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Contribution of pits dug by goannas (*Varanus gouldii*) to the dynamics of banded mulga landscapes in eastern Australia

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The densities of pits made by goannas *Varanus gouldii* were estimated in the three distinct zones of banded mulga landscapes (erosion slope, interception zone, and mulga grove) in paddocks of a grazing study in north-western New South Wales, Australia. In light and moderately grazed paddocks, soil pits were significantly more abundant in the interception zones (M = 119·7 m^{-2}) than in the groves and erosion slopes (M = 16·7 m^{-2}). In the overgrazed paddock there were no differences in densities of pits in any of the zones. In the groves and erosion slopes approximately 70–80% of the pits contained litter, seeds, and fruits. However, on the erosion slopes less than 20% of the pits contained litter and seeds. The data support the hypothesis that soil disturbance by *Varanus* lizards produces a positive feedback mechanism for the viability of the interception zone and the functioning of banded vegetation landscapes.

Keywords: Australia; banded vegetation; goannas; grazing; landscapes; lizard; pits; seeds

Introduction

Many arid and semi-arid landscapes are situated on infertile soils. However, low rainfall and soil infertility does not preclude the development of a diverse and productive vegetation. Noy-Meir (1973, 1985) has suggested that this diversity and productivity is the result of patchiness (heterogeneity) in the spatial distribution of water and nutrients. There is an increasing body of evidence that soil disturbance and soil modification by a variety of animals contributes to the heterogeneity and functioning of arid ecosystems (Lobry de Bruyn & Conacher 1990; Meadows & Meadows, 1991). Most of the literature on soil disturbance by animals focuses on the effects of these

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disturbances on soil properties such as organic matter content, soil nutrient patterns, and water infiltration. Soil pits can serve as litter traps and also serve to trap seeds (Steinberger & Whitford, 1983; Longland, 1995).

Banded vegetation is characteristic of many arid regions of the world (Tongway & Ludwig, 1990). In banded vegetation landscapes, water infiltration, nutrient availability, and plant establishment are hypothesized to be greatest in the runon areas (interception zones) at the upslope edge of the vegetation band (Tongway & Ludwig, 1990). In the banded mulga landscapes of north-eastern New South Wales, Australia, goannas *Varanus gouldii* excavate deep pits in their effort to capture burrowing spiders and beetle larvae. In a landscape characterized by unvegetated erosion slopes that drain into bands of vegetation dominated by mulga *Acacia aneura* and several species of bunch grasses, the abundance of burrowing prey species was hypothesized to be highest at the interception zone of the mulga bands. We hypothesized that pits dug by *Varanus* would serve as seed repositories and would also serve as points of litter accumulation producing water–nutrient rich patches for germination and seedling establishment. Here we report the results of a study on the distribution of pits dug by *Varanus* in paddocks with varying grazing intensities in a banded mulga landscape. We also report on the quantities of plant litter, seeds, and fruits in the pits.

Methods

This study was conducted at the 'Lake Mere' station which is located approximately 250 km north-west of Cobar, New South Wales. Measurements were made in the paddocks of a grazing study established to examine the effects of stocking sheep with and without kangaroos at different stocking rates. We measured densities and characteristics of soil disturbance in paddocks of different sizes and adjusted stocking rates. The ungrazed paddock was 16 ha that was grazed lightly by kangaroos and infrequently by sheep when they were being moved to other paddocks. The overstocked paddock was 4 ha grazed by four sheep. This stocking rate was well above the expected carrying capacity for banded mulga rangeland, and this paddock had no remaining perennial grass cover. Typical stocking rates in this region are 0·6–0·7 sheep ha^{-1}. The lightly grazed paddock was 10 ha grazed by six merino wethers (dry sheep), i.e. a rate of 0·6 sheep ha^{-1}. The moderately grazed paddock was 12·9 ha, stocked with sheep and kangaroos (0·7 sheep ha^{-1}) and the heavily grazed paddock was 7·5 ha grazed by six merino wethers at a rate of 0·8 sheep ha^{-1}.

The densities of pits dug by *Varanus* were estimated by a wandering quarter technique (Bonham, 1989). We made between 50 and 60 distance measurements within each of the paddocks. We measured the distances between pits along a transect initially oriented perpendicular to the slope. The locations of pits were assigned to the specific portion of the landscape by noting the location of each pit identified. Within the moderately grazed paddock, we selected 10 pits at random in each of the zones for detailed measurements of dimensions, and collected the contents of the pits for identification. The pits selected for measurements and sampling were those nearest one of the 10 points picked at random from 100 pace transects within each landscape unit.

The distance measures were used in a Kruskal–Wallis one-way ANOVA on ranks to determine if there were significant differences in densities of pits within the landscape units. The distance measurements also were used in a Kruskal–Wallis one-way ANOVA to examine differences among paddocks with different stocking rates. The Kruskal–Wallis ANOVA was used because the data failed the normality test. The surface areas and depths of the pits were examined by a one-way ANOVA to determine differences among landscape units.

Table 1. *Densities (number per hectare) of pits and scrapes produced by* Varanus gouldii *in banded mulga landscapes divided into paddocks with different stocking rates of sheep. Numbers with different letters are significantly different at* $p < 0{\cdot}05$ *based on Kruskal–Wallis one-way analysis of variance on ranks*

Grazing status	Paddock mean	Interception zone	Intergrove mulga band	Erosion slope
Overgrazed	12·8	12·9	12·0	11·9
Ungrazed	19·9	14·5	14·9	30·9
Light grazing	15·1	29·7	11·9	12·6
Moderate	42·6	100·0a	11·9b	12·6b
Heavy grazing	55·6	229·4a	13·1b	28·0b

Results

There were large differences in the densities of pits among the paddocks. The overgrazed paddock was characterized by a virtual absence of grasses. In this paddock most of the soil surface was barren with the exception of dead mulga trees that had soil mounds associated with the trunk and major branches. The density of pits was lowest in this paddock ($12{\cdot}7\ m^{-2}$) (Table 1). All of the pits were associated with log mounds. There were no large burrowing spider holes recorded in this paddock and most of the pits appeared to be excavations for beetle larvae and pupae, or for small lizards (*Ctenotus* spp.). The density of pits in the ungrazed paddock was intermediate between the overgrazed and lightly grazed paddocks and the moderate and heavy grazed paddocks. In the ungrazed paddock 50% of the pits were excavations of large burrowing spiders. The remaining pits were mostly associated with log mounds. Most of the pits recorded at the interception zone of the groves in this paddock were identified as excavations of the burrows of large spiders.

The paddock with the highest stocking rate also had the highest densities of soil depressions made by *Varanus* digging (Table 1). In this paddock 30% of the *Varanus* diggings were shallow scrapes. Eight per cent of the pits were associated with log mounds both in the groves and on the erosion slope. Twenty-seven per cent of the pits were at the interception zone of the mulga groves. Although this paddock had a high stocking rate, there were abundant grasses within the groves and at the interception zones.

High densities of pits were also recorded in the moderately grazed paddock (Table 1). However nearly 80% of the excavations in this paddock were of burrows of large spiders. The remainder of the excavations were associated with log mounds. High densities of spider burrows in the interception zone in this paddock contributed to the high density of pits. Densities of *Varanus* excavations in the lightly grazed paddock were similar to that of the moderately grazed paddock with the exception of those in the interception zone (Table 1). Here the density of pits in the interception zone was only twice that of the mulga bands and erosion slopes. There were no significant differences in the depth or surface area of the pits in any of the landscape positions (ANOVA, $F = 0{\cdot}46$, $p > 0{\cdot}64$). The mean depth of the pits was $92{\cdot}7 \pm 35{\cdot}6$ cm and the mean surface area of the pits was $131{\cdot}0 \pm 144{\cdot}7\ cm^2$. There were differences in the percentage of pits in which wind- or water-transported materials were caught. Only two pits on erosion slopes contained plant material. The material in the erosion slope pits consisted of *Eucalyptus populnea* leaves from a pit below the canopy of this tree growing on an erosion slope. The material in the other erosion slope pit consisted of *Acacia aneura* phyllods and fruits plus some unidentifiable organic fragments. There were no important differences in the pit contents from pits within the mulga groves

Table 2. *Average mass (g) and range of materials collected from pits dug by* Varanus gouldii *in two locations on a banded mulga watershed at Lake Mere, New South Wales, Australia. Eight of the ten pits sampled in the interception zone contained identifiable material and seven of the pits in the grove contained identifiable material.* N *is the number of pits containing some material in which none of the identified material was recovered*

	Interception zone			Grove		
Material	M	Range	*N*	M	Range	*N*
Acacia aneura fruits	0·54	0·0–2·09	1	0·56	0·0–2·91	3
Acacia aneura phyllods	3·52	0·0–7·11	1	3·96	0·0–9·05	2
Stipa variabilis seeds	0·39	0·02–0·87	0	0·27	0·0–1·57	0
Thryidolepis mitchelliana seeds	0·01	0·0–0·06	4	0·01	0·0–0·04	5
Sheep dung	1·18	0·0–3·12	4	0·50	0·0–3·50	6
Forb fruits and seeds	0·24	0·06–0·59	0	0·24	0·0–0·54	2
Forb fragments	0·56	0·07–1·22	0	0·33	0·0–1·89	5
Grass fragments	0·53	0·08–1·16	0	0·32	0·0–1·43	4
Wood fragments	2·67	0·5–10·6	0	6·5	0·0–18·2	2
Cassia eremophila fruits	0·07	0·0–0·56	5	0·05	0·0–0·39	6
Eucalyptus populnea leaves	0·42	0·0–2·35	4	0·32	0·0–1·76	6

and from pits in the interception zone (Table 2). All of the pits in these locations contained grass seeds and more than half of the pits contained *A. aneura* fruits.

Discussion

The data support the hypothesis that the densities of pits dug by goannas in search of prey are highest in the interception zone of the mulga groves. The data also demonstrate that intensive overgrazing destroys the landscape pattern of pits and shallow excavations made by goannas. This loss of pattern is probably the result of destruction of the grass and herbaceous layer of vegetation which serves to slow water movement through the groves and which interacts with soil fauna to enhance infiltration (Whitford *et al.*, 1992; Tongway & Ludwig, 1994). The effect of degradation by grazing animals on the heterogeneity of soil resources has been implicated as one of the important feedback mechanisms that inhibit recovery from desertification (Whitford, 1993). The high density of pits in the interception zones of moderately grazed paddocks shows that the negative impact of grazing on this process is limited to areas that are heavily impacted by domestic stock.

The dynamics of banded mulga watershed landscapes is dependent upon establishment of dense vegetation on the upslope portion of the mulga groves or the interception zones for water and materials moving off the erosion slopes (Tongway & Ludwig, 1990). The maintenance of the grove structure is also dependent upon establishment success of a number of plant species. Data on the distribution and contents of soil pits dug by goannas suggests a positive feedback mechanism where potential prey abundance is greatest in the interception zone on the upslope edge of the mulga groves. The pits dug by the lizards preying on ground-burrowing spiders and beetle larvae and pupae serve as litter traps. An important component of the material that accumulates in the pits is the seeds of forbs and two of the perennial grasses. The pits therefore become organic matter-rich patches with buried seeds. Germination of these seeds and establishment of grasses and forbs in the filled pits increases the density and vigor of the interception zone grass–herbaceous layer. This enhances infiltration and organic matter retention and provides habitat and resources for the prey of the *Varanus*. This feedback is an important part of the mechanism that maintains the banded landscape pattern in these mulga woodlands. Even on the erosion slopes, the pits capture seeds of *Acacia aneura* in addition to seeds of grasses and other trees or shrubs. It is likely that the few trees on the erosion slopes, as well as the small patches of grasses and forbs on log mounds on erosion slopes (Tongway *et al*., 1989) owe their presence to pits dug by goannas in search of food.

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