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HOW EROSIONAL HISTORY AFFECTS THE DEVELOPMENT OF PASTURE AND SCRUB - A CENTRAL AUSTRALIAN CASE STUDY

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ABSTRACT

We investigated the vegetation of two active floodplains and associated stable landforms over a period of seven years, paying particular attention to the types of soil surfaces on which the plants grew. Long-lived trees were established on stable surfaces laid down in 700-year-old superfloods and during much older activity. Less stable surfaces supported shorter-lived trees and shrubs, while the most active surfaces were entirely treeless.

Many pasture species also showed preference for particular erosional surfaces. For example, the presence of *Sclerolaena bicornis* distinguished active floodplains from stable sand sheets, while *S. divaricata* separated severely eroded from less damaged floodplains. The dynamics of pasture composition over the seven-year period were also different for contrasting surfaces. Interestingly, erosion of stable surfaces did not change pasture dynamics until the subsoil became exposed. Regardless of surface type, changes in species composition brought about by major rainfall persisted for several years. We could not detect any impact of grazing cattle on pasture composition over time, despite independent evidence of grazing patterns in the area.

INTRODUCTION

The process of soil erosion creates a diversity of soil surfaces. Not all of them will be equally suitable for plant life. Some surfaces are created by past activity and are now relatively stable, while others are currently active. In an active and relatively flat arid-zone landform such as an alluvial fan or a floodplain, runoff water and sediment from one area will accumulate temporarily on their way to a sink in another area. These three components - the source zone, transfer zone and sink - together form an erosion cell (1), which is repeated many times to form a mosaic or a set of alternating waves of erosion and deposition along a floodplain. In steeper country, similar patterns develop but with sinks along incised watercourses.

These patterns are not fixed in time. Depending on the size of an erosional event, sediment will shift down the transfer zone but may temporarily accumulate. Movement will be intermittent because rainstorms large enough to cause erosion are infrequent and transient. Any grazing effects will be superimposed on this shifting pattern and might be expected to vary systematically with distance from water.

Erosion cells can be as small as a few centimetres but, for practical management, cells of the order of tens of metres to kilometres are important because each zone is large enough to support distinctive vegetation. If an erosion cell mosaic is to be monitored to determine the impact of grazing, it will be necessary to identify vegetational response to the underlying erosional pattern as part of the procedure.

We report a study of two floodplains with a mosaic of active erosion cells, and some of the more stable landforms which border on them. We wanted to determine whether there were predictable associations of species or functional groups of species with particular erosional surfaces, and whether the impact of grazing cattle at nearby watering points could be detected.

METHODS

Two floodplain systems were selected on Kunoth Paddock, a typical central Australian paddock of 170 sq km, northwest of Alice Springs in the Northern Territory. Of the five watering points in the paddock, two, both dams, were located within the area studied (Figure 1).

While the mean annual rainfall is 263 mm and 70% falls in summer (October to March) on average, variability is the norm. Over the period of this study, there were four successive years without effective summer rain, and several major rainfall events when a large proportion of the annual total was received within a single month. One of these occurred in winter (Table 1).

Table 1. Rainfall (nearest mm) during the experimental period; 1982-6 figures are for Alice Springs, 1987-8 figures are for Kunoth Paddock. Major periods of rainfall are underlined and sampling times are indicated by *1 to *9.

Year	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1982	5	185	49	4 *1	-	-	3	-	17	3	-	26	292
1983	23	1	357	68	-	-	-	12	-	22 *2	19	46	548
1984	105	1	1	28	- *3	-	25	6	29	32	4	58	289
1985	-	17	26	1 *4	1	17	1	3	-	31	22	3	122
1986	13	-	-	- *5	8	81	144	13	-	37 *6	78	20	394
1987	5	27	22	3 *7	3	41	-	-	-	-	24	39	164
1988	1	-	-	191	15 *8	-	11	6	-	5	35	38	302
1989	*9												

Vegetation
On each floodplain, vegetation was monitored over a series of parallel transects which, combined, created a grid of points. The transects were aligned along the drainage lines, and points were marked by steel posts which were narrow enough to prevent major disturbance to flow patterns. Points were located 0.5km apart along the transects and the transects were separated by a distance of 0.25km. A total of 88 points were established on "Kunoth", the easterly floodplain, while there were 68 points on "Greentree", the westerly floodplain. Each point was identified with a

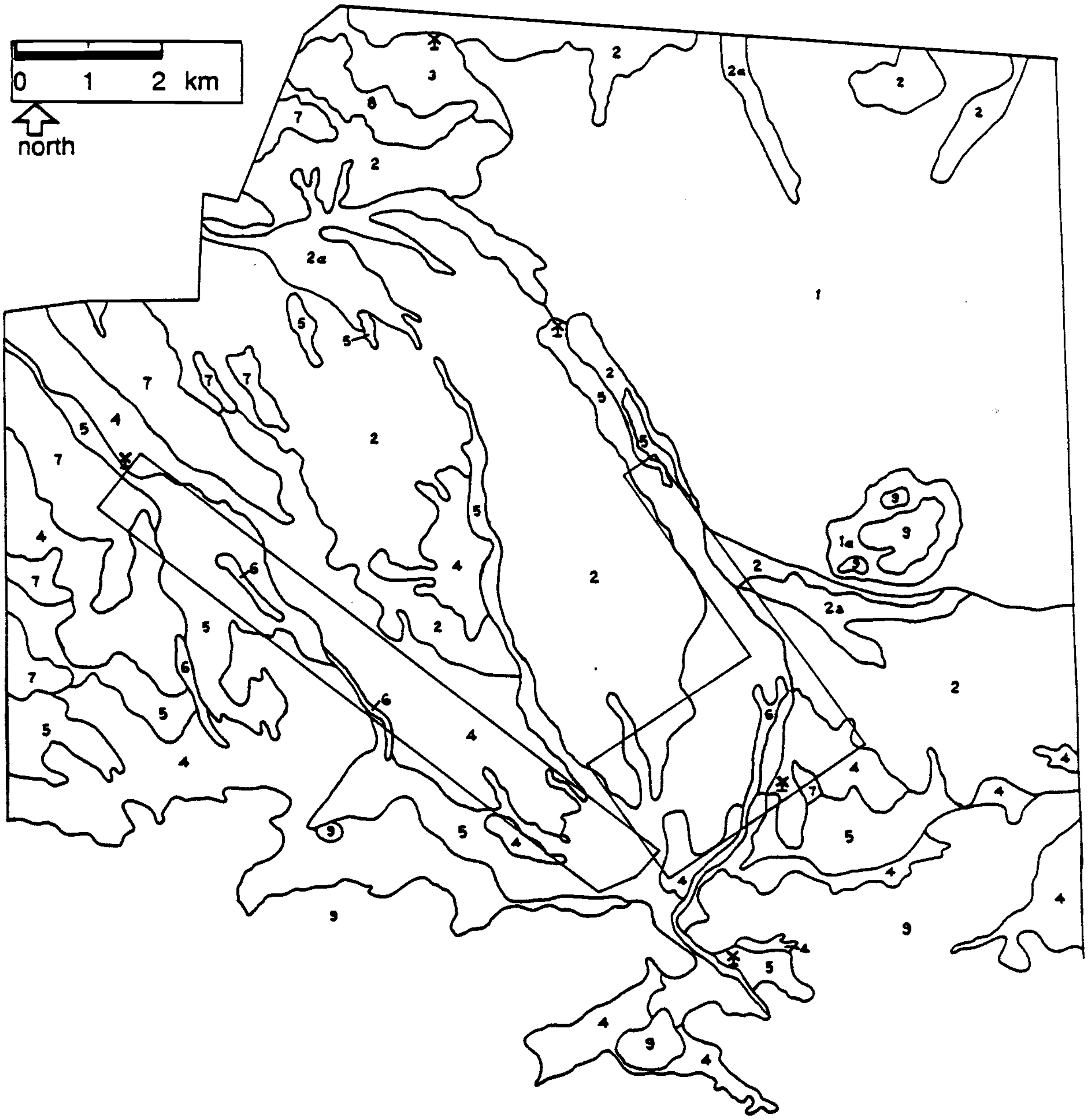

Figure 1: Map of Kunoth Paddock showing plant community types, position of grids and waterpoints. Plant community types are 1 = mulga shrubland, perennial understorey; 1a = open shrubland; 2 = mulga shrubland, annual understorey; 2a = mulga depression; 3 = calcareous shrubby woodland; 4 = open woodland; 5 = floodplain herbland/shrubland; 6 = riparian grassland; 7 = gilgaied grassland; 8 = spinifex grassland. Outline of Greentree grid to left hand side, Kunoth grid (L-shaped) to right hand side. ✱ = waterpoint.

number. Due to areas of uniformity not all available points were used on the Greentree transects.

Vegetation was recorded on nine occasions from 1982 to 1989 (Table 1), following major rainfalls, and a photograph from a fixed position was taken each time, incorporating both the marker post and a portion of the landscape. The sampling unit was located in this portion, in an area bound by the width of the field of view and extending approximately 200m frontally.

All plant species at each point were assigned to one of four frequency categories: Abundant, Common, Infrequent, or Rare. An Abundant species was dense. In the herbage layer it covered most of the ground while the canopies of an Abundant woody species either touched or almost touched. Usually only one species was Abundant at any point. Common species covered less area than the Abundant class, and several species could be Common at once. Infrequent species occurred as scattered plants while Rare species were represented by very few plants. A single observer (D.J.N.) assigned the vegetation to the various categories for the entire period, using photographs to ensure consistent classification between points and sampling occasions.

Soils

The study area contains a bewildering variety of soil surfaces whose origin has only recently been explained. Much of the floodplain is covered by sand sheets which were probably laid down during two "superfloods" occurring about 700 years ago and perhaps 1500-2000 years ago. These events were far larger than anything which has occurred since European occupation (2) and left a discontinuous sand veneer over older, heavily weathered deposits across much of the landscape. The sand sheets are dissected by shallow channel systems which were created during the superfloods and either partly filled with clay-rich deposits or cut into the pre-existing surface. Some of these channels contain the modern active floodplain and have recent sand deposits laid down by creeks emanating from the Chewings Range. Others contain erosion cell mosaics in which surficial material is being redistributed under current processes. There are also ancient alluvial fan surfaces with red earths that remain largely intact but there is some movement of a thin discontinuous surface sand layer.

The complex erosional history of Kunoth Paddock has produced a number of surface types which we have classified as follows. Firstly, there are the intact and largely inactive superflood sand sheets (TI). The red earth alluvial fan deposits (DM) are similarly intact and inactive.

Secondly, there are the eroding surfaces which may be stratified according to the extent of soil loss. The initial stages of erosion involve loss of topsoil (TE) or the sandy veneer which covers much of the study area. As erosion progresses, the older clay material starts to be exposed (TS) and when topsoil has been removed from 50% of the area, the subsoil-exposed (SE) class is used.

Several types of deposition occur. In the initial stages, thin discontinuous sandy bars are laid down, only to be disturbed or removed entirely during the next large flood event. These mobile sandy deposits (MS) may eventually stabilise, and where there is a progressive build-up of sediment, the depositional class (DO) is used. Erosion cells may expand or contract and new cells may develop. Others may only be active during the larger flood events. This produces a set of composite surfaces which include situations where an eroded area is now being covered by deposited material (DT) or an area of deposition is experiencing renewed erosion (DE).

Data analysis

The major tools were multivariate analytical techniques within the PATN package (Belbin 1987). Sites were classified using the Bray-Curtis measure of dissimilarity while species were grouped using Two-Step (Austin and Belbin 1982) which incorporates the Bray-Curtis metric. Sites were ordinated with the multi-dimensional scaling program and compared with extrinsic data such as soil surface type by two dimensional scatter plots.

The whole time series by species abundance data set was far too large to be analysed in its entirety, and still be readily interpretable. Instead the data were grouped in various ways in order to explore relationships between soil surface types, long- and short-lived species, seasonal variability and the impact of grazing cattle.

The initial separation was between long-lived tree and shrub species and the shorter-lived herbage, on the assumption that the occurrence of trees and shrubs reflected past establishment events and conditions different from those currently affecting the herbage. As well, the abundance of woody species was unlikely to change much with the short-term seasonal fluctuations of the study period, so the woody plant data were analysed from just the final sampling. Initially, tree and shrub data from Kunoth and Greentree floodplains were treated separately but the outcomes were sufficiently similar for the data sets to be combined.

Herbage data from Kunoth and Greentree floodplains were not combined after initial examination. The structure of the Kunoth floodplain was more complex than Greentree, incorporating for example stranded islands of inactive red earth alluvial fan deposits amongst very active erosional or depositional surfaces, so that spatial and temporal processes were different. Only the Greentree data analyses are reported here, due to space limitations.

Prior to analysis, sites were classified according to their distance from water and to an index of grazing and trampling (here entitled simply "use") developed by Pickup and Chewings (5). This index is derived from Landsat MSS data and a cattle distribution model which relates animal numbers to distance from water and plant community preference. Matrices of either "distance" or "use" classes (untransformed or log transformed) and soil surface types were inspected for relatively even distributions of data classes, and subsets were chosen from them. For example, a class of "use" on one of the floodplains might be selected because the sites in it were distributed over most soil surface types. Conversely, a particular soil surface category might be preferred because all "use" classes were well represented in it. These subsets provided the data base for numerical taxonomic analysis.

Once a subset of sites had been selected, data from all nine sampling occasions were added sequentially to produce a time series. The size of the sites by species abundance matrix thus created was excessive for the available computing capacity, and was reduced by eliminating all species that were rare or infrequent on all nine occasions or else occurred as an isolated common record on one occasion only.

RESULTS AND DISCUSSION

Woody species - what scrub grows where?

Two-way classification of sites produced groupings that could be equated with broadly recognised plant community types (Table 2) on the basis of their dominant species. Mulga shrubland has developed largely on old stable surfaces (TI, DM) and a few progressively accumulating surfaces (DO). These latter few are not anomalous, taking into account that, over a period of centuries, DO surfaces evolve into TI surfaces if left largely undisturbed, and the distinction between them can be blurred.

Table 2. Two-way classification of Kunoth and Greentree sites, according to dominant woody species and type of soil surface. The number of sites in each class is given. Species groups have been named according to generally recognised plant community types; see Methods for explanation of the soil surface types.

Plant community and dominant species	Soil surface type								
	TI	TE	TS	SE	DT	MS	DE	DO	DM
Mulga shrubland (*Acacia aneura*)	11	1	--	--	--	--	1	3	5
Open woodland 1 (*Atalaya hemiglauca, Ventilago viminalis*)	14	10	1	--	2	--	--	5	--
Open woodland 2 (*Acacia tetragonaphylla, Cassia nemophila*)	1	1	1	--	--	--	--	--	1
Open woodland 3 (*Cassia oligophylla*)	1	2	1	--	--	--	--	--	1
Open woodland /floodplain fringe (*Hakea leucoptera, Eremophila duttonii*)	1	3	1	--	--	--	--	--	--
Cottonbush flats (*Maireana aphylla*)	2	6	3	7	3	1	1	4	--
Riparian (*Eucalyptus camaldulensis*)	--	--	--	--	--	--	1	6	--
Floodplain anomaly	--	--	--	--	--	--	--	1	--
Treeless	3	15	11	11	3	--	8	3	--

The different woodland groups occupy somewhat different positions in the landscape, with Open woodland 1 occurring on some of the least disturbed surfaces, (TI, TE) but not the red earths (DM). The dominant species *Atalaya hemiglauca* (whitewood) and *Ventilago viminalis* (supplejack), together with *Acacia aneura* (mulga), can live for periods exceeding a century and might be expected to occupy the most stable sites. The other woodland groups are also on relatively stable surfaces and are distinguished by species which prefer coarse sandy situations *(Acacia tetragonophylla* (dead finish), *Cassia nemophila* (broombush)), margins of red earths and skeletal soils *(Cassia oligophylla)* and better-watered sandy floodplain fringes *(Hakea leucoptera* (needlebush), *Eremophila duttonii* (a native fuchsia)). In other words, the species concerned are very likely responding to subsurface features, and not just surface conditions. The latter two species occupy potentially less stable sites on the woodland margins, and the trend of the data towards more TE surfaces within this group confirm this, although the sample is small. The lifespan of all five species is of the order of decades to a century, rather less than the Open woodland 1 species.

Maireana aphylla (cottonbush) also has the potential to live for many decades. It is tolerant of temporary water-logging and so prefers the relatively inactive portions of the floodplain and heavy soils at depth. The substantial mounds of windblown sandy material which collect around cottonbush during drought indicate the plants' considerable age, yet the variety of unstable surfaces, especially SE, associated with it appear at odds with a long lifespan. The reason is that recent disturbances of grazing and extreme rainfall events have destabilised the floodplain and shifted activity back into the areas occupied by cottonbush. New erosion gullies are eating back into formerly stable cottonbush flats and erosion products are being deposited onto other flats downslope.

Recently active DO surfaces support fast-growing *Eucalyptus camaldulensis* (river redgum) but the majority of these trees may not live long. Establishment was rapid following several wet years in the mid-1970s and the trees reached some 6-7m in height by the late 1980s. With the cutting of a new channel by floodwaters at that time, these riparian areas became starved of water, resulting in wide-spread death of redgum.

The floodplain anomaly was an atypical site containing only *Rhagodia parabolica,* an uncommon species of wetter areas, in keeping with the DO surface.

Consistent with the overall trend of the foregoing, the treeless sites are predominantly on unstable surfaces. Not surprisingly, fast-growing herbage species are able to complete their life cycles in between disturbances, whereas slow-growing woody species cannot. As the return time of the disturbance increases, so can longer-lived woody vegetation persist, until species with a lifespan of centuries can occupy both the sand sheets deposited 700 years ago and the ancient alluvial fans.

<u>**Herbage species - the dynamics of pastures**</u>

When Greentree sites were classified into subsets according to distance from waterpoints, six classes of "distance" produced the most even distribution of sites within the greatest number of soil surface types. Log transformation made no improvement. When the classification was based on "use", five classes were most effective but only if the data had been log transformed.

Class 3 of both the "distance" and the log transformed "use" classifications incorporated up to five sites in respectively five or six categories of soil surface type. Ordination of the "use" subset produced a much clearer separation between the various soil surface types than could be obtained from the distance subset, and so just the former is presented (Fig.2). Shifting herbage compositions on TI and TE surfaces traced similar paths over time, when plotted on the first two MDS axes. Exposure of subsoil (TS, SE) placed the compositional paths further to the

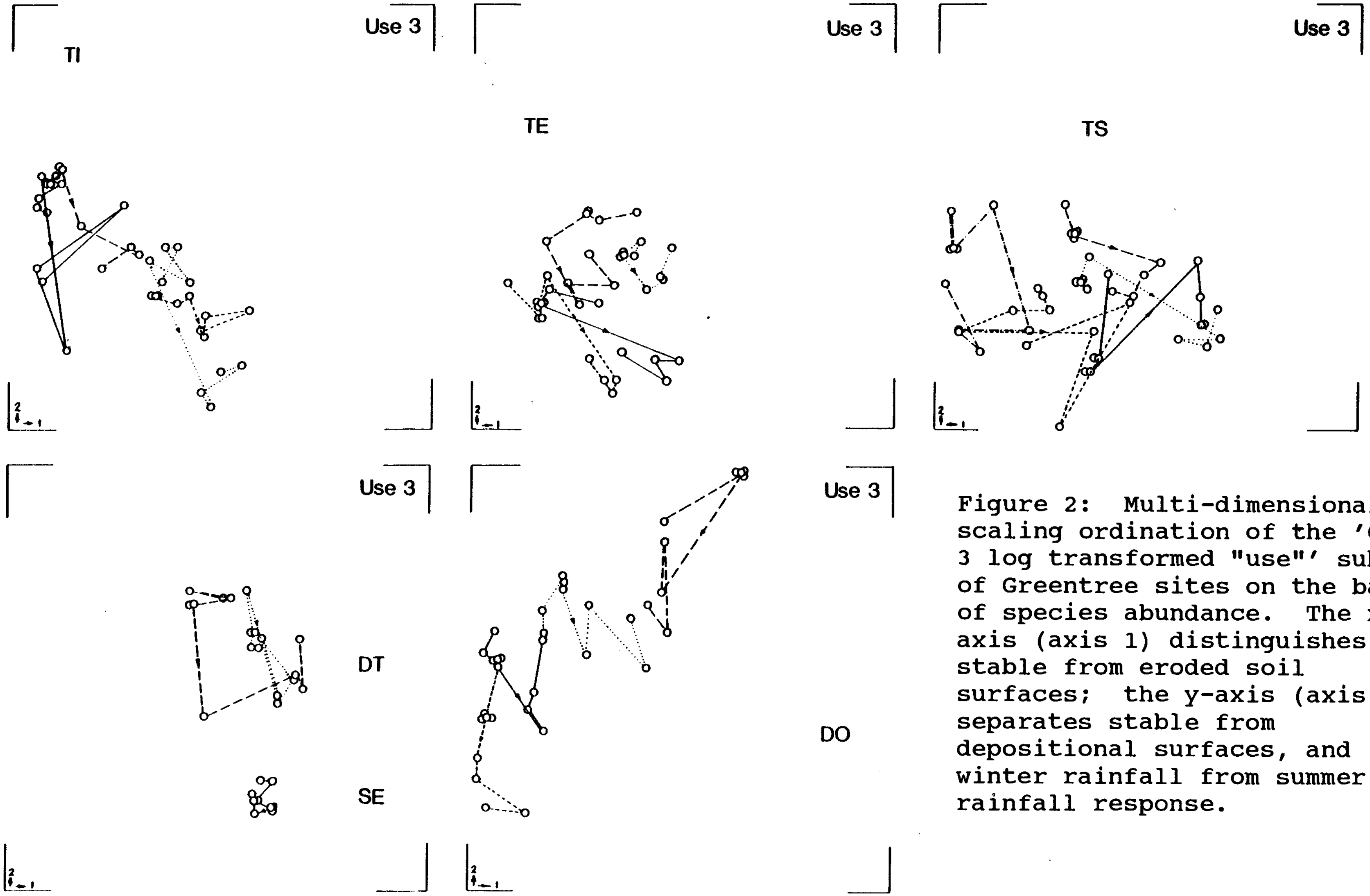

Figure 2: Multi-dimensional scaling ordination of the 'Class 3 log transformed "use"' subset of Greentree sites on the basis of species abundance. The x-axis (axis 1) distinguishes stable from eroded soil surfaces; the y-axis (axis 2) separates stable from depositional surfaces, and winter rainfall from summer rainfall response.

right along the first axis. With new deposition over eroded surfaces (DT), compositional paths were diametrically opposite TI and TE paths, while DO paths spanned the scatter plot from the DT to the TI and TE positions.

Several features are evident. Firstly, the ordination discriminates between species responses on erosional and depositional surfaces (axes 1 and 2 respectively). Secondly, the range of compositional paths from the depositional to the stable type on DO surfaces is indicative of the developmental gradient mentioned earlier between the two surface types. Thirdly, erosion of topsoil (TE) in itself does not appear to have influenced species composition. The critical point was where subsoil was exposed (TS), presumably changing both water and nutrient regimes and disrupting plant establishment and growth. Finally, the composition on individual sites shifted relatively little until the sixth sampling occasion, which followed a major winter rainfall. Previously, there had been effective summer rainfalls for three years (Table 1), then two years without effective summer or winter rain, leading to dominance by summer-growing species. The 1986 winter rain caused a marked shift in composition which persisted through subsequent dry summers. A substantial between-season rainfall in April 1988 did not have a major impact on that trend. In other words, persistent changes in species composition were brought about by differently timed rainfalls.

A two-way classification of sites and species within the time series data set (not shown) did not clearly discriminate between the different soil surface types, because of the interaction of surface type and season. The exceptions were the depositional surfaces, DO and DT, dominated by perennial grasses such as *Astrebla pectinata* (barley Mitchell grass), *Bothriochloa ewartiana, Dichanthium sericeum* (Queensland bluegrass), *Digitaria coenicola* (umbrella grass), *Enteropogon ramosus* (a curly windmill grass), and *Eulalia fulva* (silky browntop).

Two-way classification of sites and species from the first sampling occasion (not shown), representing a post-summer rainfall response, discriminated between open woodlands and floodplains. *Enneapogon polyphyllus* (oat grass) characterised the woodlands, while *Sclerolaena bicornis* (goathead burr) typified the floodplains. Within the two community types, classification identified several unique depositional sites (DO, DT) and one TE site. The remainder of the floodplain sites were split into a more eroded group (TS, SE), with *Sclerolaena divaricata* present, and a less eroded group (TI, TE, TS) without it. Similarly, the woodland sites were split into an eroded group (TE, TS), lacking *Digitaria coenicola* and *Indigofera linnaei,* and a depositional to intact group (DO, TI) which included them.

A similar analysis of the sixth occasion (not shown), after an effective winter rain, produced an interesting contrast. Floodplains and woodlands were distinguished on the presence or absence of *Sclerolaena bicornis,* since short-lived summer-growing species had largely disappeared. Some of the unique sites that were identified from the first occasion were no longer distinct, and the surface types within the main floodplain and woodland groups were mixed. Winter-growing species did not respond to soil surface characteristics in the same way as did summer-growing species, perhaps because surface soil moisture was less critical in cooler weather.

When the Greentree sites were classified according to soil surface type, the TE class contained sites representing all five "use" classes (log tranformed). Ordination of the TE subset (Fig. 3) appeared to present

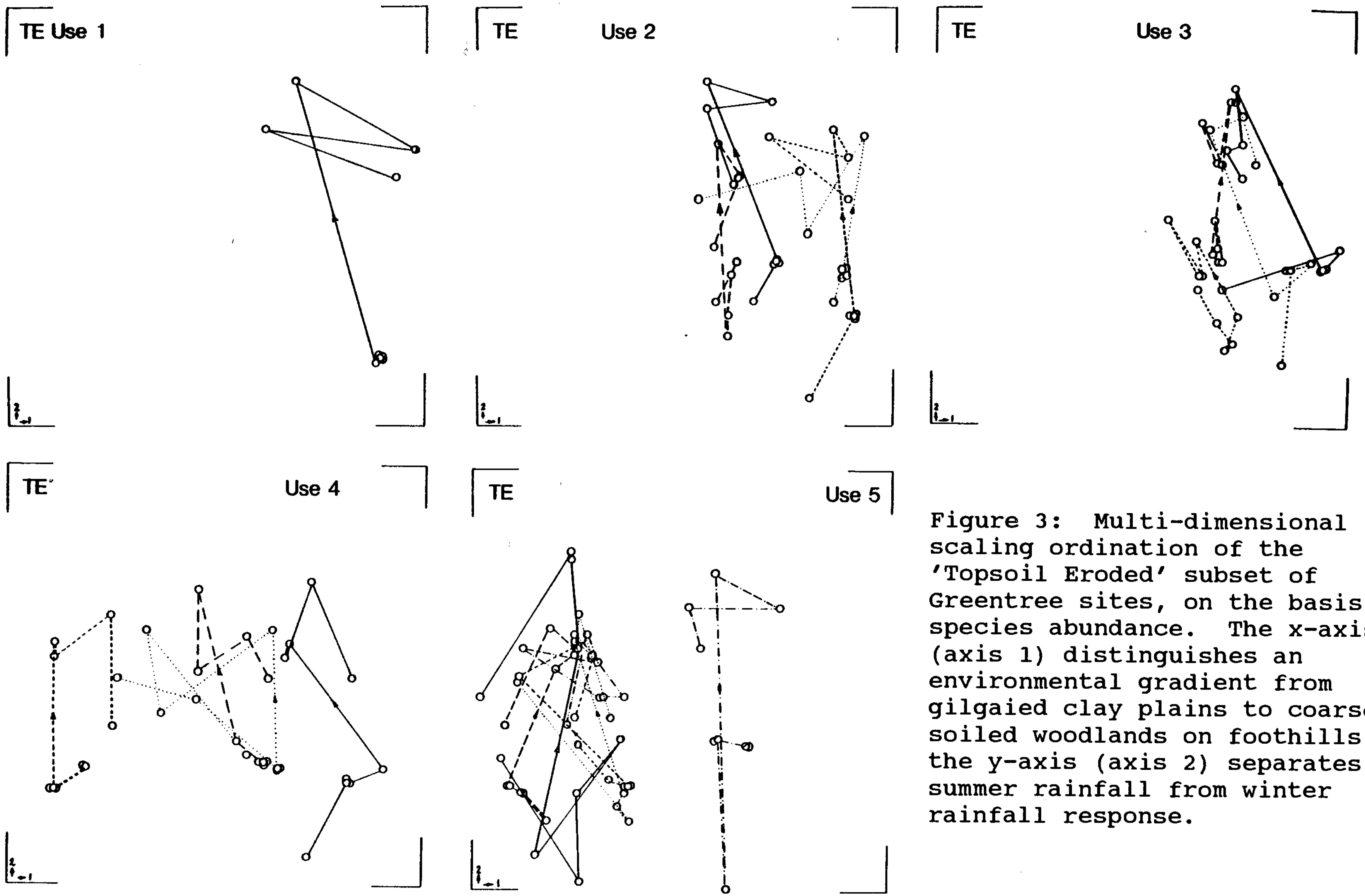

Figure 3: Multi-dimensional scaling ordination of the 'Topsoil Eroded' subset of Greentree sites, on the basis of species abundance. The x-axis (axis 1) distinguishes an environmental gradient from gilgaied clay plains to coarser-soiled woodlands on foothills; the y-axis (axis 2) separates summer rainfall from winter rainfall response.

clear evidence of distinctive species responses to high levels of utilization (Classes 4 and 5) but closer examination of site locations suggested that this was not the case. There were two dams which influenced the use of the Greentree grid, one at its northern end and another northeast of its southern end and about 2km distant. Nine of the ten Class 4 and 5 sites were close to the northern dam. Naturally, the dam was located downslope of the Chewings Range, so that the sites near the dam were at one end of an environmental catena. Self-mulching clays which form gilgais prevailed close to the dam, while sandier soils in floodplain, woodland and foothill communities occurred further back towards the hills. As a consequence, the gradient of utilization was confounded with environmental gradients.

In conclusion, we can say that predictable associations exist between erosional surfaces and the species which grow on them. At the broader scale, the most stable surfaces, the intact superflood sand sheets and the ancient alluvial fan surfaces, support the longest-lived trees and shrubs. Successively less stable surfaces have increasingly short-lived trees or shrubs, until the currently active floodplains have none at all. Of the herbage species, some are characteristically part of the floodplain flora (e.g. *Sclerolaena bicornis)* while some are a part of the sand sheet flora (e.g. *Enneapogon polyphyllus),* but they are also strongly season-dependent because they are short-lived. At a finer scale, different herbage species are associated with different erosional surface types on ancient and modern soils. Various long-lived perennial grasses dominate well-watered depositional surfaces on both the old sand sheets and the recently active floodplains, while *Sclerolaena divaricata* occupies the degraded floodplains. Post-winter measurement is less successful than post-summer measurement at detecting these associations. A noteworthy feature of the pasture layer is the shift in composition which follows major rainfalls and which persists for several years, irrespective of soil surface type.

The impact of grazing cattle could not be detected, despite the fact that grazing patterns in the same area could be identified with Landsat imagery (5). There are several causes. Firstly, an environmental gradient was confounded with the grazing gradient. This is likely to be the case wherever a dam is located, since it must be downslope of a catchment. Secondly, there were insufficient sites to stratify according to soil surface type and environmental position and to represent utilization levels adequately as well, despite having 68 sites available. Thirdly, the use of four abundance ratings for plant species, over a relatively limited area per site was probably an inadequate procedure for such a diverse and active landscape. Other ground-based techniques are available that should be more sensitive to the impact of cattle (6), provided the landscape is adequately stratified.

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