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Restoration of vegetation and soil patterning in semi-arid mulga lands of Eastern Australia

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Eastern Australia has been used largely as pastureland in the last century (Noble and Tongway 1986). Grazing, reduced fire frequency and poor understanding of rainfall patterns have led to degradation of this area (Tongway and Ludwig, 1996). Loss of perennial grasses, soil erosion and the increase of inedible native shrubs are some of the long-term effects of degradation. Several attempts to re-seed bare areas of the landscape using mainly exotic grass species failed due to the poor match between introduced species and soil type (Tongway and Ludwig, 1996). The soils in eastern Australia are primarily infertile acidic red earths, while the exotic grasses that were introduced were adapted to fertile neutral soils. This combination resulted in low survival rates of the introduced exotic grasses. Re-seeding along with various mechanical soil reclamation treatments were also attempted with minimal success (Tongway and Ludwig, 1996). In previous reclamation efforts, water infiltration was the primary factor considered. Where only infiltration issues were addressed, however, reclamation efforts were considered unsuccessful because not enough attention was paid to soil nutrient cycling.

This paper describes several studies that focus on the restoration of semi-arid mulga lands in eastern Australia. What characterizes these studies from previous restoration attempts is the recognition of the need to take a more comprehensive approach. This entails understanding the natural vegetation patterning and nutrient cycling of a landscape. If the nutrient cycling of a soil system is understood, it is more likely that a reasonable strategy for restoration of the soil will be developed. Once the soil is restored, re-establishment of vegetation is more feasible, thereby making the re-establishment of vegetation patterning and the effective restoration of the landscape possible.

D.J. Tongway and J.A. Ludwig (1990) studied the patterning of the semi-arid mulga lands of eastern Australia to determine the processes make the existing natural vegetation patches fertile. The landscape was considered as a whole instead of only concentrating on only the bare patches. Once the landscape patterning was determined, it was possible to develop a strategy to restore the soil's characteristics and nutrients, increasing the likelihood of successfully reestablishing vegetation.

A landscape consists of clusters of interacting stands of vegetation or ecosystems that are repeated in similar form (Forman and Godron, 1987). Between the clusters are transition zones that may vary in width from being abrupt to gradual and wide. Interactions between clusters such as nutrient and water flux, and species dynamics are all affected by the size of the landscape patch (Forman and Godron, 1987).

The mulga (*Acacia anuera*) woodlands of eastern Australia contain regular sequences of alternating *Acacia anuera* groves and intergroves on gently sloping landscapes (Tongway and Ludwig 1990). There are three distinct zones within a landscape sequence described as the runoff, interception, and run-on zones. These sequences are patterned over and over until they end with the last sequence, which is called the drainage line. The drainage line is located in the lowest contour of the landscape, and consists of dense mulga trees with the preceding interception zone being more distinctive than mid-slope groves (Tongway and Ludwig, 1990). This patterning of zones within a sequence is a natural occurrence, and has been disturbed in the last 120–150 years due to pastoral settlement (Tongway and Ludwig, 1996). The patterning Tongway and Ludwig defined is presented below.

The runoff zone is an *Eragrostis eriopeda* savanna. It contains approximately 7% grass cover and 3% shrub and mulga cover, and is characterized by soils with poor surface condition. These soils have a high vulnerability to erosion and a very low infiltration rate; therefore runoff is almost immediate after rainfall begins.

The interception zone is a *Monachather paradoxa* savanna that contains about 20% grass cover and 8% shrub and mulga cover. There is less runoff from this area because it has a higher infiltration rate. The soils of this zone are considered to be in good surface condition, and have a high stability to erosion.

The run-on zone is the *Acacia anuera* (mulga) woodland that contains approximately 12% grass cover and 40% shrub and mulga cover. There is no runoff from this area because it has a high infiltration rate. Its soil has a better surface condition, and higher stability to erosion than the interception zone.

In a normal rainfall event, the runoff zone sheds about half of the water it receives as rainfall, which then travels to the interception zone. The interception zone composes about 12% of the entire landscape. The amount of water stored in this zone is approximately the amount of water it receives from rainfall. Runoff from this area (excess water received from the runoff zone) moves to the run-on zone. This is located on a nearly level ‘step’. No runoff occurs from here. The captured and stored water is almost double the amount of water received from rainfall, due to the excess water it receives from the interception zone. This area has the best infiltration rate of the landscape. Only large, intense rainfalls result in water loss from this area, in which case the water will travel through the sequences until it ends up in the drainage lines.

In the mulga woodland, there are high levels of organic nitrogen and carbon, and available nitrogen. The interception zone has lower levels of these nutrients and the runoff zone has the lowest levels. However, there are higher amounts of available phosphorous in both the interception and runoff zones. A possible explanation might be that the zones with the higher phosphorous levels have less vegetation, thus less demand for phosphorous.

This system of grove – intergrove sequences serves to concentrate scarce water and nutrient resources from source areas into sinks. Groves consist of the mulga run-on zones, and intergroves are where the less vegetated runoff and interception zones are located. Within open intergroves shrubs and fallen logs form distinct mounds, and clumps of grasses form discrete soil hummocks (Ludwig and Tongway, 1995). These mounds are an important part of this system because they collect water from rainfall and air-borne particulate matter from wind. The soils underneath the mounds have significantly higher levels of nutrients and rates of water infiltration than soils adjacent to the mounds. The processes that govern this source/sink system are erosion and deposition. In semi-arid mulga woodlands fluvial (water) runoff/run-on processes dominate. Aeolian (air) processes also play a role in dry times by transporting dust and litter debris over considerable distances. Grass clumps trap wind borne material to form accretion mounds. Bridges are made when litter collects between adjacent grass tussocks, these bridges hold back water and transported material during rainfall events. Mounds create microhabitats where soil aeration and infiltration are improved due to microfauna and microflora (Tongway and Ludwig, 1989).

These patches of grass clumps and debris bridges act as filters allowing large water flows to pass through without damaging the patch (Ludwig and Tongway, 1995). They capture and retain scarce resources within the landscape system rather than being carried out of the system. Loss of these patches alters the whole system of erosion and deposition. Each runoff volume increases with loss of patches, thereby transporting larger quantities of eroded materials. The interception zone may not be able to handle larger volumes of runoff, which may lead to a reduced infiltration rate. This will lead to degradation of soil quality, which could decrease to levels below what is necessary to support the microhabitat.

In order to start reclamation of vegetation patches it is necessary to restore soil quality in patches. Rehabilitation must be designed to re-establish resource control processes. The two pioneers of this restoration strategy are once again D.J. Tongway and J.A. Ludwig. The theory behind Tongway and Ludwig's restoration strategy is that water and soil nutrients are in short supply, natural undegraded lands have a high diversity of perennial plants occurring in natural patches, and these patches capture and store water and nutrients (Ludwig and Tongway, 1996). The patches then slowly release these resources so that perennial plants that comprise the patches can survive over long time spans. Tongway and Ludwig tested this restoration strategy by constructing piles of branches that were expected to obstruct water flow and create aerodynamic drag. The hypothesis was that the obstructions would filter out or capture resources entrained in water flows or wind, which would then create resource-rich or fertile patches. This would then restore the natural patchiness of these landscapes.

The study site that was chosen was on a property called Lake Mere in Eastern Australia. Lake Mere is a 200 ha grazing trail composed of 13 paddocks. Two of these paddocks were chosen for this study, one was being grazed by both sheep and kangaroos, the other was substantially ungrazed by domestic stock and feral or native animals (Tongway and Ludwig, 1996).

Grazed and ungrazed paddocks were used to compare results. Eight different combinations of treatments were prepared: with and without a pile of branches, with and without nutrients, and with and without organic matter. The piles of branches used were from locally available of *Acacia aneura* trees, and were stacked 0.5 meters high, making sure main stems were in contact with the soil. Each autumn a mixture of single superphosphate, and ammonium sulfate was added in a total of three nutrient applications. The organic matter was added as litter at the start of the experiment in the form of *Acacia aneura* leaf mulch.

Pre-test soil samples were collected. Soil elevations were carefully measured to a precision of 1 mm, and electrical conductivity, pH, organic carbon, organic nitrogen, available phosphorous, and exchange capacity were measured. After the test run (3 years) soil samples were analyzed.

Soil elevations were taken again, soil was analyzed as above, water infiltration rate was taken, and soil respiration was measured.

Tongway and Ludwig's experiment resulted in significant increase in organic nitrogen, organic carbon, and exchangeable potassium and calcium on the surface layer of soil. It is interesting to note that the added fertilizer and litter treatments had no statistically significant effects. The piles of branches trapped significant amounts of soil, and areas with no branches lost soil. The grazed paddocks both gained and lost more soil than the ungrazed paddocks.

Areas of soil treated with branches resulted in higher infiltration rates. The temperature of the soil was kept cooler during the day and warmer at night. The fluctuations of temperature more closely tracked the air temperature above the soil. This results in less evaporative losses, which leads to more favorable microhabitats for organisms. More ants were also found in these areas.

Accumulated soil was a result of both fluvial and aeolian processes. The branches caught debris brought by the wind from as far as 100 meters away. Once the branches caught the debris, it was dropped onto the soil, and was not easily re-suspended. Water also brought leaf litter and dung from the surrounding areas.

Water infiltration showed a 10-fold increase in the grazed paddocks. The authors of the experiment speculated that this increase might have occurred as a result of an increase in number or activity of soil organisms that are able to process litter and create openings in the soil. These openings will allow water to pass through the surface resulting in a greater water infiltration rate.

Once the soil was rehabilitated vegetation could be restored. Four major perennials were studied; *Maireana villosa*, *Monachather paradoxa*, *Thyridolepis michelliana* and *Eragrostis eriopoda*. *Maireana villosa* is a perennial forb or subshrub present over most of the Lake Mere site, *Monachather paradoxa* and *Thyridolepis michelliana* are cool season grasses that are abundant on the site, and *Eragrostis eriopoda* is a warm season grass which is also abundant on the site (Ludwig and Tongway, 1996). The increase in vegetation was a result of natural succession. No planting was done of the fertile soil patches.

Over the years that this experiment was run, rainfall varied greatly. From 1988 to 1990 the rainfall was average, but from 1991 to 1995 there was a drought. In the pre-drought conditions vegetation responded favorably within the patches created by branches, both in grazed and ungrazed paddocks. Areas with no branches showed a decline in vegetation. In the grazed paddock the difference between areas with and without branches was more noticeable. The branches protected the vegetation from over-grazing. There was no consistent improvement in vegetation cover in the areas treated with fertilizer or litter without branches. The authors state that "the only treatment to consistently rehabilitate bare slopes, alone or in combination with fertilizer and litter treatments, was the application of branches" (Ludwig and Tongway, 1996). All species of plants declined during the drought in areas with and without branches. Most species declined to or near zero, but recent field observations indicate that vegetation continued to survive within the fertile patches even with the prolonged drought.

This restoration effort was successful in proving that a simple, inexpensive technique can be used to reestablish the landscape to pre-pastoral conditions. This technique demonstrates a way to amend the nutrient cycling in the soil, improve water filtration and create a microhabitat for organisms. It also demonstrated success despite drought conditions. This is a very important aspect since the climate has unpredictable rainfall events. The restoration effort also shows the importance of understanding the natural patterning of the landscape. Previous restoration efforts had failed because the important landscape processes had been ignored.

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