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REINTRODUCED NATIVE ANIMALS AND THE RESTORATION OF ECOSYSTEM FUNCTION IN RANGELANDS

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INTRODUCTION

Native animals have many important roles in ecosystems, and all organisms that modify, maintain, create or destroy the abiotic environment have been termed 'ecosystem engineers' (Jones *et al.* 1994). Modifications resulting from these engineers can affect energy flows and the availability of resources to other organisms in the ecosystem, including positive feedback to the engineers themselves. Ecosystem engineers may also increase species richness, diversity and productivity by constructing and altering habitat (patches that differ in their availability of resources), enabling organisms of differing resource requirements to co-exist.

The process of soil surface disturbance has major ecological implications for soil movement, litter capture and breakdown, soil nutrition, and consequently, survival of plants and animals in arid systems. Foraging pits created by animals lead to the development and enhancement of 'fertile patches' in arid landscapes. The activity of animals reinforces the natural patchiness that is critical to the functioning of arid systems. Our limited field observations, and empirical data collected over the past five years, indicate that this soil disturbance has a dramatic effect on soil and ecological processes.

Despite the large amount of work conducted on the role of native animals in soil and ecological processes in the northern hemisphere, relatively little is known about their roles in the generally nutrient-poor soils in Australia. Ecosystem theory suggests that the effects of animals on soil processes should be greater in areas where the soils are nutritionally the poorest. We expect that positive feedback processes will likely operate on the animals themselves, improving the functionality of degraded landscapes, and ultimately allowing populations of native animals to be self-supporting. We maintain that the loss of many native ecosystem engineers from arid and semi-arid Australia will have interrupted the natural processes of soil digging and surface recovery, and will have had major effects on landscape resilience. In this paper we review Australian studies of the effects of surface-foraging animals on soil and ecological processes, with an emphasis on the semi-arid woodlands of eastern Australia and the arid shrublands of central Australia.

SOIL EXCAVATION CONTRIBUTES TO PEDOGENESIS

One of the most apparent and persistent effects of foraging animals is the excavation of surface soils during foraging. Soil disturbance increases the area of capture for seeds, traps litter, and activates mineralisation processes that ultimately result in nutrient-rich, healthier soils. A number of generalities are apparent. There is considerable variation in the mass of soil moved by animals (Table 1). Bilbies (*Macrotis lagotis*) and bettongs (*Bettongia* spp.) together move up to 6 t/ha of soil. Assuming that the longevity of their pits is about 3-5 years (using allometric relationships from Whitford and Kay 1999), annual rates of 1 t soil/ha are not unrealistic. Data from western Australia suggest that small hotspots of intense activity can generate large volumes of soil (Garkaklis *et al.* 2004) with high turnover rates of up to 4 t/ha/yr.

Bilbies and bettongs studies in Central Australia excavated significantly more soil (five to eight-times) than rabbits, with greater excavation in the dunes and the ecotones between gibber plains and dunes, compared with the gibber plains (James and Eldridge 2007). Digging destroy soil structure and reduces stability of soil aggregates by converting non-erodible macro-aggregates (> 0.84 mm diameter) into micro-aggregates that are susceptible to erosion. Depending on the soil texture, loose and poorly-structured material may be left on the surface, and this material is susceptible to wind and water erosion (Whitford and Kay 1999). Finer material is generally clay-enriched and more porous compared with surface soils. Therefore erosional losses are likely associated with reduced concentrations of essential soil nutrients such as nitrogen and carbon. Simulated rainfall experiments on soils with varying density and cover of foraging pits indicated a greater concentrations of fine material in eroded sediment compared with the intact soil. Digging also destroys the microphytic soil crusts comprising lichens, bryophytes and cyanobacteria that binds the soil and prevents soil erosion. This likely affects infiltration processes, with feedback effects on soil nutrients and soil respiration.

Table 1. Reported one-off rates of soil excavation by native and feral ecosystem engineers in arid and semi-arid Australia. [a] annual rates

Animal	**Study location**	**Soil mass (t/ha)**	**Reference**
Bettong	Western Australia	1.60 – 4.00[a]	Garkaklis *et al.* (2004)
Bilby-bettong	Central Australia Cobar NSW	1.27 – 5.99	James & Eldridge (2007) Huang (2007)
Echidna	Scotia NSW Bourke NSW	0.39 – 2.07	Eldridge & Kwok (in press) Huang (2007)
Goanna	West Darling NSW Cobar NSW Central Australia	0.07 – 0.88	Huang (2007) Eldridge & Kwok (in press) James & Eldridge (2007)
Kangaroo	Cobar NSW	0.74 – 2.70[a]	Eldridge & Rath (2002) Eldridge & Kwok (in press)
Rabbit	West Darling Cobar NSW Central Australia	0.10 – 0.60	James & Eldridge (2007) Huang (2007)

FORAGING PITS TRAP WATER, LITTER, SEDIMENT AND SEED

Animal foraging pits are known to intercept water, organic matter and seeds (Reichman 1984, Boeken *et al.* 1995, Whitford and Kay 1999), developing into sites of greater moisture and litter mass, and therefore nutrient-rich hotspots of litter decomposition (Steinberger and Whitford 1983, Hawkins 1996, Garkaklis *et al.* 1998). Data from artificially-created echidna pits in the semi-arid woodlands indicate higher decomposition rates in pits compared with the surface soils, and greater seed capture and plant species diversity (D.J. Eldridge unpublished data).

The ecosystem effects of reintroduced bilbies and bettongs is currently being compared with those of the European rabbit (*Oryctolagus cuniculus*) and Gould's sand goanna (*Varanus gouldii*) in desert shrubland in Central Australia. This work shows that the foraging pits of all species trap litter and seed (James and Eldridge 2007), with litter restricted almost exclusively to the pits and areas under tree canopies. Litter trapped below the surface in pits likely contributes to soil nutrient pools, unlike material on the surface which is broken down by photo-oxidation and does not contribute to carbon and nitrogen pools. Pits also contain higher levels of labile (active) carbon and mineralisable nitrogen compared with the surrounding soil (James *et al.* in review).

The ability of foraging pits to intercept litter and to retain it close to the soil where it is decomposed by micro-organisms is a critical process that could drive nutrient dynamics in semi-arid ecosystems. Foraging pits of native and reintroduced species have significantly higher concentrations of labile carbon compared with rabbit pits (James *et al.* in review. This work provides strong evidence for the view that rabbits have not assumed the ecosystem role of native animals in terms of enhancing soil nutrients and thus their effects on survival of pit-resident plants is likely to be different from those of native animals. Further, goannas appear to excavate more soil in the presence of bilbies and bettongs than where they occur alone or with rabbits. We believe therefore that structures constructed by different animal species may have markedly different effects on the way that litter is trapped and therefore how nutrients are mineralized.

SOIL FORAGING ANIMALS AND RESTORATION: KEY KNOWLEDGE GAPS

With an increasing understanding of the effect of soil- foraging animals on ecosystem processes comes an appreciation of the impact of their loss throughout much of arid Australia and the question of whether reintroductions can initiate ecosystem restoration. A number of key issues need addressing.

Are we reintroducing animals into suitable habitat?

Because large areas of Australia's rangelands are now severely overgrazed, we may be releasing animals into environments that may now be sub-optimal due to changes in soils and vegetation over the past 150 years. Altered fire regimes and the introduction of exotic pests such as the European rabbit, with which these animals compete is thought to have had a substantial effect on reintroduced animals. For example, relict mounds of the burrowing bettong (*Bettongia lesseur*) are found across large areas of eastern Australia. While they may have occurred, for example, in the semi-arid woodlands many years ago, the landscape is now substantially different to what it was and thus their ability to survive in today's environment is likely compromised.

Can we control feral predators ?

The largest impediment to reintroducing locally-extinct soil-disturbing animals is the need to control feral animals, particularly feral predators. Arid Australia has suffered the highest rate of recently recorded mammal extinctions worldwide (Short and Smith 1994), most likely due to the introduction of feral predators such as the European Red Fox (*Vulpes vulpes*) and the domestic cat (*Felis catus*) (Morton 1990, Short and Smith 1994). Rabbit control is also an issue. As well as being potential competitors (Robley *et al.* 2001), many existing rabbit warrens are thought to be abandoned bilby and bettong warrens, and are being destroyed to reduce re-invasion by rabbits. Widespread elimination of rabbit warrens without replacement by warrens of reintroduced species may be detrimental to the survival of a range of native vertebrates and invertebrates that inhabit these warrens.

Can reintroductions benefit land managers?

If conservation agencies are to be successful at reintroducing native animals back into the rangelands, they must be able to demonstrate to all users that, not only is control of feral predators possible and practical, but that reintroduced animals will provide ecosystem benefits that will make their protection financially viable. These services could be in the form of greater soil productivity or more effective control of woody shrubs (Noble *et al.* 2007). However, once the ecosystem engineering role of native animals is widely recognised, land managers will be more inclined to adopt measures that are likely to enhance the prospects of survival of native mammals outside of exclosures.

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