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ANTHROPIC EROSION OF MOUNTAIN LAND IN CANTERBURY

Summary: Anthropic, or man-induced erosion can be recognized on Canterbury's mountain land. Almost all of it is identical in form and mode of origin to other erosion types, and may be indistinguishable unless obviously associated with roads, tracks, or fences. In particular, where vegetation is destroyed or impaired by fire or grazing, it is impossible to separately identify anthropic and natural components of the erosion. Early surveys reported significant anthropic erosion throughout the region. Subsequent work has revealed some errors in methodology, but more importantly it allows the human influence to be viewed in context with the more significant and more extensive natural erosion. The highest sediment yields and erosion rates in Canterbury are within the wetter, and in some places well-forested, areas near the main divide, rather than in the drier, depleted eastern ranges. Some barren screes have changed little over centuries, and even very active unstable screes may be old landforms. Soil stratigraphy reveals a long history of episodic stability and instability. Dated charcoals provide a fire history spanning more than 40,000 yr. More frequent fires between 500 and 1000 yr ago brought widespread deforestation. There probably were regional increases in erosion while forest soils adjusted to loss of tree-root strength. Early pastoralists further increased the frequency of fires and grazed sheep, greatly modifying the grass- and shrub-land vegetation in both stature and composition. Erosion rates would have increased because sheet erosion is more than 10 times greater from bare soils than from those with intact tussock, scrub, or scree cover. Repeat photographs near Porters Pass, however, show both increases and decreases in bare ground rather than a general trend over the last 90 yr. Widely distributed grassland transects also show little consistent change in bare ground in the last 10 to 35 yr. Harsh climate and soil infertility slow or inhibit plant re-establishment on bared ground for decades and probably centuries in the drier mountain lands of Canterbury .

Keywords: Anthropic erosion, accelerated erosion, natural erosion, sheet erosion, sediment yields, scree, soil stratigraphy, fire history, deforestation, pastoralism, human influence, repeat photography, grassland vegetation transects, Canterbury, Mountain land, soil erosion.

Introduction

Humans have been part of the New Zealand ecological scene for about 1000 years, and are accused of initiating a major increase in the extent and rate of erosion in their brief tenure (Zotov, 1938; Jacks and Whyte, 1939; Committee of Inquiry, 1939; Cumberland, 1944, 1962; Gibbs *et al.,* 1945; Tussock Grassland Research Committee, 1954; Molloy, 1962; McGlone, 1983). In this millenium, the mountain land of South Island has passed through 3 eras of stewardship. Beginning perhaps as early as the 10th century AD, it was exploited by small numbers of Polynesian hunters (Davidson and Vaile, 1976). In the 19th century, beginning about 1846, this 'Polynesian' era changed abruptly to one of pastoral exploitation as grassland was settled by pastoralists, and stocked with sheep and cattle by 1870 (O'Connor, 1982). A slow transition from this 'exploitative' era to the present one of pastoral conservation began about 1900 with the. dawn of an awareness internationally of the value of soil conservation. The transition may still continue today. For convenience we place the beginning of the 'conservation' era in New Zealand at 1941, with the passage of the Soil Conservation and Rivers Control Act (McCaskill, 1973). The current self-sustaining spread of exotic trees, and the increase in recreational use may herald another transition: to an era of re-afforestation and tourism.

Most concern about erosion of mountain land in Canterbury has been with the eastern, pastorally-occupied high country, where it was seen as a threat to downstream assets through a heightened risk of flooding, and to production onsite through loss of plant cover. A large share of a perceived increase in erosion (Zotov, 1938; Jacks and Whyte, 1939; Committee of Inquiry, 1939; Cumberland, 1944; Gibbs, *et al.,* 1945) was attributed to early pastoral farmers who used fire and heavy grazing to break the land into production (Tussock Grassland Research Committee, 1954). There is unequivocal evidence. (Molloy, 1962; Cumberland, 1962; Harrison, 1982; McGlone, 1983) that some of this erosion occurred in the Polynesian era, and further understanding of erosion rates indicates that erosion always has been rapid here (O'Connor, 1976; Whitehouse, 1987). By its very nature, the erosion story will never be complete. Research in the South Island high country in the last 10 to 15 years, however, provides much new evidence on erosion, and of the human influence, or lack of influence on it.

This analysis examines some of the new information, concentrating on the mountain land of Canterbury, with which we are most familiar. Recent papers by O'Connor (1980, 1984, 1986), Mather (1982), and Whitehouse (1984) have reviewed much recent high-country research. The present synthesis adds to these reviews, discussing the human influence on sediment yield and erosion. It also attempts to modify the widely held perception that sees a lack of vegetation as erosion.

Normal, accelerated, and anthropic erosion

Erosion, which is the loss of soil and detritus from the land, can be influenced by intentional and inadvertent human intervention. A conceptually useful teaching aid has been to recognize two broad categories: *normal* and *accelerated* erosion (Bennett, 1939). *Normal* (also called *geological)* erosion occurs under so-called 'natural' environmental conditions. Bennett portrayed normal erosion as being imperceptibly slow and benign with no nett loss of soil when occurring under grass and trees. But he recognized that naturally bare and sparsely vegetated areas, precipituous slopes, and water-concentrating depression eroded more rapidly. *Accelerated* erosions pertains to speeded-up loss of material after plant cover is removed or impaired. It includes *naturally* accelerated erosion (induced by extreme drought, lightning, wind-throw, plant disease, snow avalanche, and natural erosion on precipitous slopes, and in water-concentrating depressions). It also includes erosion accelerated by human activities. Bennett proposed no special term for the latter, which he variously calls *erosion, soil erosion,* and *accelerated erosion,* although none of these is specific to it. Bennett's ambiguous usage was thoroughly instilled into New Zealand usage by Prof. C.A. Cotton (a member of the Committee of Inquiry, 1939) and Prof. K.B. Cumberland. It still is the most frequently followed English usage internationally. Strahler (1956) introduced the term *induced* erosion to overcome the ambiguity, but many agents independent of human activities induce erosion, so the term is barely more preferable. More recently, Belpomme (1980) has used the term *anthropic* erosion for any erosion attributable to human activity. This usage is followed in the present paper.

Recognizing anthropic erosion

In the early reconnaissance surveys of erosion in New Zealand (Cumberland, 1944; Gibbs, *et al.,* 1945), extensive areas of accelerated, or anthropic erosion were recognized in the South Island high country, identified ostensibly by the presence of truncated soil profiles or expanded screes. At the rapid speed with which these surveys were made, however, it was necessary to make use of the 'remote sensing technology' of the day, and much of the erosion was recognized simply by a perceived impairment of the completeness of the vegetation cover. Thus, Gibbs *et al.,* could write (1945, p.31) '...every advantage was taken of any changes in vegetation which might serve as indices of degree of erosion... [making]...it possible to estimate the degree of erosion of several adjoining mountain slopes by inspection from a single elevated point.' Thus was introduced into the eastern South Island high country, a paradigm which equated much of the lack of vegetation with soil erosion, and soil erosion with anthropic erosion. Given the thinking of the day, the over-simplication of the association of bare ground and erosion, was appropriate for an initial rapid reconnaissance. Combined with the error of equating soil erosion with anthropic erosion, however, it led to a distortion in the perception of the extent of the human influence which still persists. The paradigm, which was widely expounded internationally by Bennett (1939) and Norton (1939) was accepted in New Zealand (MWD, 1969) with little critical appraisal, and is applied routinely, even today (Eyles, 1985).

Recognizing anthropic erosion was never as simple as indentifying a 'less-than-natural' vegetation cover, nor finding where erosion had taken place within the time of human occupation. It always required the positive determination that erosion had occurred and with human assistance. With the exception of a few minor erosion forms such as engineering excavations, roads, and wheel ruts, there are few unique types of anthropic erosion. Almost all are identical in form and mode of origin to other types, and thus usually are indistinguishable from them. The attribution of human involvement must be from seeing the people, or from inferring their involvement from the manner of association of the erosion with their artifacts, or other signs of their activity. In a few instances, this association is direct and may be obvious, as with slope failures and rilling along roads, tracks, and plough furrows, stock trampling along fences, in trails, and at gates, and widespread slope failures on deforested hillsides. But, often the association is neither direct nor obvious, and offers a subject for much debate. The occurrence of a truncated soil profile in an area of burned or grazed land for example is not sufficient to identify it as a result of anthropic erosion: it is necessary also to establish beyond reasonable doubt that the fire had a human cause, and that the truncation resulted from the burning or grazing.

There was no anthropic erosion in New Zealand before human invasion about 1000 yr ago, but we live in a region of frequent natural erosion, and not all of the erosion occurring subsequently has been anthropic. Most researchers recognize some anthropic erosion from each of the Polynesian and European eras. With no agreed criteria for recognizing it, however, there is not likely to be agreement on what is anthropic and what is natural erosion. Thus, a distinction so easily made in the late 1930s at mapping scales of 1: 1 000 000 or so, was abandoned when erosion next came to be mapped at the more detailed scale of 1:63 360 (Eyles, 1985).

Table 1: *Soil loss from runoff plots in Canterbury*

Plot	Area† (m^2)	Total sediment yield (kg)	Cover	Proportion of Bare soil	Total 'erosion rate' ($kg/m^2/yr$)	Soil* erosion rate ($kg/m^2/yr$)	Downslope Sediment Flux** (kg/m/yr)
Cass††							
1	3.42	1.66	Grassland	0.20	0.24	–	0.117
2	3.59	0.28	Grassland	0.00	0.039	–	0.019
3	3.66	0.08	Shrub, grass	0.05	0.011	–	0.005
4	3.70	6.07	Nil	1.00	0.82	–	0.400
5	4.10	0.06	Grassland	0.00	0.008	–	0.004
6	3.86	0.20	Shrubland	0.50	0.026	–	0.013
7	3.92	0.10	Shrub, grass	0.00	0.013	–	0.006
Porters Pass#							
1	3.50	0.04	Shrubland	0.01	0.010	0.009	0.005
2	3.50	0.02	Shrubland	0.00	0.005	0.003	0.002
3	3.50	0.01	Shrubland	0.00	0.005	0.001	0.002
4	3.50	0.01	Shrubland	0.00	0.004	0.003	0.002
5	3.50	0.03	Scree	0.00	0.054	0.009	0.026
6	3.50	0.07	Scree	0.00	0.032	0.19	0.016
7	3.50	0.07	Scree	0.00	0.040	0.19	0.020
8	3.50	0.01	Scree	0.00	0.010	0.003	0.005
9	3.50	1.06	Nil	0.55	0.303	0.079	0.148
10	3.50	0.45	Nil	0.45	0.129	0.021	0.063
11	3.50	0.18	Shrub, grass	0.55	0.050	0.028	0.024
12	3.50	0.72	Shrub, grass	0.62	0.206	0.054	0.101
13	3.50	0.02	Shrub, grass	0.00	0.005	0.004	0.002
14	3.50	0.01	Shrub, grass	0.00	0.004	0.003	0.002
15	3.50	1.22	Nil	0.32	0.348	0.021	0.170
16	3.50	6.21	Nil	0.34	1.772	0.057	0.865
17	3.50	0.25	Nil	0.18	0.071	0.022	0.035
18	3.50	1.77	Nil	0.61	0.504	0.014	0.246
19	3.50	1.38	Nil	0.74	0.394	0.035	0.192
20	3.50	1.30	Nil	0.29	0.370	0.032	0.181

† Map projection area of nominal 0.001 acre plots on the hillslope.
* Defined as particles < 2mm diameter.
** Material intercepted per metre of collector across the slope.
†† Calculated from Soons and Rainer (1968). Data from April 1964 to May 1966.
\# Calculated from Hayward (1969). Data from November 1967 to November 1968.

Sheet erosion

Sheet erosion in the strict sense is the removal of thin layers of soil, more or less evenly, by very shallow sheets of flowing water, but it is used more loosely in New Zealand to describe a common form of slow, incremental erosion by wind, raindrops, thinly flowing water, and soil creep including frost heave. It is generally viewed as a major component of anthropic erosion because it is the most frequently occurring form of erosion on bared soil. Whatever its origins, it occurs widely on the mountain land of Canterbury.

Sheet erosion has been 'measured' in three published studies in Canterbury (Soons and Rainer, 1968; Hayward, 1969; O'Loughlin, 1984). It is not known whether these studies were entirely of anthropic erosion. This is of lesser importance here than the information provided on rates of erosion which *can* be anthropic in origin.

Soons and Rainer (1968) measured sediment yields from sheet erosion for 2 years on 7 sloping "4-m^2" (0.001 acre) plots with a variety of plant covers and conditions near Cass (Table 1). Hayward (1969) measured yields for 1 yr on 20 "4-m^2" plots near Porters Pass (Table 1). In both studies the total material reaching the downslope side of a plot by moving across the ground surface was assessed as deriving from sheet erosion on the plot. Thus, material that was in creep transport down the slope when the plot was installed was intercepted and measured as sheet erosion on the plot. This shortcoming overestimates the true erosion rate: from the information we have, the material simply in transport might be any proportion of the measured total. Nevertheless, the data imply much about the erosion. Although the two sets of measurements were made in different areas, at different times, and over very short intervals, the yields from similarly vegetated plots in the two studies are of similar magnitude, which gives reason for faith that the data are broadly representative of yields occurring from "sheet-erosion" processes elsewhere in the area. To this extent, the data are very useful.

If the transport component were negligible, our analysis of the data suggests that soil (defined as particles < 2 mm in diameter in Hayward's study) erodes from surfaces covered with larger rock particles (> 12 mm diameter, such as on scree and erosion pavement) at about 0.012 ± 0.004 kg/m^2/yr. This is 4 times faster than from totally vegetated sites (0.0028 ± 0.0005 kg/m^2/yr), and 3 times less than from non-vegetated surfaces other than scree (0.035:t 0.008 kg/m^2/yr). The 12-fold difference between well-vegetated surfaces, and the latter bare ones, is highly significant.

If the transport component were 100%, the same data would suggest a downslope sediment flux of 0.017 ± 0.004 kg/yr per metre-across-the-slope of all particle sizes on scree and erosion pavement. This is 3.4 times more than moves down totally vegetated slopes (0.005 ± 0.002 kg/yr/m), and about 15 times less than moves down slopes of bare soil (0.256 ± 0.084 kg/yr/m). At least 50 times more sediment moves down bare soil slopes than moves on well-vegetated ones. Sediment transport also should vary with the sine of the slope angle, but the exposure of soil dominates all other influences in the data of Soons and Rainer, and individual plot slopes are not given with Hayward's data.

If we had information on the true areas of slopes delivering the measured sediment fluxes, we could turn the transport rates to erosion rates. We know of no systematic differences in true contributing areas between scree, bare soil, and vegetated areas, however, so it is likely that the true erosion rates on the various surfaces have similar ratios to one another as those calculated above.

Establishment of forest on bare areas greatly reduces soil movement and loss. O'Loughlin's (1984) study of 4.5-m' plots at Hut Creek, within the Craigieburn Forest Park, saw downslope sediment flux decline from 0.07 kg/yr/metre-across-the-slope to negligible quantities over 10 yr with the growth of *Pinus contorta*.

Wind erosion

The prevalence of strong, drying winds throughout Canterbury, makes the entire region susceptible to wind erosion. Numerous shallow closed basins (deflation hollows) and pedestalled grasses in the Mackenzie basin provide very clear evidence there of often extreme soil erosion by wind. Much of this has occurred since the area was deforested early in the Polynesian era (McGlone, 1983), and some can be seen occurring today. Erosion associated with the movement of military tanks and other vehicles, and with the congregation of sheep and cattle about boulders, water troughs and fences, clearly is anthropic. Much of the erosion pavement, and loss of soil in this area probably has resulted from the reduction in plant cover which accompanied the use of the area for pastoral farming, but it is unlikely that we will ever know how much.

Although wind erosion is acknowledged in the mountains of Canterbury, there are no measurements of its rate. Amounts of soil-sized particles in transit in the wind can be measured by suitable sediment traps, as has been done by Butterfield (1971) at 6 sites in the Rakaia, Waimakariri, and Ashburton River Basins. But these amounts represent fluxes of sediment past a small area: they do not provide an erosion rate, because the length of fetch upwind of the collection device is never well defined. Locally thickened accumulations of loessial soil, which can be found within a few metres down-wind, and often upslope, from unvegetated erosion scars, attest to significant and long-continued wind erosion on many areas of broken vegetation cover in the eastern ranges of the Southern Alps. Locally blackened winter snow about areas of exposed rock and soil likewise demonstrate ongoing erosion by wind. Hayward's (1969) 4-m^2-plot study included measurements to compensate the yields for material moved by wind. His results confirm that there is more material moved by wind where there is more fine material exposed to it. Although they allow his plot yields to be corrected for deposition by wind, they do not provide a rate of wind erosion, because the material blew from wider areas than the plots. Past, and continuing accumulation of loess on extensive areas down-wind of the Southern Alps is evidence of continuing, significant, widespread wind erosion within the alps. Evidence that the rate of accumulation of loess has increased in any of the European eras, or the longer Polynesian era is lacking or yet to be documented.

Soil disturbance

Both frequency and magnitude of soil disturbance vary systematically over the Canterbury mountain land, both being greater in the wetter areas near the main divide, and less in the drier eastern ranges (Basher and Tonkin, 1985). For the weakly leached, relatively fertile Haldon and Hurunui soil sets of the eastern ranges, Basher and Tonkin infer that deforestation caused little soil loss because of the low rate of surface erosion, and because new vegetation grew readily on the fertile soils in a benign climate. For the strongly leached and infertile Tekoa, Kaikoura, and Bealey soil sets of the wetter areas, deforestation resulted in much local disturbance, but not enough soil was lost to destroy these impoverished forest soils. Here, the widespread exposure of infertile subsoil and an inhospitable climate continues to inhibit both natural and assisted revegetation and much evidence of erosion will be plainly visible for a long time (Holloway, 1970; O'Connor, 1980; Basher and Tonkin, 1985). Although the drier eastern high country appears to be more eroded, the rates of soil are lower than in the wetter areas. Basher and Tonkin (1985) conclude that the extent of depleted vegetation and the proportion of bare ground are not reliable indicators of the amount or rate of soil erosion.

A quantitative measure of regional soil disturbance, if we knew how to measure it, would be a statistical magnitude-frequency distribution, giving information on the return periods of various volumes or areas of soil disturbance. In the absence of this information, it is useful to have a simple single-value indicator of the activity of steep-land soil erosion. Such an indicator is the life expectancy of a soil - the statistical mean time between the initiation of soil development on a slope and the complete removal of the soil by erosion processes. The concept is new to the study of soil erosion in Canterbury mountain land. It has been approached qualitatively by Basher and Tonkin (1985), and quantitatively by McSaveney and Griffiths (1987). Haldon and Hurunui soils are older on average than Tekoa, Kaikoura and Bealey soils (Basher and Tonkin 1985) because their life expectancies are longer: they last longer because the frequency of destructive storms is less. The quantitative data set assembled by McSaveney and Griffiths is too small to permit discrimination of life expectancies between the various soil sets, but it does reveal an order-of-magnitude reduction in life expectancy for eastern South Island steepland soils in general, occurring with an upsurge in fire frequency in the region beginning almost a 1000 yr ago (McSaveney and Griffiths, 1987). We have no reason to doubt that this reduction is anthropic in origin, and it dramatically pinpoints the beginning of the Polynesian era in the Canterbury mountains at between 940 and 950 yr B.P.

Sediment yields and source areas

Studies of soil disturbance and sheet and wind erosion provide "point" measurements relating to erosion. The very high variability over small areas means that point measurements have not been useful for estimating regional averages, even for a small basin. Hayward (1969) estimated that 8000 4-m^2 plots would be needed to obtain a usefully precise average for his 30 ha study area.

Erosion also provides sediment to streams. Surveys of sediment sources to streams show an even greater variability of erosion than is found for plots. Most sediment comes from a relatively few sources (Mosley, 1980). For most basins, natural factors such as geology, glacial history, and topography appear to be the primary influence (Cuff, 1981; Hayward, 1980; Mosley, 1980; Oaks and Oaks, 1982). For example, in the Harper and Avoca River drainage basins, most sediment arises from erosion of bedrock gullies, cliffs and gorges, and eroding terrace and fan edges in the forested parts of the basins. Erosion attributed to human interference supplies little sediment there (Mosley, 1980).

Although surveys of sediment sources emphasize the extreme variability of erosion, basin sediment yield is a precise measure of regional erosion rate because it integrates rates over the entire basin. Specific annual sediment yields (Table 2) are c. 100 t/km^2/yr in the drier intermontane areas of Canterbury (Twizel and Forks Rivers), c. 600 t/km^2/yr in the eastern foothills (Selwyn and Ashley Rivers), c. 1800 t/km^2/yr for larger rivers draining the eastern Alps (Waimakariri and Rakaia Rivers), c. 4000 t/km^2/yr near the main divide (Hooker River), and even higher west of the divide. Griffiths (1981) finds that rainfall is the most significant variable correlating with sediment yield in the Southern Alps. The highest yields are from basins with the highest annual rainfalls. Yields from the drier and more sparsely vegetated eastern ranges are several orders of magnitude lower than the highest yields, but they are still high in comparison with many other steep-land areas of the world. The high rates reflect the climate and the vigour of the tectonic plate collision which together are forming the Southern Alps (Whitehouse, 1987): they are not high because of recent anthropic influences.

As well as varying by several orders of magnitude from west to east, sediment yields show even greater variability in time. In New Zealand mountain basins, most of the sediment is yielded irregularly during rain-storms. Sediment yielded by the 3.85 km2 basin of Torlesse Stream during a 1951 storm of about 150-yr return-period was 326 times the subsequently measured annual yield (Beschta, 1983). As with annual yields, most sediment yielded during a single storm comes from a few large sources.

This enormous variability in time and space, and propensity for most erosion to occur in major storms makes it very difficult to accurately study individual components of erosion. Thus, anthropic components in basin sediment yields have not been successfully studied in Canterbury. The regional pattern of yields (Table 2) shows that whatever their values might be, they do not mask the dominant variation caused by storm rainfalls. Because most sediment comes *from* a few major sources, anthropic erosion will be an important component in the yield only when the 'major sources are anthropic in origin - as with large slope failures associated with roading, or where spoil is pushed into stream channels. In the major drainage basins of Canterbury, the dominating sediment sources are natural.

Erosion following deforestation

Human alteration of the vegetation cover sometimes causes slopes instability. There are many sites in Canterbury where charcoal *from* woody species is found in the soil. Much of the charcoal is from species of forest trees, and many of the soils have characteristics of forest soils (Burrows, 1983; Molloy, 1962, 1964, 1977; *Molloyet 01.,* 1963; McGlone, 1983;

Table 2: *Measured sediment yields for rivers in Canterbury.*

Location	Specific sediment Yield (t/km^2/yr)	Catchment mean rainfall (mm/yr)	Catchment area (km^2)	Catchment mean elevation (m)
Waimakariri River	1836	1900	3210	752
Selwyn River	642	1300	164	218
Rakaia River	1805	3000	2640	1151
Ashburton River	631	1400	540	1000
Ahuriri River	108	1600	557	1240
Twizel River	144	1800	250	1014
Hooker River	3892	6500	103	1680
Irishman Creek	12	820	142	970
Forks River	132	1600	98	1383
Jollie River	218	1400	139	1490
Dry Acheron Stream†	250	2000	6	1100
Opihi River*	130-185	1100-2000	5-160	700-850
Torlesse Stream#	40	2000	4	1300

Sediment yields calculated from Griffiths (1981) as 1.1 times suspeded yield, or from:
† Griffiths (pers. comm. 1984); *Cuff (1974); and #Hayward (1980), and Beschta (1983).

Wilson, 1976). The charcoals have a wide range of ages to beyond the limit of radiocarbon dating at >40,000 yr BP (Harvey, 1974). The extent of deforestation in early fires is unknown, as much forest regenerated. A sample of 45 radiocarbon dates of charcoal from east-central South Island compiled by McSaveney and Griffiths (1987) shows a large sudden increase in the frequency of fires about 950 yr ago, which continued for 530 yr. The number, and exact timing of these fires early in the Polynesian era is likely to remain unknown: even a single fire forms charcoals having a variety of ages because of the range of ages of living and dead trees in a forest (Molloy, 1977). The charcoal and pollen record from; a peat bog at Porters Pass suggest that a fire 765 yr ago was responsible for the final deforestation there (Goh and Molloy, 1972; Molloy, 1986 *pers. comm.;* McGlone, 1983), but forest removal was far from synchronous over the whole region.

On some of the land, forest regenerated, but much has remained as scrub and grassland. Historical records indicate another increase in fife frequency from about 1850, as early pastoralists burned the scrub- and grass-land regularly (O'Connor, 1984). Areas of forest also were burned then.

The effect of clearing forest and dense scrub from steep-lands on the dynamic processes of erosion is straightforward: the strength of the soil mantle decreases as the contribution from tree roots is lost. The strength of even large roots decays to insignificance within c. 10 yr (Sidle, Pearce and O'Loughlin, 1985). Whether the loss of this binding increases the rate of soil loss depends largely on 3 factors: the state of stress within the treeless soil; the soil's strength; and the occurrence of other events leading to an increase in stress or decrease in strength. No loss of soil through mass movement is expected so long as the soil strength exceeds the *in situ* stresses, and there will be no major loss of soil if there are no storms. Two- to 12-fold increases in sediment yield due to mass movements have often been observed after forest removal, with increases of up to 40 times occurring locally on particularly susceptible lithologies and land forms (Sidle *et al.,* 1985). Longer-term studies (10 to 32 years) generally show increases at the lower end of this range, 2 to 4 times the values under forest, as the increase is mostly within the first few years of removal. These increases do not include sediment from roads or tracks.

For these reasons, we suspect that regional erosion rates increased in Canterbury as the area of forest cover was reduced and slope deposits which had developed under forest, adjusted to their new strengths without tree roots. Regolith instability, where colluvium has buried soils with charcoal at the interface, occurs widely in the eastern high country (Molloy, 1964; Harrison, 1982; McGlone, 1983). About 3 out of every 4 radiocarbon dates for such sites in Canterbury are in the range 500 to 1000 yr BP (McSaveney and Griffiths, 1987). Although the association between the charcoal and soils is only stratigraphic, it is probable that the fires which formed the charcoals led to the regolith instabilities which ultimately buried the soils. With this assumption, the changes in frequency of occurrence of charcoals indicate that the frequency of disturbance rose by almost an order of magnitude at c. 950 yr BP, as might be expected from the increases in sediment yields following deforestation discussed above. McGlone (1983) reports an almost 3-fold increase in the rate of bog infilling near Porters Pass, from 0.6 mm/yr when the bog was surrounded by forest, to 1.7 mm/yr when the area became grassland at 765 yr BP.

Burning of forests and scrub by the early pastoralists also will have increased erosion rates in some burned areas, but we will always have as much difficulty in assessing what contribution this made to the total erosion as we have with the earlier Polynesian period.

Scree dating

It has long been recognized that screes at high altitudes are natural features with highly specialized endemic biota adapted to the ecological niche that originated long before the arrival of Polynesians and Europeans (Fisher, 1952; O'Connor, 1984). Much scree, particularly that below 1500 m, has been attributed to fires and overgrazing during the era of exploitative pastoralism (Cumberland, 1944). Many screes in Canterbury, however, though still currently active at their heads, have a skirting of red-coloured boulders about their bases, often with weathering rinds 0.2 to 0.4 mm thick. This indicates that these screes have been about the same size for at least 400 yr (Whitehouse, McSaveney, and Chinn, 1980). Some low-altitude screes are much older: two described by Whitehouse and McSaveney (1983) have parts of their surfaces that are at lest 2,500 yr old. There also are many screes which intersect stream channels, and so are unable to retain a stable base. Large active screes certainly were present within forested areas before the fires of the Polynesian era. Screes still cut through little-altered forests today. Thus, the presence of screes today in areas which formerly supported forest does not imply that they developed because the forest was removed. We also now know that forest and scree can coexist at the same site. Within a part of an intact forest at Dry Acheron Stream, we find currently active scree on the forest floor, with living trees scarred by rock falls originating from rocky bluffs below the forest limit. The activity is low, but fire would immediately expose active scree to the wider view. Some screes we see today where grassland has replaced forest, may have been exposed intact when the forest was destroyed, but we probably will never know which these are.

Nevertheless, there are places where fresh scree material can be found overlying forest soil with charcoal fragments between the two. Such evidence positively shows extension of scree after fire (but not necessarily because of fire).

Erosion following grassland depletion

Measurements of soil movement on mountain slopes in Canterbury (Hayward, 1969; Soons and Rainer, 1968; O'Loughlin, 1984) suggest that soil is lost fastest from areas of bare soil, diminishing as erosion pavement forms or the soil revegetates. Fires and grazing, principally by sheep, but also by rabbits and other animals during the era of pastoral exploitation are known to have depleted the plant cover within the tussock grassland. The effects of fire and grazing are detailed in Mark (1965, 1980), Payton *et al.* (1986), O'Connor and Powell (1963), O'Connor and Lambrechtsen (1964) and O'Connor (1982). Severe local depletion is well documented for rabbits (Campbell, 1966; Moore, 1976) and tahr (Wilson, 1976). Grazing induces changes in plant-species composition in favour of less palatable plants. Fire and grazing, separately or in combination reduce plant stature and numbers. There is an overall loss in nutritional content. We expect that most change occurred either at the time of initial modification or when stock numbers were at their maximum. In Canterbury, stock numbers peaked in the 1880s and 1890s (Evans, 1956; Dick in Hayward, 1967; O'Connor, 1981, 1982, 1986). Reduction in grassland stature and proportion of grassland cover at this time exposed some soil to erosion. The New Zealand Land Resource Inventory records wind, sheet, and scree erosion as affecting more than 100/0 of a map unit, on over 45% of South Island mountain land (Lynn, 1981), but we do not know how much of this is anthropic or when it occurred.

Vegetation transects

Although the extent of vegetation depletion at the peak of the grazing may not be known, depletion occurring more recently can be assessed from vegetation records. Since 1947, catchment authorities and some central government agencies have supported quantitative assessments of vegetation in the mountain. lands. Where repeat surveys include measurements of area of bare ground, they can be analysed for trend. For the transects in Canterbury, this has been done by Whitehouse *et al.,* (1988) and Rose (1983) and is summarized here.

At 4 sites of eight 20-m transects in the upper south Opuha River, the proportion of bare ground has varied from year to year since surveys began in 1963 (Fig. 1). There was a significant decrease in bare ground from 1963 to 1985 on all transects at the lowest altitude site. At the other 3 sites, there was no significant trend, although 4 transects showed an increase, and 6, a decrease in bare ground.

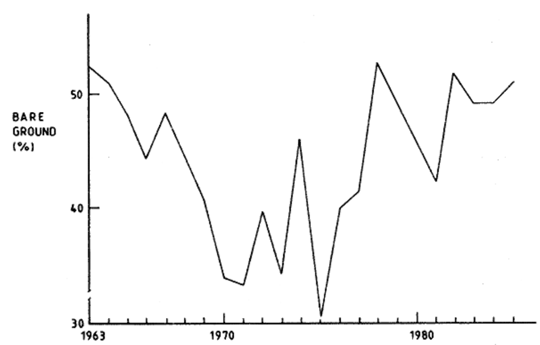

Figure 1: *Variation in the proportion of bare ground, 1963 to 1985, at Fox Peak. upper south Opua River (line 3, Site B). Data from Whitehouse et al., (1986).*

Transects 200-m long were established at 7 sites in the extensively-grazed mid-altitude (780 to 1300 m) tussock grasslands of central Waimakariri basin in 1947. Vegetation was assessed annually until 1963, and again in 1980 and 1981. No significant trend in the proportion of bare ground was found for any site, although 36 individual segments showed significant increases or decreases: 21 were increases (Whitehouse *et al.,* 1988). The transects were also analysed by Scott, Dick, and Hunter (1988). They found no overall trend in the proportion of bare ground from 1947 to 1981, although bare ground increased significantly from 1947 to 1953, then decreased from

1954 to 1981. They infer that the proportion of vegetation decreased on the 3 highest altitude transects and increased on the two lowest. The proportion of living vegetation also decreased significantly on poorly vegetated sites where vegetation covered less than 40% of the area, and increased on well-vegetated sites. It appears that once bare ground reaches some threshold proportion, of 60 to 80% of the area, it is likely to continue to increase at the expense of the plants.

Another set of transects in the alpine tussock grassland of the Waimakariri basin were surveyd in 1%2 (Wraight, 1966). In 1972,27 were re-surveyed (McLennan, 1974), and, in 1978, 113 more were done. Whitehouse *et a1.,* (1988) found no significant trend in testing pairs of measurements for change in bare ground.

In 1975 and 1980, grazed tussock-grassland transects and quadrats, established in 1955/56 and 1965/66 in the basins of Harper and Avoca Rivers at 800 to 1350 m, were resurveyed. Results from 10 transects established in 1955, and 26 established in 1%5 show no significant trend in proportion of bare ground (Rose, 1983).

Overall, the vegetation transects show little consistent change in the proportion of bare ground to vegetation cover on the grazed tussock grasslands of Canterbury in the last 10 to 35 yr.

Repeat photography and persistence of bare ground

The record of changes in extent of bare ground can be extended with historical potographs. Relph (1958) used repeat photography to assess changes in vegetation and erosion in the Castle-Hill area. He concludes that plant cover was not more extensive in 1882 than in the 1950s, and that if there were changes in the extent of cover caused by human activity, they had occurred by 1882. Whitehouse (1978, 1982) reached similar conclusions when comparing c. 70 historical (pre-1910) and modem (late 19708) photographs, mainly of the Waimakariri basin. These photographs show little change in the distribution of bare eroding areas in the last 100 yr. Areas of scree have remained fairly constant, and slopes prone to gullying have continued to gully.

The earliest photographs of Canterbury mountains that we have seen were taken in 1868, but most were taken after 1880. Most are broad landscape scenes. Whitehouse (1982) analysed a few showing hillslope details. In a small area around Porters Pass, 4 were taken in the 1890's of slopes within 5 km of each other. Modem photographs of the same sites show marked increase in bare ground at one site, no nett change at two, and increase in plant cover at the other.

All of the photographs were taken at least 10 years after the initial burning and stocking, and most, 20-or-more years later. If there were a brief period of increased slope instability and soil erosion following the initial burning in the 1850's, then there should be a higher frequency of fresher erosion scars and deposits in the earlier photographs than in their modem counterparts. Althought the quality of available reproductions of the earliest photographs is poor, most scars do not appear to have aged over the century between photographs. By far the majority of scars were much older than 10 to 30 years when first photographed.

The sparse evidence from repeat photography adds to the equally sparse evidence from vegetation transects, from soil stratigraphy, and from absolute age dating by radiocarbon and weathering rinds in show a regionally consistent picture of bare ground, of whatever origin, persisting for decades and centuries in the eastern South Island high county. Truncated soil profiles in the upper montane and subalpine zones there show little sign of revegetating naurally, even with grazing animals excluded (O'Connor, 1980). In contrast, natural revegetation occurs quickly on eroded surfaces in wetter areas close to the main divide, provided grazing pressure is low. Major differences in soil fertility and climate explain the contrast (Basher and Tonkin, 1985; Kelland, 1978; Nordmeyer *et a1.,* 1978; Davis, 1981; Holloway, 1970; Gradwell, 1960).

Conclusion

Early surveys of soil erosion in the South Island mountain land (Cumberland, 1944; Gibbs *et a1.,* 1945) equated bare ground and sparse vegetation cover with soil erosion, and soil erosion with anthropic erosion. As a consequence, they found much anthropic erosion over large areas of the eastern South Island high country. Within these same areas, we now recognise areas where the sparseness of the vegetation cover is neither anthropic, nor associated with soil erosion, and areas where soil erosion is not anthropic. We also recognize areas where there is unequivocal anthropic soil erosion. These places are not as abundant as earlier portrayed, but they occur widely. There are more areas, however, where we are unable to tell what is anthropic and what is not. As Shakespeare so succinctly put it - *all that glisters is not gold* - but to make matters worse, there is no infalible test for our *gold*.

The earliest workers also portrayed the anthropic erosion as largely due to mismanagement of the land during an era of European pastoral exploitation, but we now know, in part through their own continued work (Cumberland, 1962), that a significant portion of the established anthropic erosion occurred in the first 500 years of Polynesian occupation, prior to the European invasion.

The present shape, or physical landscape of the Canterbury mountain lands is a product of long-continuing high rates of natural erosion, with an added component of anthropic erosion over the last 1000 yr. Over most of this land, the evidence from basin sediment yields, studies of soil erosion processes, and repeat photography suggests that the additional component has been too small, or is likely to be too fleeting to be contributing to the evolution of a significantly different-shaped new landscape. That most of the erosion of the mountain land may be natural and not anthropic, however, does not make any of it less of a problem for the management and use of the land. Both components constrain the available options for land use and limit the intensity at which these options may be taken up.

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