soft coasts is the presence of seasonal and perennial freshwater sources at shallow depth, which in the littoral zone occur as a lense overlying saline water. Used since hunter-gatherer times until today these freshwater sources were relied on by man and animals. Today they are often used for watering stock.

These dune or sand aquifers are however sensitive to over abstraction with saline water replacing the fresh; to pollution due to their lateral subsurface extent, and to breaching of the compact sand or clay-loam subsoils of spits or low barrier dunes. Breaching by cattle pads, vehicle tracks or storm seas allows the incursion of sea or saltlake waters that then replace the freshwater aquifer or the seasonal swamps, springs and seeps. In addition many dune blowouts and mobile sand sheets on the coast have their origin from stock dinking sites in dune swales (at the littoral or slightly inland), as exemplified by the Ningaloo Coast.

Coastal stock stations occur along almost the full length of the 2600 km coastline between Shark Bay and King Sound. The only hard rock coast sectors are small outcrops halfway between Roebuck Bay and the De Grey delta, then again at Point Samson, the Burrup Peninsula and the limestone coast of the NW Cape and Ningaloo Coast. The latter, however, also has dunes banked against or over the limestone derived from sandy pocket beaches and seaward curves in the shoreline that catch the strong southerly summer wind driven sand.

Deltas or deltaic estuaries and inlet systems occur at all the larger river mouths in the Kimberley, Pilbara and Gascoyne. From NE to SW these are: The Ord – West Arm outflows that enter Cambridge Gulf; inlets of the NW Kimberley ria coast, and the Fitzroy and Meda-Lennard systems that enter King Sound near Derby; in the Pilbara the de Grey, Turner, Yule, Sherlock, Fortescue, Robe, Cane and Ashburton Rivers. In Shark Bay the Gascoyne and Wooramel Rivers.

This entire coast from the Kimberley to Shark Bay is subject to the impacts of tropical cyclones in one part or another between November and April (January – March peak). Springtide range is from 0.8m in Shark Bay rising up the coast to 1.8m in Exmouth Gulf, 5.5m at Port Hedland and 12m north of Broome.

(a) Coast Buffer Zone

The constant state of flux which characterizes the littoral active zone highlights and emphasises one simple rule in the use of soft coasts. If you want to retain the diversity and viability of their unique resources and simultaneously protect productive lands and developments from damage or destruction, do not allow any development within reach of the littoral active zone. In estuaries this means not only within reach of storm seas, equinox or normal high spring tides, but also that of 50 to 100 year river flood levels. The worst flood damage on coasts occurs when high spring tides coincide with river floods or cyclone or storm sea surge.

Frontal dunes are a major component of the littoral active zone. With beaches and mangroves, they form the most important sea and wind energy dissipating front to the land. They store and yield sand, damping coast recession by maintaining the sand supply to shores and beaches. Their protective buffer shields all landward resources and developments from the direct impact of the elements.

Overgrazing or thinning out of dune vegetation by stock should be prevented as this initiates blowouts and gully slumping. Where mobile dunes pose little or no threat either to natural resources, such as productive soils, forests, wetlands and estuaries, or to infrastructure the option is to leave them alone, i.e. only protect from extraneous disturbances such as trampling and vehicle traffic or from expensive stabilisation schemes.

The single simple rule for the long-term sustainable use of soft coasts is to put all developments out of reach of the littoral active zone. This alone will obviate most, if not all, problems by protecting the diversity and viability of coast resources and at the same time secure developments and property from wasteful damage or destruction (Tinley 1985a, 1985b).

The variety of coast landforms, their dynamics and conservation use is an enormous subject on its own. In this manual the emphasis is on how to use the station soft coasts without causing unnecessary erosion and the unwitting loss of their freshwater lenses.

(b) Dune Type Features on WA Rangeland Coasts

1. **Beach ridge hummock dunes:** Beach parallel primary foredunes. Each ridge line separated by a narrow slack or trough. Typical of advancing or quasi-stable shorelines. On the West Australian coast these dunes are typically colonised by dune spinifex grass *(Spinifex longifolius)* as the frontline stabiliser (e.g. 80 Mile Beach coast sector). Hummock foredunes are highly susceptible to erosion by storm seas and winds, a rising sea level and also from stock trampling on damage by vehicles. When eroded transgressive blowouts result that disrupt or mask the zonation.
2. **Ascending accretion parabolic dunes: beach sand transported landwards and built up against lee** slopes stabilised by plant growth. Some examples occur on the Ningaloo coast in the embayment SE of Cloates Point, and the NW trending shoreline between Quobba Point and the Gascoyne River delta. In the arid climate with strong southerly winds at the hottest and driest time of the year many of this type are converted into migrating parabolic dunes. Dunes composed of beach sand are typically calcareous (pH 8.5), to gypsic from shoreline saltpans, and beige to white in colour.
3. **Migrating hairpin deflation parabolic:** vegetation stabilised forms with bare secondary transverse dunes occur on dirk Hartog Island, Steep Point and Cape Bellefin Peninsulas on Carrang Station. Also between the Ningaloo coast and McLeod Saltlake where the pallid alkaline coast sands abut the older S to N trending linear dunes of red sand.
4. **Linear/longitudinal dunes:** Two major areas of these older Pleistocene red ferruginised sand dunes (pH 6.5) reach the NW coast of Western Australia. In the north between the De Grey River delta and Roebuck Bay are the E to W trending linear dunefields of the Great Sandy Desert that reach their continental endpoint close to 80 Mile Beach and the low rocky shores of Frazier Downs and Thangoo Stations. To the south between the Ashburton and Wooramel Rivers are the NW to N trending linear dunefields of the Carnarvon Coastal Plain. These sands, more compact due to the red oxide coating of sand grains, are mostly stabilised by perennial vegetation, except for isolated blow-outs along their crests, but are bared to the wind for long periods after fire.
5. **Sand Sheets:** Bare mobile sands with broad, flat to gently undulating surface. Common, often with nearby blowouts, on the Ningaloo Coast as near Red Bluff and Norwegian Bay where bare eroding hairpin parabolic dunes have become laterally confluent.
6. **Transverse and Crescentic Dunes:** Dune crests aligned at right angles to the formative winds. These include transverse dunes (e.g. at same location as (2)) and barchan dunes. Barchans are isolated, crescent-shaped with the leading horns at each side facing downwind. typically occurring in groups on firm desert floors where there is a sparse sand supply and a unidirectional wind field. One of the best examples of these rare dunes in WA occurs on Tamala Station, together with barchanoid dunes which are linked barchans.
7. **Blow-out:** Bare elliptic or oval shaped deflation hollow enlarged by wind eddying in otherwise vegetated dunes.

Of these dune types bared migrating hairpin parabolic and sand sheets have the fastest rates of advance, and bare transverse and crescentic dunes relatively the slowest. As clearly shown on Google Earth the Ningaloo Coast has the most widespread erosion of dunefields.

(c) Specific Guidelines

1. First, before any kind of development identify the erosional status or condition of the coast area or site:
   (a) Is the shoreline growing seaward? Indicated by shore-parallel beach ridges of decreasing size seawards.
   (b) Is it 'stable'?
   (c) Is it eroding from wind, sea or rain run-off? Is it being actively cut-back (cliffed).
   (d) Where are the nodes of least change?
   (e) What parts are most vulnerable to the elements and/or stock and human activities?

2. The landward boundary of the littoral active zone can generally be identified by wattle scrub appearing on the dunes or lee slopes. The foredune zone is part of the littoral active zone.

3. Any permanent structures to be set back at least 100m inland of the wooded mid to backdune zone (not measured from the foredune pioneer spinifex grass zone).

4. All footpath and vehicle access onto beaches should be orientated away from the predominant and gale force wind directions.

5. Mobile dunes: First identify the type of dune, e.g. ascending parabolic, hairpin deflation dune, sand sheet, or one of several kinds of traverse dunes (Tinley 1985a). Of these the migrating hairpin deflation dunes and sand sheets have the fastest rates of advance, and transverse dunes relatively the slowest. Only stabilise if they threaten unique habitats or valuable structures. Otherwise leave alone and they will self-stabilise over decades. Stabilise at the two ends of the dune – at its sand source area and at its leading nose. Use cut brushwood and old fishing nets pinned in place. Brush is most effective when positioned with the crowns facing the formative wind and pinned in place. Interplant with dune Spinifex.

6. Estuary and riverbanks require protection from damaging tracks and wrongly sited structures (such as roads, tracks, housing, camp sites and beach access).

7. Stock watering from a littoral dune aquifer – the simple strategy, using a solar pump, is to pipe the water inland to a leeward site, or best of all to an area of limestone rubble. Exclude all stock from the littoral active zone.

8. After a cyclone, check on the condition of the front line buffer of mangroves in low coast parts, such as Roebuck Bay and the salt-couch pastures. If devastated by cyclone or tsunami, replant with mangrove seeds (plantlings) simply by sticking them upright in the mud.

The soft coast buffer zone is a malleable composite made up of beaches, vegetated sand dunes, saltflats, mudflats and mangroves, all of which require to be treated in ways that are creative, best done by observing closely how they function. On soft coasts it is the coral reefs, beaches and beach rock, dunes and mangroves that protect the coast by dissipating the impact of tropical cyclones and tsunamis.

(4) Ecological Succession: Cascading Effects

"You can't step into the same ecosystem twice" (Rivers 1996).

Ecological succession is the sequential replacement process whereby ecosystem or habitat changes are either progressive, regressive or 'to and fro'. The first is an advance from a simple habitat, such as a grassland, into a more complex one such as a woodland or forest. The second is when a more complex system reverses towards an earlier simpler seral stage (such as weed or shrub pioneers) as a result of disturbance influences. A third kind of succession is typified by the fire-induced 'to and fro' shifting sequences in wooded grasslands, including the spinifex. In the aridlands a sequence of exceptional high rain years can result in dense growth of scrub or trees, with rank grasslands. A following drought can result in the death of the denser patches, opening up the cover again and allowing expansion of grass cover possibly aided by the occurrence of intense fires. If followed by heavy stock grazing this can turn the balance back again towards scrub.

The factors affecting successional shifts include: soil moisture, erosion, fire, plant colonisation and maturation, floods, droughts and animal influences (grazing/browsing, seed dispersal, animal irruptions e.g. locusts, rabbits). These can act singly or in various combinations of interactions depending on timing and sequences of events. In combination, each of these factors can affect changes in the others either directly or via feedback loops resulting in kaleidoscopic ecosystem or habitat transformations. Often overlooked in conservation is that geomorphic processes orchestrate landscape function and this is a determinant of biodiversity patterns, structure and composition (Tinley 1977; Pickup 1985; Smith et al. 1993).

However, change can occur in situ without any outside influences. For example, merely the growth maturation of plants can result in a dense canopy of increased shade that in time excludes light demanding plants and animals. This favours the shade tolerant plants thereby changing the structure and composition of the habitat.

Here four main geoecological factors are used as examples:

(a) Erosion.
(b) Overgrazing/overbrowsing.
(c) Fire.
(d) Berry-bird mediated bushclumps.

(a) Erosion

I. Sheet Erosion: fragmentation and coalescence

Best exemplified by the fragmentation and coalescence process of ecosystem or habitat transformation and replacement (Tinley 2001; Pringle & Tinley 2003). This involves two related phenomena:

a) Overgrazing caused baring of the field and ground layers with topsoil stripping **(Figures 9, 10, 11, 13, 14, 15, 17, 21)**.
b) Landscape desiccation from breaching of ponding surfaces by erosion incision and excessive runoff loss of rainwater along gullies, tracks and stock pad 'creeks' **(Figures 7, 8, 22, 23 in Field Guide)**. Well illustrated by White (1998, 2000).

Fragmentation starts with the opening up and depletion of plant ground cover in patches resulting in the baring and erosion of topsoils by sheet and rill erosion (and wind erosion when dry). This is either due to: (1) gully incision which lowers the local base level causing excessive and rapid run off resulting in further erosion and water starvation of the area upslope (i.e. system becomes unplugged); and/or (2) groundcover and fieldlayer depletion due to overgrazing and the break-up of topsoil by hoof action. Either or both of these result in the stripping of friable topsoils exposing the subsoil as the new land surface **(Figure 9)**. As the bare patches enlarge and coalesce they leave decreasing sized fragments of the original soil-plant system **(Figure 15; Figure 13 in Field Guide)**.

The bare patches of textured subsoil exposed at the surface are typically hard and water-shedding. They may become salt-scalded with soft saltpuff patches. Both conditions are inimical to the continued survival of perennial plants (including the chenopod shrubs) which die from water starvation, excess salinity or both.

Continued expansion of the topsoil stripping process becomes self-perpetuating as the area of bare-patch catchments enlarge. Enlargement increases runoff volume and multiplies its erosive power. Eventually, a critical threshold is reached such that erosion continues even under greatly reduced stock numbers. Unless it is arrested naturally, or by intervention, this process sequence continues until the greater part of the affected area is denuded. Denuded scalded flats can remain bare for decades, even without the presence of stock, and exposed stony subsoils develop into gibber surfaces (Curry et al. 1994, photos 2-6, pp. 351-352).

However, even when eroded down to the hardpan, the bare condition is a process stage in landscape development, not an end point. When these denuded flatter surfaces are incised or guttered by rill and gully erosion, the soil moisture conditions and excess salinity are ameliorated by the channeling of rain run-off along the incisions (Pringle & Tinley 2003, Pringle et al. 2006). This provides entry for woody plant colonisation of the denuded area along the erosion gutters, resulting in a stage of progressive succession towards habitat re-diversification by scrub **(Figure 13)**. Expansion of gullies upslope and laterally entrains the spread of scrub cover resulting in a scrub dominated ecosystem replacing the original chenopod or grassland system **(Figures 6, 7, 10, 14 in Field Guide)**.

The major habitats affected are those supported by duplex soils of various kinds. They include floodplains, the chenopod shrublands, bottomland alkaline textured soils, snakewood clays, as well as the mulga loams and wanderrie sand fans over hardpan of lower pediplains **(Figure 13, 14, 15)**. With their thin friable topsoils chenopod shrubland habitats, in even the slightest perched situation above the surrounding terrain, are most susceptible to surface stripping and replacement **(Figure 9 in Field Guide)**.

The sandy topsoil is the critical rain-absorbing surface. Once this is stripped off by sheet erosion, the soil moisture balance is changed toward the xeric from excessive rainwater loss shed by the exposed subsoil. The resultant water starvation causes the demise of the perennial grasses and dieback of scrub, including woodlands of mulga *Acacia aneura* or myall *Acacia papyrocarpa* **(Figure 11)**. Water starvation is also a cause of the demise of perch trees and their bushclumps that have been left on remnant mounds **(Figures 16c & 21)**.

The fragmentation-coalescence process is insidious and can easily escape notice because the full extent and severity of the damage can only be judged from the air. From a ground view perspective the eye is easily tricked by the remnant strips and patches of vegetation as this gives a benign, covered appearance to the landscape. By means of secondary scrub encroachment this regressive succession is turned around progressively towards dominance by 'woody weeds' **(Figure 17)**.

II. Gully Erosion: unplugging and desiccation

Rill and gully erosion are insidious geomorphic processes widespread across rangelands that orchestrate far-reaching changes in ecosystem form, function and composition by altering soil moisture content and edaphic patterns. The incision of soil profiles results in terrain desiccation of what were at least seasonally moist run-on habitats with green grassy growth. Most important is the loss of run-on ponding surfaces due to breaching of their sills by headward erosion, the wetlands then being replaced by scrub thickets (e.g. black mulga *Acacia citrinoviridis,* curara *Acacia tetragonophylla*). In summary, landscape incision means that dry season and drought impacts appear sooner, are more intense and last longer.

Similarly nickpoint incision and guttering of alluvial clay flats (e.g. Mitchell grasslands) and of chenopod shrublands entrains their eventual replacement by scrub. The former by unplugging and hence reducing effective flooding and waterlogging responsible for their pure grassland form and conversion to savanna (Tinley 2001 Fig. 1). The chenopod shrublands by fragmentation and stripping of topsoils, which changes the soil moisture balance towards the xeric entraining an erosional sequence that facilitates colonisation by scrub **(Figure 13 in Field Guide)**. See also Pringle & Tinley 2003; Pringle et al. 2006.

Most depressions may only hold potable water for several months after rains and then dry out, nevertheless together with the more permanent springs, seeps, soaks, deep rock pools and billabongs they are arid zone keystone habitats.

These indispensable moister more dependable and fertile habitat patches ('sweet spots') also function as drought refugia. But with the introduction of foreign herbivores, native animals, such as emus, have had unequal competition for this key arid-land resource (Davies 1973, 1977; Morton 1990; Morton et al. 1995; Stafford Smith & Morton 1990; Reid & Fleming 1992; Recher 1999; White 1998, 2000; Woinarski & Fisher 2002).

Ponding surfaces are typically isolated from one another even within the same floodplain system. However, the 'sweet spots' are an important focus for many animals. These 'sweet spots' become connected to each other by stock pads, particularly the deeper more incised pads of cattle which habitually walk in single file **(Figure 8 in Field Guide)**. When heavy rains occur these pads erode linking up the depressions, breaching their sills and thus causing their demise.

In a similar way pervasive landscape desiccation across the rangelands is caused by the artificial 'rivers' of vehicle tracks, roads, and graded fencelines that act as channels for excessive run-off loss of rainfall and are major causes of drainage dislocation, soil desiccation and of fragmentation and erosion processes **(Figures 6b, 7a, 47, 48 in Field Guide)**.

(b) Overgrazing/ Overbrowsing

The breakdown of habitat form, structure, and plant species composition is in the main caused by the interaction between heavy selective grazing pressure and erosional processes. These result in the opening up and depletion of the ground and field layers below 2m, and hence depletion of recruitment (except of unpalatable species). A self-reinforcing cascade effect is entrained whereby bare areas spread and coalesce causing a simplified array of plants and loss of pastoral integrity.

The preferred woody plant browse species that at present exhibit little to no recruitment across most of the central and southern WA rangelands include: *Acacia sibilans, Alectryon oleifolius, Brachychiton gregorii, Eremophila longifolia, E. oldfieldii, Erythrina vespertilio, Pittosporum phylliraeoides, Psydrax (Canthium* 3 spp.*), Santalum* (4 spp.); and *Acacia grasbyi and Scaevola spinescens* in some areas (authors' field records from ground traverses of central and southern WA rangelands).

Where permanent waterpoints are 3-5 km apart grazing pressure is hugely exacerbated as the grazing and trampling zones (piospheres) of 3km radius are touching to overlapping **(Figure 12)**. As this figure shows, a major cause of landscape degradation in many parts of the Gascoyne-Carnarvon-Murchison-Yalgoo-Sandstone region is that the permanent artificial waterpoints are too close together *for the continuous grazing habit* **(Figure 15, 16, 17)**. Under continuous grazing plant community fragmentation and linking up of degradation results in landscape morbidity and the down spiral of biodiversity (Burnside et al. 1990; Landsberg et al. 1997; James et al. 1999; Lindenmayer & Fischer 2006). Where there is some form of rotational grazing, high density waterpoints may not be a cause of degradation.

There is growing realisation that grazing strategies that involve specifically planned recovery (rest) periods are not only more ecologically beneficial, they can also allow net higher stocking of quality animal production. Degraded lands almost certainly require this recovery/rest-based approach (Purvis 1986, 2004; Savory & Butterfield 1999).

The typical habitat simplification process caused by a legacy of overgrazing by sheep is the selective depletion of the palatable lower shrub (<2m) and groundlayer plants, particularly the palatable perennial grasses. Brennan (2005) has drawn attention to the far reaching effects on grazing animals' nutritional status and productivity where grasses and annuals (carbohydrate energy foods) are depleted by overgrazing and replaced by a predominance of woody plants (protein foods). Increasing conversion to cattle on many stations has further compounded the problem. Widespread depredations by feral goat populations of over 2 million (Woolnough & Martin 2003), has had far reaching impacts which are generally underestimated **(Figure 13)**. Large areas of the mid - lower Gascoyne-Lyndon catchment, that once supported chenopods, perennial grassland, snakewood *(Acacia xiphophylla)* and wait-a while *(Acacia cuspidifolia)*, now have dense low shrublands of unpalatable eremophilas *(E. cuneifolia, E. fraseri)* and cassias *(Senna helmsii, S. luersseni)* in even aged/size stands.

In response to the exceptional flood events of summer 2010-11 across the Gascoyne River catchment, a WA Department of Agriculture rangeland and soil assessment team undertook an aerial and ground survey of its impact during June-August 2011 (Waddell et al. 2012). They found that the widespread erosion and degradation recorded some fifty years previous (Lightfoot 1961; Wilcox & McKinnon 1972) of the best grazing lands is still ongoing and exacerbated by the advent of extreme flood events. Until station management includes erosion control and run-off calming with lower stock numbers in a grazing rotation, erosion and woody weed encroachment is bound to continue, with the loss of most run-on pastures.

Over many large areas all that is left is the out-of-reach top layer scrub. A 'standing dead' predicament due to the absence of younger replacement sequences, and the elimination or suppression of any recruitment except for unpalatable 'woody weeds' **(Figure 12 in Field Guide)**. Congruent with this opening up of vegetation and baring of the ground is the loss of water absorbent sandy surfaces, the litter layer and the important cryptogamic crust (Eldridge & Greene 1994; Belnap 2003).

'Canary in the mine' indicators of scrubland habitat change are birds that forage and/or nest mostly within 2m of the ground of which 83 species occur in the central WA rangelands **(Table 3)**. Assessment of the conservation status of arid zone birds across Australia by Reid and Fleming (1992) show those groups most adversely affected by habitat disintegration include: (a) the three small passerine families of wrens, thornbills and their allies, and the quail-thrushes, (b) cockatoos, parrots, doves and pigeons amongst the non-passerines, and (c) those associated with chenopod shrubland habitats (e.g. redthroat, white-winged fairy wren and rufous fieldwren). In the central region of WA, spotted nightjar and bush stone-curlew (both ground nesting) are rare to extremely rare in our experience, as are the bustard (bush turkey) in grass-depleted scrublands (Grice et al. 1986).

Reid and Fleming (1992) make the point that in the absence of widespread regeneration of ground cover and field layer "the next major drought could cause accelerated declines and extinctions" (see also Recher 1999). On the other hand species such as the banded plover, inland dotterel, Australian pratincole and Richards pipit, which show preference for bared, sparsely vegetated terrain, have hugely expanded habitat areas (Saunders & Curry 1990).

The cascading effects of the habitat impoverishment processes reach through changes in structure, composition, productivity and hence carrying capacity, to impact on economic and socio-cultural viability and wellbeing.

> *"Lack of systemic wisdom is always punished.*
> *If you fight the ecology of a system, you lose –*
> *especially if you win" (Gregory Bateson).*

(c) Fire

A 'to and fro' fire induced selective succession is imposed over time on wooded grassy savannas enhancing either the grass layer or the woody strata at the expense of the other depending on the coincidental timing of a number of factors. These factors include height and density of the grass layer, seasonal timing and weather, fire intensity, fire frequency, soil moisture status (Walter 1964), post fire conditions, and impact or absence of grazing pressure.

Long-term burning experiments in the moist to mesic ecologically equivalent miombo savanna woodlands of Africa (Trapnell 1959) and the monsoon savanna woodlands of northern Australia (Russell-Smith 1995; Bradstock et al. 2012) show an increase of woody plants from no burning and cool early dry season burns. The latter also weakens the perennial grasses which at this time have not completed the translocation of nutrients to their root store for the dry season. Conversely, hot late dry season burns damage or kill woody plants in the peak of their pre-rain spring flush and results in an expansion and dominance of mostly fire tolerant/dependent taller and coarser grasses such as the Top End sorghums *(Sarga* spp.*)* and elsewhere spinifex *(Triodia* spp.*)*.

Grasslands and savannas bared by intense late night season fires, where closely followed by thunderstorm or cyclone rain deluges, are also causes of major erosion events.

Like overgrazing, fire can, under certain conditions and seasonal timing, entrain a progressive succession from the predominance of grassland towards woodland or thicket (e.g. Russell-Smith 1995). At the thicket end of the sequence (excluding wattles) where there is little to no grass, fire can be excluded. Where hot burns are frequent and large scale, transformation is from wooded savanna to predominantly grassland, with any woody coppice survivors at or below the grass canopy level, as occurs in the ongoing expansion of spinifex grassland in the arid zone (Latz 2007). Over time this leads to changing habitat structure, species composition, and diversity between the successional extremes of a grassland, or dense woodland/thicket whose plant components may end up comprised of only one or a few pyrophytic dominants.

The highly flammable spinifex hummock grasslands exhibit a return succession in which annuals and short-lived perennials flourish during the several seasons following the advent of fire before the spinifex re-asserts a near total dominance of cover (Burbidge 1943; Suijdendorp 1967; Latz 1995, 2007). Depending when rains occur, the post-fire succession is mainly *Asteraceae* and other herbs with winter rains, and of grasses with summer rains. In droughts burnt spinifex landscapes are subject to wind erosion (Latz 2007) as they can remain bare for a year or more. In wooded grassy terrain a shifting threshold of dominance occurs between spinifex (or wanderrie grass swards) and wattles for example, depending on the timing of fire and rains. The development of a dense scrub canopy from maturation of coppice regrowth or the mass germination of wattle seedlings, typically exhibits an even aged/size structure and single species dominance.

With the widespread reduction of traditional Aboriginal mosaic or patch burning, the uncontrolled grass fires that occur over vast areas (e.g. Google Earth images of the Great Sandy Desert and its northern margin) are suspected to be a main cause of the disarray amongst seed eating birds across northern Australia (Woinarski 1990, Franklin 1999). In complete contrast the traditional Aboriginal mosaic patch burns throughout the year has been proved by detailed follow-up field studies to have all round benefits ecologically. These include maintenance of high flora and fauna diversity, and survival of fire-sensitive plant communities such as native cypress pine and heaths (Yibarbuk et al. 2001).

The introduced tufted buffelgrass *(Cenchrus ciliaris)* is invading many habitats such as riparian woodland, chenopod shrubland and bottomland bushclump habitats that naturally would rarely if ever experience fire. When ungrazed, rank buffelgrass poses a major fire threat to the above habitats but is itself revitalized and thus becomes the predominant cover as has occurred on a calcareous sand plateau south of the Cape Range (Ningaloo Coast), where the woody plants have mostly been eliminated. The negative influence of buffelgrass on native flora and fauna is recorded from Western Australia and Queensland (e.g. Franks 2002). However, the pastoralist, Bob Purvis, on his Woodgreen station north of Alice Springs found that when he restored healthy drainage functioning on his station the native perennial grasses came back and buffel became confined to the drier bunds (Purvis 2004).

Table 3.

Ground and Near-Ground Foraging and/or Nesting Birds in Central Western Australia

Non-aquatic birds that forage and/or nest mostly within 2m of the ground (as determined from Pizzey & Doyle 1983; Johnstone & Storr 1998, 2004; Ron Johnstone pers.com. WA Museum) i.e. within the shrub and ground layers. This is the habitat most susceptible to modification by stock, feral goats, fire, erosion and within reach of fox predation. (Nomenclature after Johnstone 2001).

Casuariidae
- Emu

Megapodiidae
- Malleefowl

Phasianidae
- Stubble Quail
- Brown Quail

Otidae
- Australian Bustard

Rallidae
- Black-tailed Native Hen

Turnicidae
- Painted Button Quail
- Little Button Quail

Burhinidae
- Bush stone-curlew

Charadriidae
- Banded Plover
- Inland Dotterel

Glareolidae
- Australian Pratincole

Columbidae
- Peaceful Dove
- Diamond Dove
- Bar-shouldered Dove
- Common Bronzewing
- Crested Pigeon
- Spinifex Pigeon

Psittacidae
- Pink Cockatoo
- Red-tailed Black Cockatoo
- Bourke's Parrot
- Budgerigar
- Cockatiel
- Elegant Parrot
- Galah
- Little Corella
- Mulga Parrot
- *Night Parrot
- Port Lincoln Parrot
- Princess Parrot
- Scarlet-chested Parrot

Cuculidae
- Black-eared Cuckoo

Centropodidae
- **Pheasant Coucal

Caprimulgidae
- Spotted Nightjar

Halcyonidae
- Red-backed Kingfisher

Meropidae
- Rainbow Bee-eater

Climacteridae
- Rufous Tree-creeper
- White-browed Tree-creeper

Maluridae
- Splendid Wren
- Variegated Wren
- Blue and White Wren
- Rufous-crowned Emu-wren
- Striated Grass-wren
- Thick-billed Grass-wren

Pardalotidae
- Redbrowed Pardalote

Acanthizidae
- White-browed Scrubwren
- Redthroat
- Fieldwren
- Broadtailed Thornbill
- Chestnut-rumped Thornbill
- Slate-backed Thornbill
- Yellow-rumped Thornbill
- Samphire Thornbill
- Banded Whiteface
- Southern Whiteface

Meliphagidae
- Black Honeyeater
- Grey-headed Honeyeater
- Yellow-fronted Honeyeater
- White-fronted honeyeater
- Crimson Chat
- Orange Chat
- White-fronted Chat

Petroicidae
- Hooded Robin
- Red-capped Robin
- Southern Scrub-robin

Pomatostomadae
- Grey-crowned Babbler
- White-browed Babbler

Cinclosomatidae
- Chiming Wedgebill
- Chestnut Quail-thrush
- Cinnamon Quail-thrush

Pachycephalidae
- Crested Bellbird

Dicruridae
- Magpie Lark

Campephagidae
- Ground Cuckoo-shrike

Cracticidae
- Australian Magpie

Sylviidae
- Little Grassbird
- Spinifex Bird
- Rufous Songlark
- Brown Songlark

Alaudidae
- Singing Bushlark

Passeridae
- Painted Firefinch
- Starfinch
- Zebra Finch

Motacillidae
- Australian Pipit

*Now considered extinct in pastoral areas at least.

**Moist tropical species with western south range limit coastal to Minilya River in recent past. Range now contracted back northwards to Ashburton River.

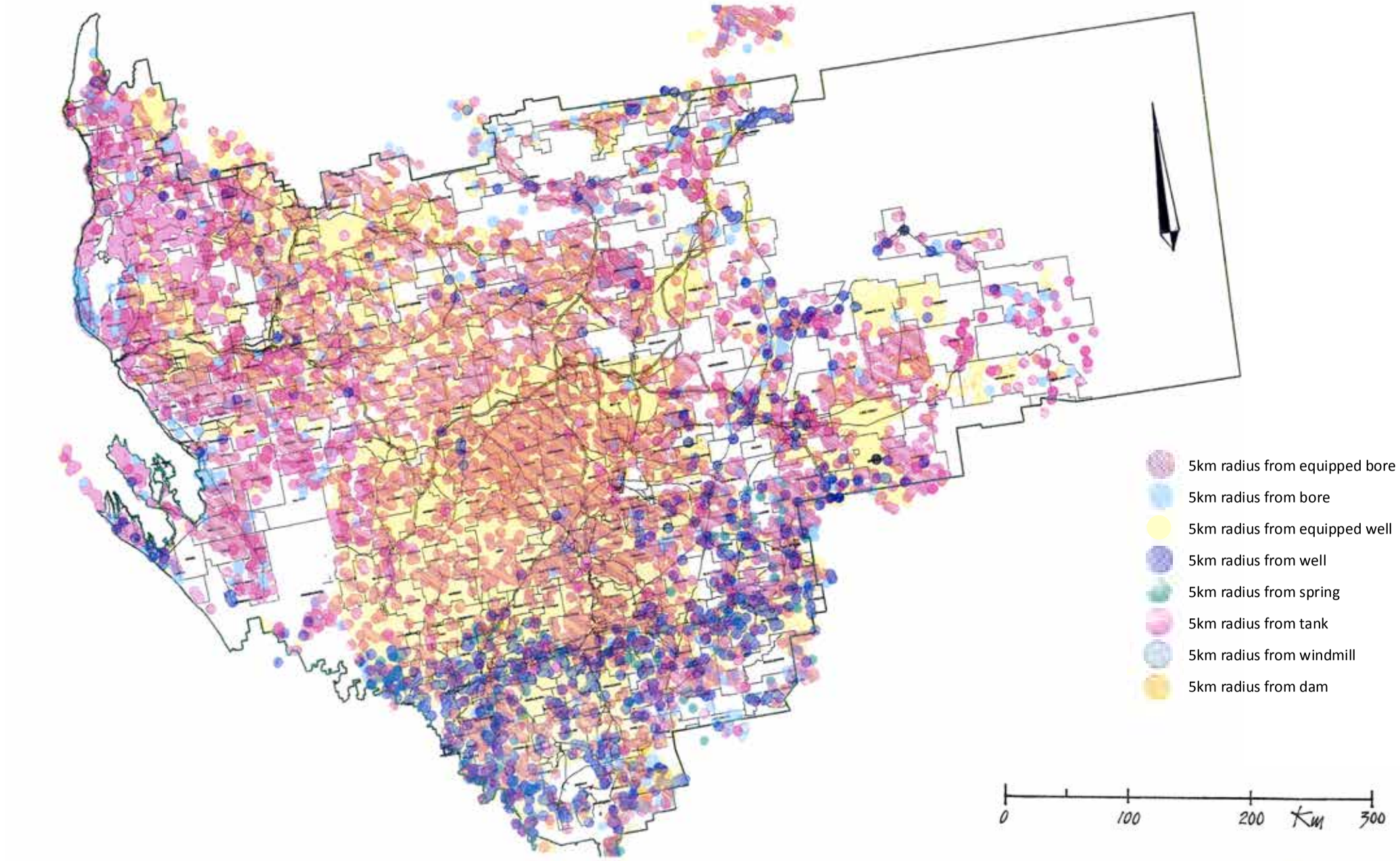


Figure 12. High density of artificial waterpoints in the Gascoyne-Carnarvon-Murchison Region. (GIS by Damien Shepherd DAFWA 2004).

Figure 13. Erosion and fragmentation of breakaway footslopes from longterm depredations by high sheep and feral goat numbers (all photos from the same escarpment in the Murchison):

(a) Breakaway with two initial saline subsoil patches that likely once supported chenopod shrubland on duplex clays. The wooded footslope below the scarp is typical where the red sand mantle over the laterite is naturally eroded off the edge of the top of the breakaway by rain, and deposited over the saline duplex of the footslope below.

(b) Expansion of the initial topsoil stripped patches on the footslopes involves the whole tributary unit of dendritic drainage off the breakaway. Dense woodland on sandplain mantling the laterite is predominantly wanyu *Acacia ramulosa*, with mulga, sandpine and mallees (2-8m height).

(c) Lateral coalescence of drainage heads below the scarp. Surface stripped areas white, leaving pale grey areas of remnant topsoil held by the biennial grass with rosette growth form *Eragrostis dielsii*. Note widened sand stripped margin above the scarp exposing laterite at the surface. Once an important habitat for heaths, this is highly impacted by goats.

(d) Almost total elimination of the footslope and pediment topsoils exposing scalded gritty-clay subsoils at the surface with remnant patches of the biennial grass. Scrub remaining on red sand veneered footslope (bottom right), and colonising the gully incisions. Note laterite remnant of the old Tertiary planation surface stripped of its red sand mantle, and the actively eroding scarp.

a.

b.

c.

Figure 14. Fragmentation of a wanderrie sand fan in the lower pediment zone.

(a) Grey areas of surviving perennial wanderrie tufted grassland on sand.

(b) Receding from sheet erosion and being replaced by bare compact subsoil over hardpan.

(c) Bare areas colonized by even-aged stands of turpentine bush *(Eremophila fraseri)*, with mulga (dark scrub) along the edges. The palatable perennial wanderrie grasses include: *Eragrosis eriopoda, Eragrostis lanipes, Monochather paradoxus and Thyridolepis mitchelliana.*

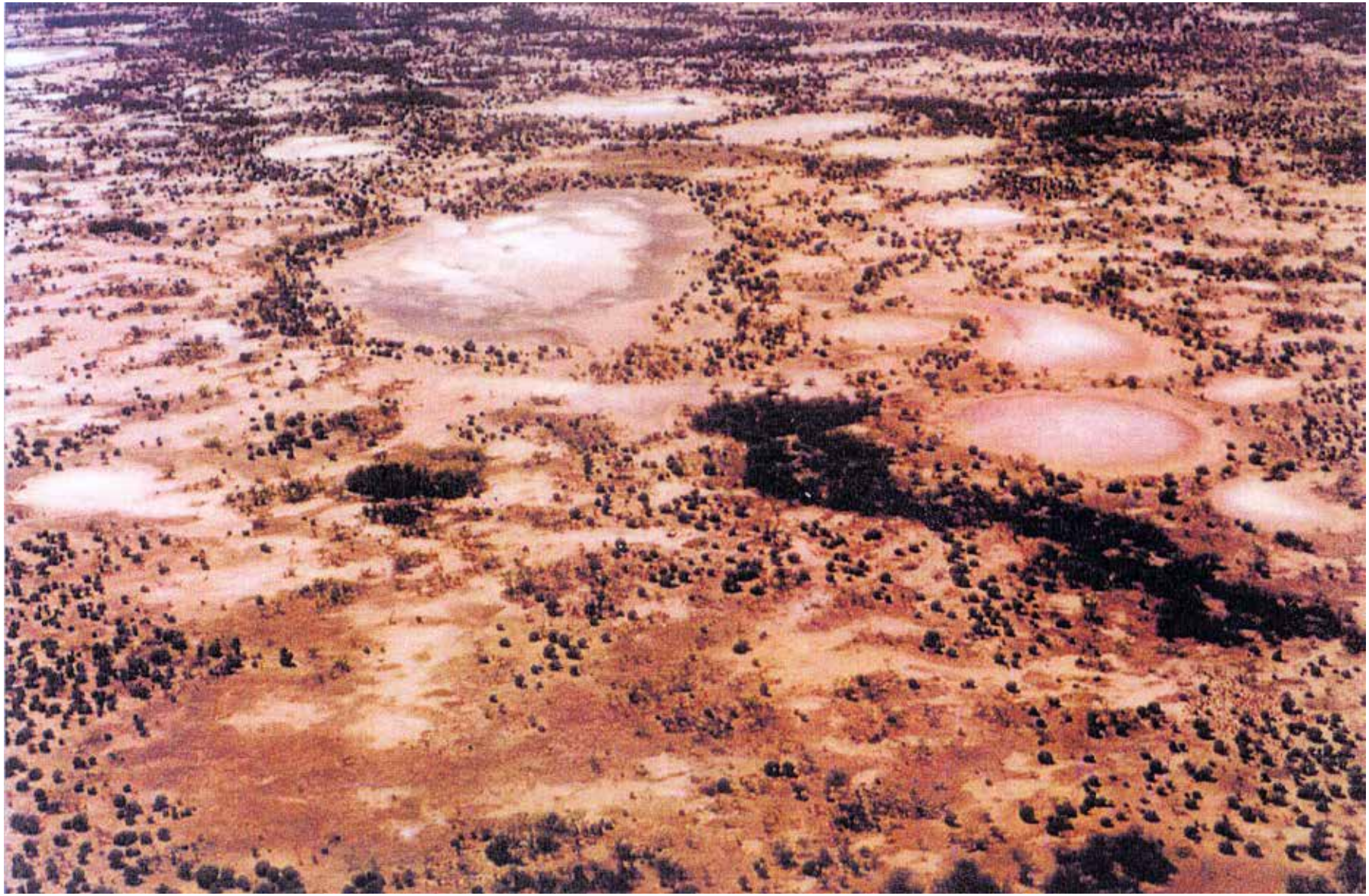


Figure 15. Overgrazing sheet erosion fragmentation of river plains with duplex soils and numerous claypans.
Originally bluebush, tussock grassland and riverine mixed shrubland with chenopods. Roderick landsystem, Murchison River catchment.
Question: If viewed only from ground level, where would any quadrat samples validate the dimensions, connectivity and trend of the degradation?

a.

b.

c.

Figure 16. Grazing of seasonal swamps on alluvial clays.
Tussock grassland of swamp grass *Eriachne benthamii,* claypan grass *E. flaccida* and Roeburne grass *Eragrostis xerophila.* (a) lightly grazed, (b) heavily grazed to the butt, (c) overgrazed degradation to a weed stage. Note surviving berry-thickets on mounds of remnant topsoil.

a.

b.

Figure 17. A Murchison River tributary floodplain (Beringarra LS).

(a) Duplex soils, clays and gilgai alluvia that once supported perennial grassland and islands of chenopods or mixed browse. Bared by long-term overgrazing and subsequently scoured by extreme flood events. A system highly susceptible to erosion and scalding.

(b) Nearby, the return plant succession on the bared subsoils is dominated by scrub with some annual grasses. The grove of coolabah *(Eucalyptus victrix)* trees surround a flood pan.

a.

b.

c.

Figure 18. Claypan plant succession in the Gascoyne and Wooramel river deltas (Delta, Sable and Target LS):
(a) Claypans initially bare. First colonisers include a robust rhizomatous grass *Eragrostis australasica*, swamp bluebush *Chenopodium auricomum,* and run-on perennial grasses such as *Eriachne* species and the large lignum shrub *Muehlenbeckia florulenta*. On more saline claypans the erect samphire *Tecticornia verrucosa* is first, later colonised by chenopod shrubland (top of photo b).

(b) Over time many claypans acquire a veneer of soil with litter and seeds washed and blown in from surrounding scrub on duplex soils. Perennial grasses include the two *Cenchrus* spp. and shrub initials of *Eremophila mackinlayi,* the arillate chenopods, and berry shrubs (e.g. *Scaevola* spp.) Followed by small trees *(Eremophila longifolia)*, together with arillate scrub (e.g. *Acacia coriacea, A.sclerosperma, A. tetragonophylla, Alectryon oleifolius*); with *Acacia subtessarogona* and A.*victoriae*.

(c) Maturation and enlargement of berry thickets. Note large patches of stripped topsoils, particularly around pan rims from stock usage.

a.

b.

c.

d.

Figure 19. Sheetwash and berry-bird mediated habitat patterns.

(a) Snakewood *Acacia xiphophylla.*

(b) Coolabah *(Eucalyptus victrix)*

(c) Dot pattern of berry thickets around a claypan.

(d) Sheetwash formed contour stripe patterns of wooded groves and broader bare intergroves on pediplains. This photo an example of eroding and fragmenting grove stripes (sheetwash direction from top right to lower left of photo). The process here: runoff from the bare intergroves has washed through the overgrazed wooded grove stripes and deposited the grove sand as an outwash along the downslope margin of the grove stripes. This then was colonised by annual windgrass *Aristida contorta.*

Note: berry bushclumps last longest in the erosion process, remaining as island clumps.

(d) Berry-bird Mediated Thickets

The pervasive dot pattern of bushclumps and thickets that occur across many landscapes is due to the dispersal of berry seeds by birds **(Figure 19)**. This is a progressive or advance succession that comes about from the growth of berry and arillate seeds voided by birds when perched on trees and shrubs.

Brightly coloured berries, or seeds with conspicuous coloured arils that are typically displayed whilst still attached to the parent plant, are identified as adaptations for primary dispersal by birds (Ridley 1930; van de Pijl 1969). Seeds with small pale yellowish or greyish-white elaiosomes and that drop to the ground are typical of those dispersed by ants. However, both are also subject to transport by wind, water or other ground-foraging animals. Both berry birds and ants are directed dispersal agents. Birds void the seeds at perch sites (Ridley 1930; Tinley 1977; Forde 1986; Tester et al. 1987), and the ants carry the seeds to their nests (Berg 1975; Davidson & Morton 1984). Emu are also important dispersal agents of seeds usually excreting them between plant clumps and often near water (Davies 1978).

Although mostly small in size and generally absent in unwooded habitats, except next to termitaria or fence-poles, the bird-mediated bushclumps are the major archipelago-like habitat (ecotope) across both arid and moist regions of Australia (authors' field records). In size bushclumps are variable, from several small plants beneath the perch through to dense tall thickets composed of up to eight or more species **(Figure 19; Field Guide Figure 11)**.

Of the 68 woody berry plants species recorded by us from central and southern WA 45 (66%) are browsed by ungulates, making bushclumps an important protein source habitat. Five (8%) of the clump components have wind-dispersed seeds (also carried by water) that lodge against the clump obstruction and mature within the perch tree's protection as do the others ('nurse effect'). Examples include these highly palatable plants: the perennial grass *Austrostipa elegantissima*, and shrubs – *Maireana thesioides, Ptilotus divaricata* and *Sida calyxhymenia.*

A total of 68 berry plant species (including arillate acacias) from 26 Families have been recorded by the authors from across the Pilbara to Nullarbor arid rangelands in WA **(Table 4)**. A total of 135 acacias *(Mimosacae)* whose seeds have arils or elaiosomes occur in WA (Bruce Maslin, WA Herbarium pers. com.). The berry or berry-like and arillate forms vary in size from 2-3mm in certain chenopods (e.g. *Rhagodia* spp.) to 20-30mm diameter in quandong *Santalum acuminatum.*

Across the arid lands two conspicuous, widespread omnivorous birds, spiny-cheeked honeyeater *Acanthagenys rufogularis* and singing honeyeater *Lichenostomus virescens* **(Figure 20)**, are important seed dispersers that are found in, or move through, virtually all habitats. As they both pollinate and disperse the seeds of berry trees, such as *Eremophila longifolia,* their role is referred to as doubly-ornithochorous (Forde 1986).

Berry-bird bushclumps are formed beneath tree and shrub canopies in the majority of vegetation types including chenopod shrubland, sandpine, and in the fire-prone spinifex grasslands with desert sheoak *Allocasuarina decaisneana,* eucalypt trees or mallees as overstorey. Bushclump archipelagoes are also common on calcareous coast sands and dunes, on alkaline duplex soils as exemplified by snakewood *Acacia xiphophylla* scrub savanna, beneath York gum *Eucalyptus loxophleba* woodland on clay soils, coolabahs *E. victrix* on floodplain alluvia, and river gum *(E. camaldulensis)* **(Figure 20; and Figure 11 in Field Guide)**.

Common perch-trees are the nitrogen-fixing acacias (wattles), many of which are re-seeders in contrast to the bushclump components which are re-sprouters and thus have contrasting responses to disturbance. The former are particularly prone to death from fire, and water starvation where porous topsoils have been stripped exposing a water-shedding subsoil **(Figure 21)**, or where sheetwash recharge has been blocked by roads **(Figure 47 in Field Guide)**.

Particular features: In contrast to the interpatch areas undisturbed bushclumps and thickets have (a) an enriched ecodiverse make-up, (b) enhanced litter and humus accumulation hence higher nutrient status of nitrogen and phosphorus, (c) deeper penetration of rainwater and stem run-off from the concentration of woody plants, (d) a mostly permanent shade hence moderate extremes of microclimate, enabling support of an adder-tongue *Ophioglossum* sp. and fern *Cheilanthes* sp. (e) a protective role for the palatable protein feed beneath nitrogen-fixing wattle or casuarinas trees. Bushclumps are however susceptible to opening-up damage by cattle seeking shade.

This progressive bird-mediated succession results in changes of cover, pattern and structure, function, composition, productivity and resilience. Bushclump presence and condition in pastoral country is used as one of the indicators of habitat health and integrity (Pringle & Tinley 2001; Russell 2007; Waddell et al. 2010 pp 338-347 and their excellent photo record). It is an enrichment process in archipelagoes of fertile patches that enhance and multiply favourable conditions for the dispersers and other bushclump dependents as well as the carrying capacity for ungulates. As such they are keystone ecotopes in the rangelands. These archipelago ecotopes may remain separate or, under favourable conditions, expand and coalesce into larger patches (as they do on the Shark Bay peninsulas). The expansion of bushclumps can be encouraged by establishing pole-perches protruding from bands of brushwood linkages between fragmented vegetation. In this way attracting berry birds to assist in repair of overgrazed lands.

SPINY-CHEEKED HONEYEATER ***Acanthagenys rufogularis*** 22–26 cm

Dark-tipped deep pink bill; pink gape; eye blue; long dark mask; white/yellow brush-streak down neck; throat/upperbreast apricot–buff. Inland birds paler. **Immature:** cheek-stripe yellow. Singles, pairs, parties: calls from dead branches, wires. Flight undulating, shows *whitish rump/tail-tip*. Makes steep high song-flight. **Voice:** gurgling; 'widit, widit-ear, peer-peer, peer-peer', etc., or 'wee-ear, chonk-chonk'. Song-flight: 'give-the-boy-a-go', repeated. Alarm-call, 'tok!'; mimics. **Habitat:** drier inland/coastal woodlands, scrubs; fruiting plants, incl. mistletoe; gardens. **Breeds:** June–Jan. **Nest:** flimsy cup of grass, she oak needles, spiders' web; lined with fur, grass, wool; in hanging foliage, 2–3 m high. **Eggs:** 2–3; white to cream–buff, spotted, blotched dark brown, in cap. **Range and Status:** mainland Aust., *except* (1) tropical n. Aust. (but n. to Gulf lowlands); (2) coastal se. and far sw. Aust. Reaches e. coast at points n. to Townsville (Q); extends coastally e. to Port Phillip region, casual Gippsland Lakes (Vic.); Kangaroo I. (SA). Uncommon. Sedentary; nomadic.

SINGING HONEYEATER ***Lichenostomus virescens*** 18–22 cm

Other names: Grape-eater or Grey Peter.

Fawn–grey: bold black mask runs down neck; thinner line of yellow below ends in broad silvery white mark. Solitary, pugnacious: feeds in low, often isolated, flowering, berried shrubs; raids soft fruits, grapes. **Similar species:** Yellow-faced; Varied, Mangrove Honeyeaters. **Voice:** dry 'prrit prrit prrit', running, machinegun-like 'crik-crikit-crikit-crikit'; scratchy, peevish 'scree'. **Habitat:** coastal dune vegetation; inland mulga, mallee scrubs; isolated shrubs, thickets on watercourses; orchards, vineyards, gardens. **Breeds:** July–Feb., or after rain in n. **Nest:** untidy cup of grass, plant-stems, spiders' web; lined with hair, fur, plant-down; in shrub 1–4 m high. **Eggs:** 2–3; pink–white to yellow–buff, sparsely to thickly spotted red–brown. **Range and Status:** Aust. mainland and drier islands. Absent from, or sparse on, e. coast *except* c. Rockhampton–Townsville (Q). Sparse C. York Pen. (Q), Top End (NT), Kimberley (WA). Extends e. along Vic. coast to c. Westernport–Gippsland Lakes. Common in suitable habitat. Sedentary.

Figure 20. Berry birds: the two most conspicuous berry seed dispersers across the aridlands. Both birds forage in most habitats. From Pizzey & Knight 1999.

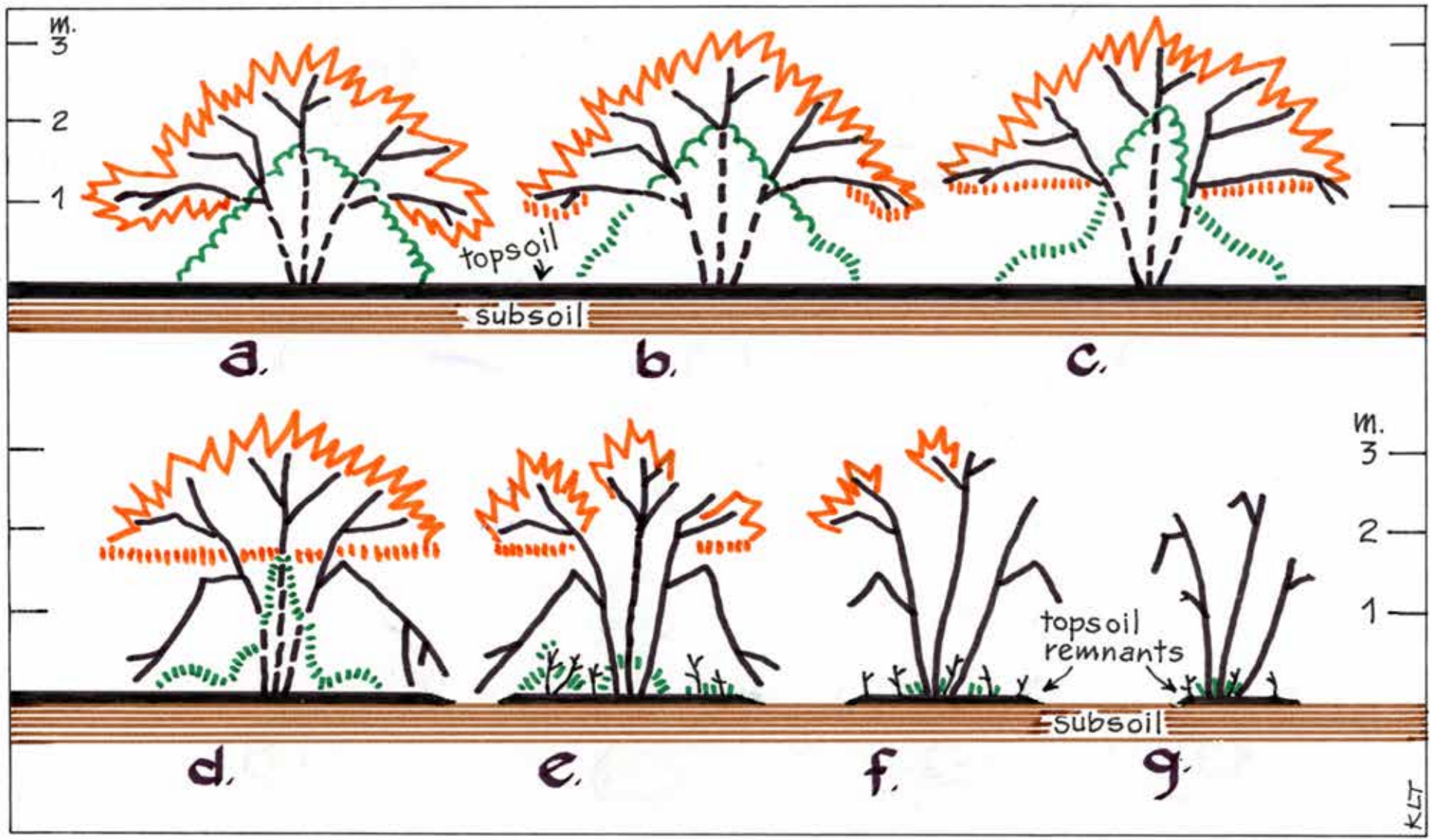


Figure 21. Perch-base berry bushclumps: browsing/topsoil stripping/water starvation sequence:

(a) Unbrowsed, (b) Light browse, (c) Medium browse, (d) Heavy browse: beginning of topsoil stripping around the bushclump. (e) Excessive browse: topsoil remnants confined to protection of bushclump. Perch tree starts to die back. (f) Topsoil stripping and consequent water starvation continues. Perch tree in demise. Berry bushes browsed to the ground. (g) Perch tree dead. Few berry bushes just surviving on topsoil remnants.

Table 4. Partial List of Australian Arid Biome Berry Plants (mainly central WA and NT)

(* plants browsed by stock and feral ungulates).

(1) APOCYNACEAE
- * Alyxia buxifolia
- * Carissa lanceolata

(2) BORAGINACEAE
- * Ehretia saligna

(3) CAPPARIDACEAE
- * Capparis lasiantha
- * C. mitchellii
- * C. spinosa

(4) CHENOPODIACEAE
- * Chenopdium gaudichaudianum
- * Einadia nutans
- * Enchylaena tomentosa
- * Rhagodia crassifolia
- * R. drummondii
- * R. eremaea
- * R. latifolia
- * R. preissii
- * R. spinescens
- * R. ulicina

(5) CHLOANTHACEAE
- * Spartothamnella teucriiflora

(6) CUCURBITACEAE
- Mukia maderaspetana

(7) EUPHORBIACEAE
- * Fluggea virosa
- * Mallotus nesophilus
- * Phyllanthus reticulatus

(8) GOODENIACEAE
- * Scaevola spinescens
- * S. tomentosa

(9) MENISPERMACEAE
- Tinaspora smilacina

(10) MIMOSACEAE
- Acacia adsurgens
- A. ampliceps
- A. bivenosa
- A. colletioides
- * A. coriacea
- A. cowleana
- A. elachantha
- A. holosericea
- * A. ligulata
- A. nyssophylla
- * A. oswaldii
- A. roycei
- * A. sclerosperma
- A. sibina
- A. tenuissima
- * A. tetragonophylla

(11) MORACEAE
- * Ficus opposita
- F. platypoda

(12) MYOPORACEAE
- * Eremophila longifolia
- Myoporum montanum

(13) OLEACEAE
- Jasminum calcarium
- * J. didymum

(14) PAPILIONOIDEAE
- * Erythrina vespertilio

(15) PHORMIACEAE
- Dianella revoluta

(16) PITTOSPORACEAE
- * Pittosporum phylliraeoides

(17) PROTEACEAE
- Persoonia coriacea

(18) RUBIACEAE
- * Canthium attenuatum
- * C. latifolium
- * C. lineare

(19) SANTALACEAE
- * Exocarpos aphyllus
- * E. sparteus
- * Santalum acuminatum
- * S. lanceolatum
- * S. murrayanum
- * S. spicatum

(20) SAPINDACEAE
- * Alectryon oleifolius

(21) SOLANACEAE
- * Lycium australe
- * Solanum orbiculatum

(22) STERCULIACEAE
- * Brachychiton gregorii

(23) SURIANACEAE
- * Stylobasium spathulatum

(24) THYMELAEACEAE
- * Pimelia microcephala

(25) VERBENACEAE
- * Clerodendrum floribundum
- C. tomentosum

(26) ZYGOPHYLACEAE
- Nitraria billardierei

Total Listed:
Plant Families = 26
Plant Genera = 35
Plant Species = 68

* Browsed = 47 spp.

Unlisted Hemiparasitic Berry Plants
Loranthaceae = 10 spp.
Lauraceae = 1 sp.

(5) Ecojunction Benchmark Paddocks

Land "health is a concept requiring a reference point or baseline against which a relative assessment is made of change with which to compare the condition and trend of the grazed areas." (Rapport et al. 1998; Campbell & Hacker 2000; Whitehead et al. 2000; Morgan 2001).

A characteristic feature in the rangelands is that exclosures are not routinely used in the grazing areas to judge grazing pressure, topsoil condition, changes in plant species composition or trend. Where exclosures have been erected they have mostly been unable to keep out kangaroos or rabbits. With time most have been left to disintegrate.

Ecojunction areas are where a number of different ecosystems or landsystems, at all scales, meet and/or overlap along a transition zone interface of varying widths known as the ecotone. Where ecotones are broadley overlapping they may be more diverse in habitat structure and species composition than the abutting systems on either side – termed ecotonal enrichment. Using the map overlay technique the core areas of highest diversity on each station are identified by finding where the largest number of landsystems abut in a 5 km radius or 10 x 10 km paddock size area (5 x 5 km on small stations). **Table 1**.

A Benchmark Paddock positioned over the highest ecojunction area would function as a station's core reference area for land and pasture management learning, comparisons, and monitoring where most systems of a station are represented in one paddock size area. The ecojunction 10 x 10 km of highest landsystem diversity typically occupies a very small area of the total station and of those parts that are best to second-best for sheep and cattle grazing, as shown by the example of Ninghan Station in the Paynes Find District of WA **(Figure 22)**.

The Benchmark Paddock would thus contain the following features: (1) highest landsystem diversity on the station, (2) high to very high number of ecotones (junction and overlap zones of the different systems) and hence, (3) potentially highest biodiversity area on the station, (4) multiple interactions between the different systems, (5) differential responses and recovery to extremes, (6) a seed source area, and (7) it provides indicators for gauging success and effectiveness of ecologically sustainable pastoral management (ESP) and for tracking change.

The importance of landsystems as proxy for biodiversity planning is supported by detailed studies in NW NSW by a team of 12 scientists (Oliver et al. 2004) who concluded "that conservation area networks that represent landsystem diversity are also likely to be representative of biodiversity".

Ideally (1) a Benchmark Paddock would be fenced off (with a fencing structure which allows access to emu, for example), with total mammal grazing control and a series of fixed-point (GPS) photo records repeated about every 3 years, and after extreme events (including fire). *Ideally* (2) each and every station should have their own Benchmark Paddock as a core management instruction and witness area. However, in some situations short term heavy grazing may be needed to reduce fire impact.

If various families wanted to develop one or more of the many kinds of nature-based enterprises the Benchmark Paddock would be an ideal diverse natural area to run them. However, the position of Benchmark Paddocks in the landscape does not necessarily always contain the most spectacular scenery on the station.

The overwhelming importance of Benchmark Paddocks as a yardstick for ecologically sustainable pastoralism (ESP), landscape and biodiversity conservation should warrant it eligible for government (or private conservation agency) funding to cover the fencing costs.

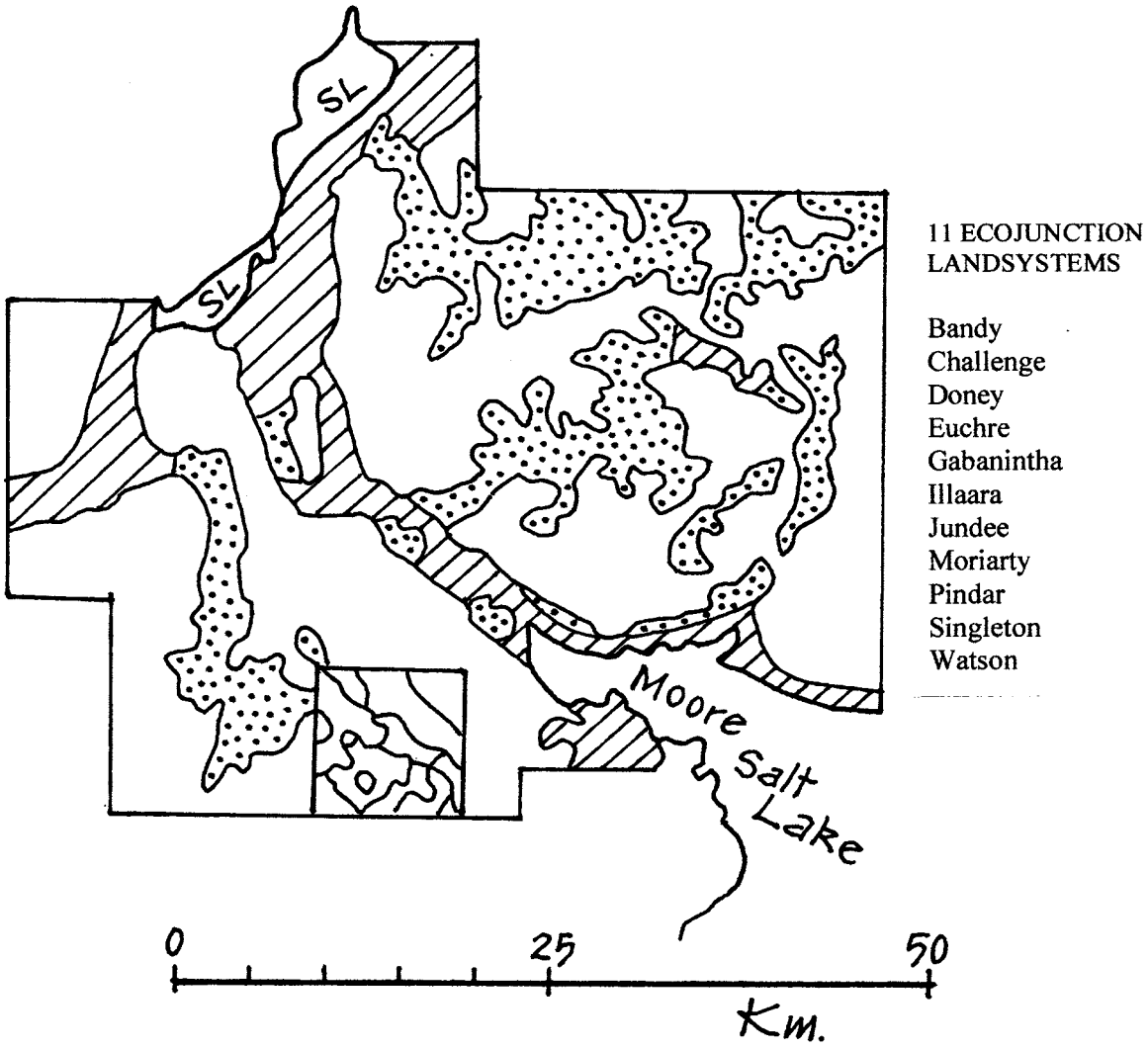


Figure **Ecojunction Benchmark Paddock**

Highest ecojunction node within a 10 x 10km paddock size area that includes 11 landsystems (example from Ninghan Station, Yalgoo Interzone).
* Note minimal area of Benchmark Paddock compared to size of station.

Best pasture landsystems for sheep and cattle.

Second best.

Figure 22. Ecojunction Benchmark Paddock.

Highest ecojunction node within a 10 x 10km paddock size area that includes 11 landsystems (example from Ninghan Station, Yalgoo Interzone, WA). *Note minimal area of Benchmark Paddock compared to size of station.*

[D] Landscape Repair

The Rangeland Rehydration 1: Field Guide contains basic information regarding where and how to undertake various approaches to Landscape Repair. This brief section is targeted specifically at facilitators supporting pastoralists. Of primary importance is that any repair project is integrated with other aspects of pastoral management such that repair works are not regarded as a silver bullet. Rather, repair work should be part of a catchment management initiative, be it a major community initiative or a local tributary within a single paddock. Some key issues that might be integrated include water point placement and management, matching stocking rate to feed-on-offer, adequate recovery periods, feral animals, weeds and so forth. This integrated approach is what is required for the ecological repair of rangelands.

Readers who have already had experience and success with landscape repair will likely have developed their own preferred methods. However, the high diversity of drainage situations means that methods can be refined by comparing them with those in our Field Guide (Handbook 1) and the records of earlier approaches and examples. These include: Alchin 2005; Andrews 2006, 2008; Ludwig & Tongway 1996 (II); Payne et al., 2004b; Thomson & Morrissey 1996; Tongway & Ludwig 1996 (I); Tongway & Ludwig 2011.

Below are some key issues to consider based on lessons already learnt through EMU and ESRM:

I. **A small starting project:** Generally start with a small, conveniently located initiative with which to build early skills and confidence in diagnosing and repairing rangeland dehydration issues.

II. **Select priority systems based on the map overlay information:** Pastoralists will often take you to their worst degraded areas and ask what can be done. Avoid falling into the trap of starting the intentionally holistic EMU approach with a pilot project focused on resuscitating subsoils – as is done by conventional soil conservation approaches. Projects should only be developed once the baseline mapping, fly-over and field traverses have been completed and the "bang for the buck" areas become obvious (these are rarely the same areas the pastoralist was initially concerned about).

III. **Collaborative planning and building confidence:** It is fundamentally important that the pastoralists own and lead their projects, even if technical advice is relied upon. Remember that the main objective is to build the pastoralists skill and confidence in managing rangeland rehydration themselves and within their local "knowledge network". Avoid doing rehydration projects for pastoralists, do them togetherwith pastoralists and plan in your redundancy in the process.

IV. **Sequencing and scheduling works:** Whenever there is even a slight doubt about finishing a set of works, make sure that the works are sequenced such that it doesn't matter if the job isn't completed. If this can't be achieved, don't start! Also leave enough time for careful final tidying up before starting a new intervention and don't start the next one if it will be a "rush job". Trying to squeeze one last intervention in can be a recipe for disaster. Always have plenty of time available to do the job properly.

V. **Accessing additional expertise:** Particularly in big and complex rehydration projects, it may be necessary to access expert support from somebody with proven experience in whatever field is required. This requirement for external expertise can be reduced by holding training days within active district groups. Management of tracks is usually a good starting point because it is both a rehydration issue and an issue critical to station management.

VI. **Pastoralist ownership and responsibilities:** It is important that pastoralists regard projects as their own and realise that most work needs initial "nip and tuck" repairs and occasional ongoing repairs and maintenance. For instance if a filter structure has not been stabilised it may need maintenance or the planting of bulky grasses or sedges **(Figures 19b, 20b, 30, 31 in Field Guide)**.

VII. **Planning and budgeting beyond initial works:** related to the above points, project budgets should allow some ongoing management and the NRM organisation supporting a regional programme should have a discretionary fund at hand for major repairs where external expertise has been used (and hence responsibility for repairs should be shared with participating pastoralists).

VIII. **Clearances:** Ensure that necessary clearances are obtained and perhaps work with relevant Government organisations to simplify and facilitate the gaining of clearances. Issues that may require some form of clearance include native vegetation clearance, registered heritage values and surface water blocking activities, e.g. building of dams or weirs.

IX. **Managing contractors:** contractors often have bad habits (e.g. grader drivers who "dig the bladein" instead of skimming the surface). It is important that contractors are supervised and aware of the requirements and standards you expect to be maintained. Also, explain carefully the completion criteria; what the area must look like when the job is done. It can be helpful to write these down, with diagrams as appropriate so that there is no confusion and the contractor can check as the work is done.

X. **Recording the journey:** too often works are done without adequate 'before' photos or video footage. It is useful to record the whole process not only for the pastoralist's records but also to build a library of photographs and footage of various approaches and techniques for future use (e.g. training manuals and videos). Careful cataloguing of such information makes it easy to access when one needs it for a field day, for reference to check changes, conference presentation or manuals and videos.

XI. **Demonstration sites:** it is important to have a series of successful rehydration interventions as demonstration sites in a variety of landscapes. These sites each require a short record for the benefit of others of how long it took to establish, the equipment/materials used, the number of people involved, and the costs.

XII. **Opportunities for interesting and meaningful work in healing country:** Rangelands NRM WA have an inspiring and positive array of land care and recovery programs that involve local people and communities. The projects include weed control, mangrove conservation, traditional mosaic burning, feral herbivore management and many others. We would like to suggest one more fundamental task for healing the rangelands and coastal areas – the stabilisation of erosion at key sites.

[E] Ecology in the Round

To restore a catchment you need to have first hand knowledge of it as an ever-changing system of many nuances. The experience of walking in the rain on flat terrain allows one to discern first hand the subtleties of flow, erosion and deposition. Experiencing the profound contrast between rain hitting bare ground or ground covered by grass, or the effect of tiny 'waterfalls' gouging out soil and cutting back gully heads. By visiting the same sites a couple of days after rain stops you can see how fast the land dries up, where moisture remains, and how deep it penetrated into different soils compared to what was measured in the rain gauge.

Any restorative project needs this kind of personal involvement in the landscape and an overview of understanding in a whole drainage unit context. In particular where are the critical control points and the key areas of change, and what are the impinging factors caused by tributaries and changes in slope. Without this sort of understanding the most careful land repair exercise can have unintended consequences. A keen response to healing country requires a keen understanding of how it functions. Innovative and explorative improvisation is often called for due to the particularities of place, hence the importance of drainage repair demonstration sites as examples.

Personal observations in getting to know a system also need time for reflection – time to talk it through, to consider the alternatives of where and how before jumping into action. "The first law of ecology is - everything is connected to everything else, hence we can never do only one thing" (Garret Hardin).

It is vital for facilitators to have a field notebook for recording and drawing observations (a palm-held computer is not enough on its own). Recording in the field sounds, scents, colours and to stop and draw the outline shapes of different plants, a wattle, bauhenia, saltbush or grass seed head helps to enliven all the senses and one's perception of what is there. Are there day and night changes in wind direction? What are the differing seasonal characteristics? What kinds of fruits, pods and seeds do the woody plants have? Can I read the night sky?

Relax into a stream of keen awareness, curiosity and interest – there is no rush. Be open and interested in everything but do not set you mind either for or against anything. On-the-ground contextual learning leads to knowing where and how different rock types, soils, plants, animals and human activities are affecting the functioning of an area or site. In these ways one comes to understand and connect with an ecological awareness that is more than just facts but a sensibility of being part of the landscape (Devall & Sessions 1985; Goldsmith 1988; Sewall 1995; Shapiro 1995; Lipton & Bhaerman 2009). As experiences with water and mineral dowsing show everything has an energy field, or spirit, as understood by traditional cultures – whether a rock, plant, animal or human, a place, or the Earth – it is possible to intuitively tap into this field.

"Although ecology may be treated as science, its greater overriding wisdom is universal. That wisdom can be approached mathematically, chemically, or it can be danced or told as myth. A deep sense of engagement with the landscape, with profound connections to surroundings and natural processes central to life" (Paul Shepard 1969).

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[G] Appendix 1: Definitions and Explanations

Base-levels: Two kinds of base-levels regulate fluvial processes: (a) Erosion base-level is the lowest level to which a stream channel can incise its bed. Erosion base-levels are primary (e.g. sea level, saltlake or dunefield), secondary (e.g. a rock bar), and tertiary or local base-levels. (b) Deposition base-level is the highest level to which a sediment deposit can be built (e.g. crest of a rock-bar or dam). Gully

Benchmark Paddock: A fenced or unfenced, mostly stock-free undergrazed area, where the highest number of landsystems abut (ecojunction) within a 5 km radius or 10 x 10 paddock size area. A reference area where responses of the different landsystems to extreme events and grazing can be compared and understood in terms of landscape function, biodiversity conservation, phenology and grazing strategies. May need short term heavy grazing to reduce the fire factor.

'Berry-birds': Birds attracted to feed on typically brightly coloured berries or berry-like drupes and arillate seeds. Seeds are voided at perch sites and can grow into bushclumps, thickets, or forest.

Biodiversity: The geographic diversity of terrestrial, freshwater and marine ecosystems. The diversity of their composition, structure and functioning. The number and variety of their plants and animals - their habitats and their genes (expanded IUCN definition).

Blow-outs: Where there are gaps in plant cover of vegetated dunes, or bared by fire or overgrazing, elliptic, oval or irregularly shaped deflation hollows are formed and enlarged by wind eddying. In high watertable terrain blowouts stabilise when they reach wet soil.

Catena: A repeat sequence of soils and their biotic components which vary with relief and drainage. (a) A topo-catena sequence is represented by a terrain profile from a hill-top to a valley bottom. (b) An alluvio-catena is a horizontal or faint slope sequence of depositionally differentiated soils. (c) Drainage or valley-side catena is a repeat pattern expressed typically by the valley-side tributaries of rivers. From upland to valley the pattern comprises of (i) a source area of dendritic streams that (ii) converge near or below the footslope, and (iii) spread out into a depositional fan.

Conservation: The wise use of the Earth's resources by humanity by protecting their capacity for self-renewal through ecologically sustainable practices (author unknown).

Critical Control Points in Drainage: Those sites, areas or situations where minimal intervention can have far reaching positive responses that entrain the natural processes to do most of the repair work.

Drainage/Fluvial Ecosystem: Surface drainage catchments or basins are geomorphic units bound by their watershed divides. These contain a size hierarchy of tributary sub-unit compartments each in turn partially enclosed by divides. Each unit contains all the landscape processes and responses between the physical, biotic and human actions that occur within it.

Drainage and Ponding Sills: A sill in a drainage process context is any low convexity, either natural or artificial, that is formative and temporarily protective of floodplain and wetland of all kinds from extinction by incision from upstream migrating gullies. Unless of rock, many sills forming local base levels are composed of unconsolidated detritus held in place by plant growth and are hence mutable. An artificial stone or concrete wall deeply embedded to obviate undercutting, at right angles across flow, with less than about 15cm sticking out above ground level. The fundamental being to form a permanent local base level to block the upstream migration of gully incision (similar to a rock bar). It does not block free flow like a weir does.

Ecology: The relationships and interactions between the physical and living components of the environment, and between organisms themselves.

Ecosystem: A natural geo-ecological system occurring in definable geographic process unit areas, and characterised by particular physical and biotic features.

Ecotone/Edge Effect/Tension Zone: The shifting transition or overlap zone of influence or interaction between two different ecological communities (e.g. between forest and grassland). Ecotones vary in width and have their own characteristic features in addition to sharing components from the abutting communities.

Hence, ecotones can be zones of greater species diversity than the adjacent communities. Sharp edged ecotones are typically caused by an abrupt change in edaphic conditions, and/or due to high frequency of fire, overgrazing or susceptibility to erosion. An expanding ecotone of 'today' can become the major ecosystem of 'tomorrow'. The ecotone attributes noted here emphasise the importance of ecojunction areas for understanding in what ways the station's landsystems function and interact, as each are likely to have different responses to extreme events.

Ecojunctions: Areas where different ecosystems or landsystems abut, containing representative areas of each type plus their ecotones. The highest number of systems within a chosen radius, say 5km or a 10x10km paddock area at a map scale of 1km=1cm, indicates potentially high or highest ecological diversity. At broad survey scales a 25 or 50km radius is a valuable first indicator of potential highest biodiversity areas.

Environment: Everything external to an organism or group of organisms.

Exclosure: An area, of varying size, fenced off to exclude herbivores. Used as a visual reference site against which a relative assessment is made in comparison to the surrounding grazed areas. Or to protect rare flora, fauna, habitat or as a seed source area (cf. Benchmark Paddock).

Geomorphology: Study of the origin and development of landforms and their formative processes.

Geomorphic Reciprocal: Process shapes form, and changing form shapes process.

Habitat: The place in which a plant, animal or a community lives; characterised by its particular physical and biotic make up.

Keystones: A keystone ecosystem or habitat is one that is indispensable for a particular reason, such as high carrying capacity run-on grasslands and seasonal wetlands and/or permanent springs and seeps in aridlands. Or one that contains and supports a complex vegetation structure and/or a unique array of species e.g. forest patches in savannas. Keystone plants and animals are those that have a disproportionately important role in affecting ecosystem structure, composition and function e.g. fig trees in native forests, frugivores, goats and large herds of stock or game. For further examples: see "Secrets of our Living Planet" BBC Documentary Film presented by Chris Packham.

Landscape Diversity=Terrestrial Ecodiversity: Embracing the total geo-biotic diversity of all kinds of ecosystems at all scales – their geography, landforms, geology, soils, water-types, biotic composition, patterns and processes.

Land Systems: A catena approach to identifying, mapping and managing landscape units. "An area or group of areas throughout which there is a recurring pattern of topography, soils and vegetation" (Christian & Stewart 1953).

Pan: Broad flat-floored depression, pan-like, oval or irregular in shape. Seasonally or irregularly wetted or flooded. Ponded by a low rim or sill formed by deposition of sediment rounding their edges by swash action when flooded and by deflation when dry. Types of pan include: (a) Claypan: bare hard-surfaced red/brown non-cracking clay (pH neutral to slightly acid). (b) Saltpan: bare salt encrusted surface. (c) Grassy and wooded pans: where pan surfaces become covered by sandy or clayey soil deposits from their surroundings they are colonised by perennial grasses, shrubs and thickets **(Figure 18)**.

Pediment: A low gradient sheetwash plain of weathered material that slopes gently (1 – 7°) down towards the bottomland from the foot of an upland. The lower pediment often a sand-mantled fan.

Resilience: "Capacity of the land to withstand and recover from drought, floods, fire or human mismanagement" (FAO, United Nations). "The amount of change a system can undergo and remain within the same regime – essentially retaining the same function, structure and feedbacks (response diversity)" Walker & Salt 2006.

Savanna: Wooded grasslands or grassy woodlands occurring between the equator and the subtropics/warm temperate overlap.

(a) Arid scrub (trees 5-10m) savanna, thickets, grasslands, and deserts between the 500 and 125mm isohyets, e.g. greater central Australia, Kalahari-Namibia, Sahel Zone of Sahara, Indian Thar Desert. Extreme Desert (per-arid) below the 125mm isohyet.

(b) Moist savanna woodlands/open forest. Tall trees (10-20m) over a grass groundlayer, with dry-forest patches > 1000mm isohyet. e.g. Eucalypt grassy woodlands of monsoon belt across Top End Australia, equivalent in Africa to the Caesalpiniaceous (Miombo) woodlands. A mesic transitional zone between arid and moist savannas (approx. between 500-600mm and 1000mm isohyet).

Soil Moisture Balance (SMB): The amount of moisture required to support and maintain a particular kind of plant community in a state of dynamic equilibrium or balance. Anything that shifts this balance over time towards drier or wetter conditions entrains inexorable changes in the plant cover's physiognomy and species make-up as adjustments to the altered edaphic condition develop.

Six Intrinsic Unifying Ecological Properties:

1. Everything is connected to everything else.
2. Everything must go somewhere (a place, habitat).
3. Nature knows best.
4. Everything and every being has a role to play (in the healthy function of Planet Earth).
5. Ever changing/Dynamic
6. Symbiotic/Synergistic

(For examples see "Secrets of our Living Planet" BBC Documentary Film, presented by Chris Packham).

Succession: Sequential replacement changes of land surfaces, vegetation and fauna in response to environmental flux, such as those induced by geoecological processes and/or in-situ developments. Examples (1) Land surfaces: topsoil truncation exposing the subsoil as the new land surface or gullied plainsland. (2) Alluvial grasslands on base-rich gley soils transformed to solonetzic aridosol scrubland due to cessation of annual flooding. (3) Vegetation Structure/Floral and Faunal composition: (a) changes brought on by undisturbed maturation development of plant community, taller and denser, favourable to shade tolerant plants and animals of closed habitats such as thicket and forest. (b) High diversity of plants forming a variety of habitats – converted by overgrazing and browsing to a simplified structure of out of reach canopy trees only (the topfeed middle and recruitment layers now missing), replacement of palatable plants by unpalatable species and annuals. (c) Changes in soil moisture balance – such as that caused by incision and drying out of run-on areas and plainslands. Or, the converse – damped or blocked runoff, or clearing of woodland, or an overspread of alluvium or sand that raises soil moisture to mesic or waterlogged conditions.

Sustainability: "Sustainability is based on a simple principle: Everything that we need for our survival and wellbeing depends, either directly or indirectly, on our natural environment. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations" (EPA of the USA). "The key to sustainability lies in enhancing the resilience of social-ecological systems, not in optimising isolated components of the system - by maintaining a system's capacity to absorb disturbances without a regime shift" (Walker & Salt 2006).

Vegetation Stripe Pattern: Pediment sheetwash deposited litter and sand trains in stripes parallel to the contour and colonized by plants (stripe groves). Each stripe alternates with broader bands of bare ground (intergrove) that forms each grove's local catchment. Hence the tiger or zebra-like pattern.

Woody Plants (Macquarie Dictionary, Oxford English Dictionary):
Tree: a perennial woody plant, typically single-stemmed (some trees have forms with several trunks).
Scrub: Small or low trees; or stunted trees (e.g. mulga country 3-7m canopy height, emergents 8-10m).
Shrub: multi-stemmed perennial woody plant branching from below or near ground level, so has no clear trunk (e.g. <1.5-3m in the arid, <5m in Top End).
Shrublet: small shrubs, e.g. chenopods, frankenia.