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The erosional impacts of grazing animals

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I Introduction

A large part (40%) of the world's land surface is rangeland, of which 80% is in arid and semi-arid parts of the world (Branson *et al.*, 1981) and much (34.5%) of the world's land degradation is attributed to the grazing animal, especially in Africa, 49.2% of that continent's degradation, and Australasia (80.6%) (Oldeman *et al.*, 1991). But the erosional impacts of the grazing animal can also be marked in temperate countries such as New Zealand (Zotov, 1938; Kerr, 1992), Britain (Evans, 1997) and Ireland (Douglas, 1995; Stapleton, 1996), where there are too many sheep, and in arctic Norway (Evans, 1996a) where there are too many reindeer. In this article, I discuss the erosional impacts of grazing animals on both rangeland and the enclosed and often improved grasslands such as those in the UK, New Zealand and temperate New South Wales, Australia.

Animals have erosional impacts on the land surface in both direct and indirect ways. Directly, animals can create and then maintain and expand areas of bare soil, upon which the weather acts; indirectly, by facilitating the rapid runoff of rainfall which may only slightly erode the surface upon which it gathers but which can downvalley incise into the ground surface forming gullies.

In the past, before the drawing up of national boundaries and the increases in countries' populations, nomadic tribes and their herds of domesticated animals roamed freely in search of food (Coppock, 1993). In these localities the carrying capacity of the vegetation was probably exceeded only in times of extreme drought.

In the natural state, or where humankind was small in number and had little impact on the land, it is unlikely that grazing animals caused widespread erosion. Only where animal routes were confined or rivers crossed at a particular point would the impacts of hooves create erosion. In arctic Canada, a herd of 500–1000 reindeer (caribou) stranded on the 40 km^2 Rideout Island starved to death once the palatable vegetation was grazed out, but hardly any erosional damage was inflicted on the landscape (Henry and Gunn, 1991). Only 3% of the tussock tundra on the island was bare of vegetation, compared to

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1% on the mainland. Off Alaska, on St Matthew Island, the reindeer population 'crashed' after all the preferred vegetation had been eaten, and although bare soil was created during this period it was rapidly colonized and protected by mosses (Klein, 1987). Only on South Georgia, in the south Atlantic, was much bare soil initiated by reindeer, and there the reindeer herds were confined to small parts of the island by rocky relief and ice (Leader-Williams *et al.*, 1987) and the carrying capacity of the vegetation was not exceeded. Even here, however, erosion was not marked nor widespread and was mainly confined to the very vulnerable peat soils (Evans, 1997). The reindeer were introduced to South Georgia by whalers.

In the rangelands of North America, Indians followed the herds of buffalo and it was not until domesticated cattle and sheep were introduced by European colonists that the vegetation and soils of the plains and mountains were put under stress. These changes were associated with the onset of erosion (Renner, 1936; Cooperrider and Hendricks, 1937; Thornthwaite *et al.*, 1942). In Argentina (Busso, 1997), Australia (Harrington *et al.*, 1984), the Falkland Islands (Wilson *et al.*, 1993), New Zealand (Scott *et al.*, 1988; Kerr, 1992) and southern Africa (Scoones, 1989a), for example, animals were introduced over the last century and a half by colonists, and vegetation types previously never or only lightly grazed were exploited – erosion followed. Where sheep were introduced much earlier, as in Iceland, the erosional impacts have been severe; 30–40% of Iceland has suffered erosion (Thorsteinsson *et al.*, 1971).

When political conditions changed in Ningxia, China, adjacent to Mongolia, especially after the revolution of 1949, the number of animals, mostly sheep, rose sharply (Ho, 1996). Now, much (77%) of the remaining grassland is suffering desertification and erosion. In Inner Mongolia, numbers of domesticated stock increased rapidly after 1955 when the land was 'liberated' by China (Zhaohua, 1982) and sand drifting became very active.

In other countries, animal numbers have increased over the last few decades for economic reasons which were closely associated with the introduction of new social and political policies, for example reindeer in Norway (Evans, 1996a), and sheep in Britain (Evans, 1997) and Ireland (Douglas, 1995; Stapleton, 1996). In these countries bare soil and erosion have been initiated by the grazing animal.

It is not only domesticated animals which initiate erosion. In national parks, such as Yellowstone in the USA, because herds of deer are largely confined to the park and their numbers are not kept in check, tracks and expanses of bare soil on many slopes could clearly be seen in 1986. The implication of such an observation is that while there may be enough vegetation in a locality to sustain animals and their offspring (i.e., the threshold carrying capacity of the land in terms of production and economics has not been exceeded), the erosional threshold has been crossed.

The impacts of the grazing animal can be confused with, or compounded by, the effects of climate on the landscape (Graf, 1988) because severe drought, especially in arid and semi-arid areas can also cause the deterioration of the vegetation cover. However, as Prosser (1996) has noted for southeastern Australia, it is unlikely that widespread erosion in valley floors which started contemporaneously over a wide area was due to climate change, which hardly changed the vegetation in the valleys, but to the introduction of grazing animals which weakened the vegetation cover in valley floors.

In this article I will describe how animals impact on the landscape to create bare soil, by weakening the vegetation cover by grazing and then by breaking this cover down by trampling. Trampling maintains and expands the area of bare soil upon which frost, rain and wind act. The erosive forces acting on the soil will not be described in detail. The

Animals prefer green vegetation (Low *et al.*, 1981; Ring *et al.*, 1985)) and in arid and semi-arid areas will concentrate on those areas where green shoots survive longest, especially on flood plains, in valley floors or in drainage lines (Foran, 1984; Coppock *et al.*, 1986; Scoones, 1989b; 1993; 1995). The surfaces of these areas are constantly trampled, therefore, and vegetation may be destroyed. In arid Australia riverine strips and calcareous soils are preferentially grazed, where green vegetation, shade and sheep campsite (shelter) locations are found. These preferred locations provide 60% of the vegetation production on 30% of the area, and it is on these areas that erosion is often prominent (Stafford Smith, 1990).

In more humid climates cattle and sheep may also congregate in preferred localities, on valley floors where the grasses and forbes are more palatable and nutritious (Skovlin, 1984; Kie and Boroski, 1996), and greener than on the more drought-prone shallow soils on adjacent slopes. Cattle prefer not to graze steep or rocky slopes and will often congregate on valley floors in summer in Colorado and in winter on gently sloping ridge crests (Senft *et al.*, 1985). Sheep will often shelter or rest in shady valleys and on ridge crests (Bowns, 1971) or on or near rocky outcrops or broken ground. Areas of bare eroding soil are often prominent below convexities because sheep often shelter there (Evans, 1996b). In upland England, scars and terracettes form more readily on slopes steeper than 15° (Evans, 1996c; Loxham, 1997). In north Norway, where reindeer travelled alongside fences, bare peat and mineral soils were exposed by trampling on 4° slopes; on slopes away from fences tracking was noticeable across peat on slopes steeper than 7°, and across mineral soil where 13° or more (Evans, 1996a). Tracking was often prominent in Finnmark on slopes of sandy or gravelly glaciofluvial terrace and subglacial esker deposits (Evans, 1996a). Where tracks and terracettes converge on the upper slopes at the heads of valleys bare soil may result (Hurault, 1968).

Much bare soil is exposed around watering points in arid and semi-arid areas (Harrington *et al.*, 1984; Valentin, 1985; Beeskow *et al.*, 1995) and along fencelines or routelines where relief forces animal tracks to converge (Evans, 1996a).

In arid and semi-arid environments crusts often protect the soil. These may have been formed by rainsplash sealing the soil or by lichens, or by algae or cyanobacteria binding soil particles. In wetter climates bryophytes may play a similarly protective role. These protective surfaces are easily broken down by hooves (Eldridge and Robson, 1997).

When soils are wet, which may be much of the time in humid areas but for much shorter periods in semi-arid areas, they are vulnerable to trampling. Grass may be buried by trampled mud (Edmond and Hoveland, 1963). Soils formed in very wet localities, such as peats, are very susceptible to trampling and the formation of bare patches, as in Britain (Evans, 1997), Ireland (Watson and O'Hare, 1979; Douglas, 1995) and arctic Norway (Evans, 1996a).

Many gullies in semi-arid areas, for example, in Zimbabwe, follow cattle trails, especially where these lead to rivers or if they follow drainage lines. Gullying along tracks has been noted in Australia (Condon *et al.*, 1969a) and the USA (Cooke and Reeves, 1976). Trampling along a track can lead not only to a decline of vegetation cover but also creates a depression in the soil surface. Thus, an increase in bulk density along a track, compared to adjacent slopes, of only one unit, say from 1.0 to 1.1 g/cc, will lead to a compression of the top 150 mm of soil of some 14 mm. Runoff channelled along such compacted and impermeable depressions can incise where a convexity is crossed, which increases the turbulence and velocity of flow. Duce (1918: 452) noted that in the American southwest 'Cattle make trails along the line of easiest passage, usually along the recolonization of bare eroding soils and gullies, as in the Australian alps (Anon, 1983), England (Evans, 1997), the middle east (Pearse, 1971), New Zealand (Zotov, 1938) the Rio Grande valley, New Mexico (Cooperrider and Hendricks, 1937) and South Georgia (Leader-Williams *et al.*, 1987). Exclusion demonstrates that it is animals which keep soils bare. Trampling is extremely effective at killing seedlings and stopping the recolonization of bare soil; in Utah, USA, after one year only 0.4% of seedlings survived trampling (3 of 759), compared to 11.6% in an ungrazed pasture (Salibi and Norton, 1987). However, in some localities where the soils are very unstable, such as peat in Britain (Evans, 1997), solonetzic or duplex soils in Australia (Condon *et al.*, 1969a), the climate is semi-arid (Fuls and Bosch, 1991) or slopes very steep and the climate harsh, as in the high country of New Zealand (Scott *et al.*, 1988), once bare soil is exposed it may never be stabilized by recolonizing vegetation.

Eroding patches of bare soil created by animals have been referred to as 'sheet erosion' (Bryant, 1973) or 'sheet wash' (Whitlow, 1988), or 'upland erosion' (Evans, 1996b); in Australia, Zimbabwe and Britain these features can look very similar. Evans (1996b) preferred 'upland erosion', for surface stripping of soil is governed not only by the weather but also, and most importantly, by animals, and in Britain it generally occurs in the uplands. Besides, though a sheet of soil is being eroded, 'sheet erosion' and 'sheet wash' are also used in connection with the stripping of soil from arable land, usually by runoff, i.e., inter-rill erosion (Bergsma *et al.*, 1996). There is a need for a better term to describe eroding patches of bare soil created by animals.

Bare soil may be created and expanded in area by animals causing the removal of the surface litter and vegetation, but surface lowering of the soil by wind or water erosion may not take place. This may be because the threshold of vegetation cover is not passed (see section IV) which constrains wind and water erosion processes. In some localities, because of low relief, mostly gentle winds and few rainstorms, as in the Kalahari (Dougill and Cox, 1995), little erosion takes place. There is negligible erosion on flat plains of coarse sandy and clay soils in central Australia (Condon *et al.*, 1969a). Vegetation may be greatly depleted, for example, around a well in a semi-arid environment but the high organic matter content in soils near the well, because of the incorporation within the disturbed topsoil of animal dung, inhibits erosion (Valentin, 1985). Many rangelands are flat or very gently sloping and though subject to occasional intense rainfalls, water may flow from the land as a sheet but not incise. In such localities, therefore, the productivity of vegetation may be affected by grazing, but accelerated erosion will not be a problem although it may be downvalley (see section VII).

IV Threshold vegetation cover and erosion

As vegetation cover, both living and dead, declines so the severity of erosion increases (Figure 1). On arable land the critical amount of cover which protects the soil from water erosion is about 30% (Evans, 1990b); less than this erosion increases rapidly in severity; more than this, amounts eroded are low. However, in some grazed semi-arid areas cover as low as 15% has largely protected the soil (Table 1) from water erosion; in other grazed localities the threshold cover could be as high as 75–85%.

Within the Rio Grande catchment the mean depth of erosion within 1 m^2 to 6 m^2 quadrats taken within areas representative of different degrees of vegetation deterioration – low, medium and high – within different vegetation types was related to the

Table 1 Threshold vegetation cover at which runoff and erosion increase markedly

Vegetation cover (%)	Location	Reference
15	Fescue grassland, Alberta, Canada	Johnston *et al.* (1971)
20	Grassland, southern Ethiopia	Coppock (1993)
20–30	Semi-arid Kenya	Dunne *et al.* (1978)
30	Rangeland	Branson *et al.* (1981)
33	Edwards Plateau, Texas	Thurow *et al.* (1988)
35–40	Semi-arid Botswana	Abel (1993)
40	Semi-arid and subhumid Kenya	Zobisch (1993)
50, 65, 70	Rangelands, USA	Blackburn (1984)
70	Semi-arid mountains, USA	Skovlin (1984)
75	Colorado, USA	Branson and Owen (1970)
75	Pasture, New South Wales, Australia	Lang and McCaffrey (1984)
75	Boise River catchment, USA	Renner (1936)
85	Highlands, Ethiopia	Mwendere and Mohamed Saleem (1997)

Table 2 Vegetation cover and depth of soil stripped in various vegetation types in the upper Rio Grande watershed, USA

Vegetation type threshold	No. in sample	Regression*	R^2 (%)	Cover**
Semi-desert savanna of lowest plains	18	D = 78.0–1.94 C	54.6	40.2
Semi-desert grassland of high valleys	18	D = 88.6–1.46 C	59.1	60.6
Semi-desert grassland of high tableland	38	D = 77.7–1.39 C	40.8	55.9
Sagebrush	14	D = 87.0–1.47 C	47.0	59.2
Savanna woodland	14	D = 73.5–1.26 C	62.9	58.3
Woodlands	14	D = 121.0–1.91 C	67.0	63.3
Pine-fir forest	18	D = 51.2–0.66 C	44.4	77.6
Spruce-fir forest	16	D = 79.3–0.96 C	68.3	82.8
All grassland	74	D = 76.2–1.38 C	43.3	55.2
All woodland	62	D = 77.4–1.05 C	52.9	73.7
All vegetation types	150	D = 72.4–1.07 C	43.9	67.7

Notes:
D = depth; C = cover.
*Polynomials slightly improved the explanation of variance, but it is the point at which the straight regression line meets the horizontal axis that is of interest here, so a simple regression will suffice.
**Cover when D = 0.
Source: Data from Cooperrider and Hendricks (1937).

percentage of ground cover (Figure 1). But the threshold varied between vegetation types from 40 to 83% (Table 2). The variation of the threshold vegetation cover probably relates not only to climate but also to the size of the bare patches within the vegetation type and whether these are linked, especially by tracks, which is more likely when animal movements are confined between shrubs and trees.

From the meagre data available the threshold vegetation cover to reduce the efficacy of wind erosion greatly is lower than that for water erosion, about 15% (Branson *et al.*, 1981). Much of the experimental (rainfall simulation, plot and catchment) and observational evidence of erosion of rangelands suggests that it is only when ranges have been subjected to high grazing intensities, compared to moderate and low, however these are defined – by stocking intensity and/or appearance of the vegetation (Ellison *et al.*, 1951) – that runoff and erosion become markedly above the norm.

V Threshold grazing intensities and erosion

For decades range scientists have concerned themselves with the impacts of animals on vegetation types (Stoddart *et al.*, 1975) because, if threshold carrying capacities are exceeded, the ranges may deteriorate significantly and the livelihood of pastoralists will be much affected (Harrington *et al.*, 1984). Within this productivity/economic framework, however, the concept of carrying capacity is now being questioned, particularly for African conditions (Bartels *et al.*, 1993; Warren, 1995). The carrying capacity of a range is an estimate of how much and what type of vegetation will grow there and how many animals and, importantly, their offspring that vegetation can support; it can be estimated for an annual grazing cycle or on a monthly basis, i.e., 1 animal unit per month (aum; Skovlin, 1984). Unfortunately, for the geomorphologist, an animal or livestock unit is defined by how much vegetation an animal needs or consumes, for example, 1 head of cattle = 8 sheep = 11 goats = 133 rabbits (Wilson and Harrington, 1984), not how much damage it does to the landscape for, even if the ratios were unvarying, and they are not (see section II), the carrying capacity of an animal need not be equivalent to its erosional impact.

Both the amount of vegetation eaten by livestock as well as the number of hooves which are impacting on the land need to be taken into account when assessing the erosional impact of animals. Grazing intensity is the number of animals which graze a range, expressed in ha/animal or livestock unit. It is expressed here in this way, rather than animal or livestock unit/ha which is used by range scientists, because it is the whole animal which damages the landscape. When grazing intensity is given in terms of the animal, generally cattle or sheep, intensities can be compared between localities. When it is given in terms of livestock units the comparison is made more difficult, because it is not known how many animals are grazing an area, for the proportions of the different kinds of animals may vary but give the same livestock unit intensity.

Grazing intensity is usually given on an annual basis, not a seasonal one, although often in the USA grazing intensity is expressed in monthly terms. Intensity is often underestimated for young unweaned animals are not counted. For example, cattle less than 6 months old are not included in carrying capacity/grazing intensity estimates in the USA (Stoddart *et al.*, 1975), nor are lambs on ranges grazed by sheep, only ewes are counted.

It is the maximum grazing intensity which is of greatest interest, for it is at this level that most vegetation is removed and trampling damage inflicted. Whether grazings recover in periods of less intense grazing is also of interest, for example, when animals have been removed for sale at market. In the hills of Britain, however, when grazing intensities are lower in winter the weather is too harsh for vegetation to recolonize bare soil.

Grazing intensities range widely according to climate and vegetation and soil. Cattle grazing intensities vary from 25 to 62.5 ha/head of cattle in arid central Australia (Foran, erosion became more prevalent (Zhaohua, 1982). In the southeastern semi-arid zone of Zimbabwe, cattle numbers increased rapidly after the introduction of disease eradication programmes in 1930 (Scoones, 1989a; 1993). Cattle numbers stabilized until the 1960s, although fluctuating around a mean because of droughts, after which they again expanded rapidly until the 1980s, by a factor of between 1.5 and 2.0, and rarely higher, for nine communal areas. In the 1990s numbers have declined greatly because of droughts. In the sandveld of Zimbabwe, grazed-out bare patches of soil are now prominent, and more prominent are the gullies encroaching along drainage lines and tracks. The doubling of animal numbers in a locality from a fluctuating, although more or less stable base which may have been accompanied by vegetation changes but not erosion, is associated with erosion of the rangelands.

VI Rates of erosion of grazed land

Many studies have been made of runoff and erosion on grazed plots of various sizes using both simulated and natural rainfall, and in small catchments, especially in the USA. Many of the USA studies have been summarized by Blackburn (1984). As grazing intensities increase runoff and erosion increase, particularly where plots or catchments are heavily grazed. Often rates of erosion on slopes are low, <1 t/ha. Amounts eroded were much greater from an overgrazed catchment (8.1 t/ha) in Oklahoma with patches of bare soil and gullies than from a grazed catchment in excellent condition (0.3 t/ha) (Menzel *et al.*, 1978). In parts of New South Wales, Australia, in winter runoff could be almost instantaneous as rain fell on saturated paddocks (Armstrong, 1992). However, the runoff in the three small headwater catchments carried small amounts of sediment (0.8–1.6 t/ha/year over a two-year period) because although the paddocks were heavily grazed, almost down to the soil surface, the vegetation cover was high. Downstream, volumes eroded in three larger catchments were higher (3.0–4.1 t/ha/year) and the material came from gullies incising into the valley floors.

When rates of erosion are higher, as in some catchment studies, it is often not clear if soil is being transported from both slopes and channels. For example, compared to ungrazed pastures cattle overwintered on improved pastures at Coshocton, Pennsylvania, increased rates of erosion by a factor of 15.5 (Owens *et al.*, 1997). The soils in winter were saturated and very susceptible to trampling. It is likely much of the sediment came from the trampled valley floor. In Kenya, measurements on slopes using Gerlach-type troughs gave erosion rates lower than those of catchment studies in a similar locality (Zobisch, 1993). In the catchments it is likely that much of the sediment was eroded from streambanks or gullies. In many grazed localities, therefore, rates of erosion on slopes are of lesser importance; it is the erosion of channels which provides much of the sediment load in streams and gullies (Blandford, 1981; Foster *et al.*, 1990).

VII Grazing, increased runoff, and channel and gully erosion

Cattle can physically initiate gully erosion, and break down stream channel and gully banks (see section II). This direct erosional impact is exacerbated by an indirect effect of the grazing animal, an increase in runoff from the land which, when it is confined has the power to scour, incise and cut back upvalley, as described by Duce (1918; see section II).

Many plot and catchment studies in both semi-arid and temperate locations show that heavily grazed ranges produce more runoff and runoff events and sediment than less heavily grazed ranges (Costin, 1980; Blackburn, 1984 – and many later USA studies; Lang and McCaffrey, 1984; Zobisch, 1993; Bari *et al.*, 1995). The greater runoff is related to a number of factors: on heavily grazed rangelands there is less vegetation biomass and cover, both live and dead, which use less water so the topsoil is moister; an increasing amount of bare soil of decreased aggregate stability; an often denser, less porous topsoil with a platy structure; and lower infiltration rates.

Blackburn (1984) summarized many USA studies of the impacts of the grazing animal, in both semi-arid and temperate parts of the country. Comparisons can be made, using his data, between ungrazed and grazed pastures and less grazed compared to more grazed ranges. Bulk density of topsoils was higher in (more) grazed pastures in 88% of 43 instances mentioned in the text; infiltration was less in 90% of 70 instances; runoff greater (95% of 19) and erosion more (81% of 32). As slopes in the USA were denuded of their vegetation because of grazing more runoff ensued. Similar results have been found eleswhere (Johns *et al.*, 1984; Heathwaite *et al.*, 1990; Mulholland and Fullen, 1991; Mwendere and Mohamed Saleem, 1997). It should be no surprise, therefore, that gully and stream channel erosion is widespread in rangelands.

In Britain and Ireland grazing appears, from field observation (Douglas, 1995; Evans, 1996b), to cause on peat moorlands the decline of rainfall-absorbing *Sphagnum* spp. mosses. This was the explanation for the greater runoff in a grazed moorland catchment, compared to an ungrazed catchment, in north Wales (Lewis, 1957), and to the increase in runoff in the Derwent catchment in the southern Pennines in England between 1945 and 1975 (Evans, 1990a); and may partly explain the recent more flashy flooding and erosion of upland riverbanks in England (Sansom, 1996).

VIII Conclusions

Erosion initiated and exacerbated by grazing animals is widespread throughout the world's rangelands. But in rangeland science the impact of grazing animals on a landscape is dominantly discussed in terms of their impacts on vegetation – species change and how many animals a range can carry – not erosion (Stoddart *et al.*, 1975). Even when the concept of carrying capacity is questioned, it is still the productivity of the vegetation and its importance to the livelihood of the grazier/herder that are stressed (Behnke *et al.*, 1993). Over the short term this probably has to be so, for the amounts of bare soil exposed and the gullying have little direct economic impact on the grazier/herder (Evans, 1996b); for even when there is much erosion, it is likely there is still sufficient vegetation to feed the herders' animals. However, the appearance of erosional features indicates to managers and researchers that a nonfavourable state is being arrived at during transitions between grazing states (Westoby *et al.*, 1989).

Over the longer term, the redistribution of soil within a catchment may not be economically damaging and can be considered as a part of an erosion/deposition cycle (Biot, 1993). However, where infertile subsoils are exposed, as in the scalds of Australia (Harrington *et al.*, 1984), or where in humid localities soil depth is reduced sufficiently to affect the availablity of moisture for grass growth, it is likely the longer-term impacts of erosion will be severe.

Although arid and semi-arid ranges may appear to recover after drought (Warren, 1995), the gradual increase in area of bare soil over time which must happen unless animals are kept off the range will have an impact on the carrying capacity of the land. It is the downwind or downvalley impacts of erosion which are probably most important over the short term – the encroachment of dunes on to productive land, the infilling of dams by sediment or the flooding of settlements. What may be even more important is the faster flow of water through a catchment, especially in arid and semi-arid rangelands, so that in headwater catchments rainfall does not seep down to aquifers and replenish water tables.

Many rangeland vegetation types have greater grazing intensities than an estimation of their carrying capacities would suggest, especially just prior to a drought (Condon, 1969; Pearse, 1971; Scoones, 1989a; Leeuw and Tothill, 1990). Although grazing will change vegetation types and reduce biodiversity the land may retain its inherent productivity, but this will be lost if accelerated soil erosion takes place. To stop erosion induced by the grazing animal, the population, social, economic and political pressures which brought about the increases in numbers of animals need to be addressed.

There may have to be a shift of the grazier's attitude – from how many animals are needed to graze a range to give a living, to how many animals can graze an area before erosion is initiated. In the latter case, for an individual grazier, the area of land required may be many times larger than that which is presently grazed. The creation, or not, of bare soil is probably a much better indicator of sustainability than trying to assess changes in vegetation productivity. The initiation and expansion of bare soil, and the formation and extension of gullies, need to be monitored in rangelands, as well as the changes in forage (Bartels *et al.*, 1993). This task may be easier to do than trying to assess the resilience, changes and productivity of the vegetation. More studies need to be undertaken to assess the grazing intensities which will initiate erosion in different vegetation types and climates.

Biot (1993) considered that computer modelling, rather than monitoring, will be more efficient in assessing the erosional impacts of grazing. This is because in arid and semi-arid areas the variation in vegetation cover from year to year is so great that over the short term it may mask the formation of bare soil by animals. A combination of monitoring and modelling rather than a reliance on modelling will probably be best.

Monitoring erosion may also help attribute which of climate change or the grazing animal is the most important in creating bare soil and increasing runoff on rangelands. On balance, presently, the evidence points to the grazing animal.

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