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EFFECTS ON NEW ZEALAND VEGETATION OF LATE HOLOCENE EROSION AND ALLUVIAL SEDIMENTATION

Summary: During the last 1800 years there have been eight periods of increased erosion and alluvial sedimentation in New Zealand, which have generally decreased in magnitude towards the present. Throughout New Zealand, alluvium of all erosion periods contains abundant remains of plants as evidence of widespread destruction of vegetation during erosion periods. Indices of the relative magnitude of alluviation, and estimates of the damage to vegetation in the current Waipawa Period (since 1950), are applied to estimate the impact of earlier erosion periods.

In 13 basins on the Ruahine Range, 2.6% of the 1950 vegetated area was destoyed by slope erosion during 1950-1986; on the Pouakai Range (Taranaki) it was 3.2%. On these ranges the areas of vegetation probably destroyed or damaged by erosion, alluviation and other factors are estimated as 17-18% in the Wakarara Period (180-150 years BP), 26% for Matawhero (450-330 years BP), 52% for Waihirere (680-600 years BP) and >52% for the pre-Kaharoa Period (1300-900 years BP). The vegetation of other areas, in both North and South Islands, would have been affected to greater or lesser extents.

Large areas of vegetation along downstream channels, and on flood plains, were destroyed by alluviation in each previous erosion period. On alluvial sites the vegetation is closely linked to the history of the site - it may grow entirely on the new surface or be a mixture of survivors and new colonists.

The accelerated erosion, alluviation and consequent vegetation destruction in erosion periods, were associated with atmospheric warming and increases of major rainstorms and floods; they did not coincide with either the colonisation or activities of humans or mammals. Since 1950, the impact of rainstorms and floods has increased, while mammal populations have been reduced.

Local fauna is seriously affected when vegetation is destroyed, and some species may have become extinct, or very reduced because of erosion periods.

The present national forest estate is dominated by relatively young forests which are still developing towards some condition of quasi-equilibrium. Even in the absence of humans and mammals this vegetation would be in a dynamic state of imbalance and change.

Keywords: Late Holocene; erosion periods; slope erosion; alluviation; soil formation; vegetation damage and re-establishment; climatic fluctuation; atmospheric temperature; rainfall; drought; snowfall; gales; indigenous animals; human influences; browsing mammals; earthquakes; volcanism; Ruahine Range; Waipawa Basin; Bonar Creek, South Westland.

Introduction

During the last 1800 years, there have been eight major periods of erosion and alluvial sedimentation in New Zealand (Fig. 1). In each there was increased erosion of mountain and hill slopes. Large quantities of sediment were transported into and through drainage systems, raising river beds by up to 20m, from their headwaters to the coast. Vegetation and soils were locally depleted or destroyed over wide areas. Between the erosion periods there were longer tranquil intervals when erosion and sediment transport declined, the fresh surfaces were revegetated, and soil formed (Grant, 1985).

The first period considered was the Taupo alluviation, which immediately followed the eruption of Taupo Pumice c.1764 years BP (Fig. 1). It is identified only in the North Island and it probably resulted from heavy rainfalls induced by the eruption. The subsequent seven periods of erosion and alluviation probably affected the whole country. They were almost certainly caused by an increased northerly airflow and atmospheric warming, leading to more major rainstorms and floods. Such changes are related to a temporary strengthening of the meridional upper atmospheric circulation in the Southwest Pacific region. Between them were tranquil soil-forming intervals, dominated by a cooler zonal (westerly) circulation (Grant, 1981a; 1983; 1985).

The alternative hypothesis is that measurable increases of erosion and alluviation since c.1000 AD were caused by humans and/or animals. If this were so we would expect sedimentation episodes to have increased in size since then; but the actual trend is of a decrease towards the present (Fig. 2). The same trend is seen in coastal sands (McFadgen, 1985). Coastal sand deposits are relatively fragile, yet during a tranquil or stable phase, well developed soils formed

Calendar Years B.P.	Chronozones	Alluvial Sedimentation Periods: Period		Years B.P.	Years A.D.	Duration Years	Soil Interval Years
	WAIPAWA	8	Waipawa	0	1950-1984 continuing	34+	
0	TAMAKI		Soil 7				50
		7	Tamaki	80-50	1870-1900	30	
	WAKARARA		Soil 6				70
		6	Wakarara	180-150	1770-1800	30	
200	MATAWHERO		Soil 5				50
		5b	Late Matawhero	360-330	1590-1620	120	
400		5a	Early	450-400	1500-1550		
	WAIHIRERE		Soil 4				150
600		4	Waihirere	680-600	1270-1350	80	
800	PRE-KAHAROA		Soil 3	690	Kaharoa Ash erupted 1260		220
1000 1200		3	Pre-Kaharoa	1300-900	650-1050	< 400	
1400	POST-TAUPO		Soil 2				200
1600		2	Post-Taupo	1600-1500	350-450	100	
	TAUPO		Soil 1				c.160
1800		1	Taupo	c. 1764	c. 186	1+	
				c. 1764	Taupo Pumice erupted c. 186		

Figure 1: *Eight North Island alluvial chronozones since Taupo Pumice was erupted c.1764 years BP. Each chronozone comprises the period of alluvial sedimentation (stippled) and the minimum interval available for the formation of its capping soil. This is the time from the cessation of its sedimentation to the start of alluviation of the next period on its surface. When subsequent sediments are not deposited on an alluvial surface, the maximum soil-forming time extends from the close of sedimentation to the present. Alluviation periods and soil forming intervals are numbered solely to assist the reader (from Grant, 1985).*

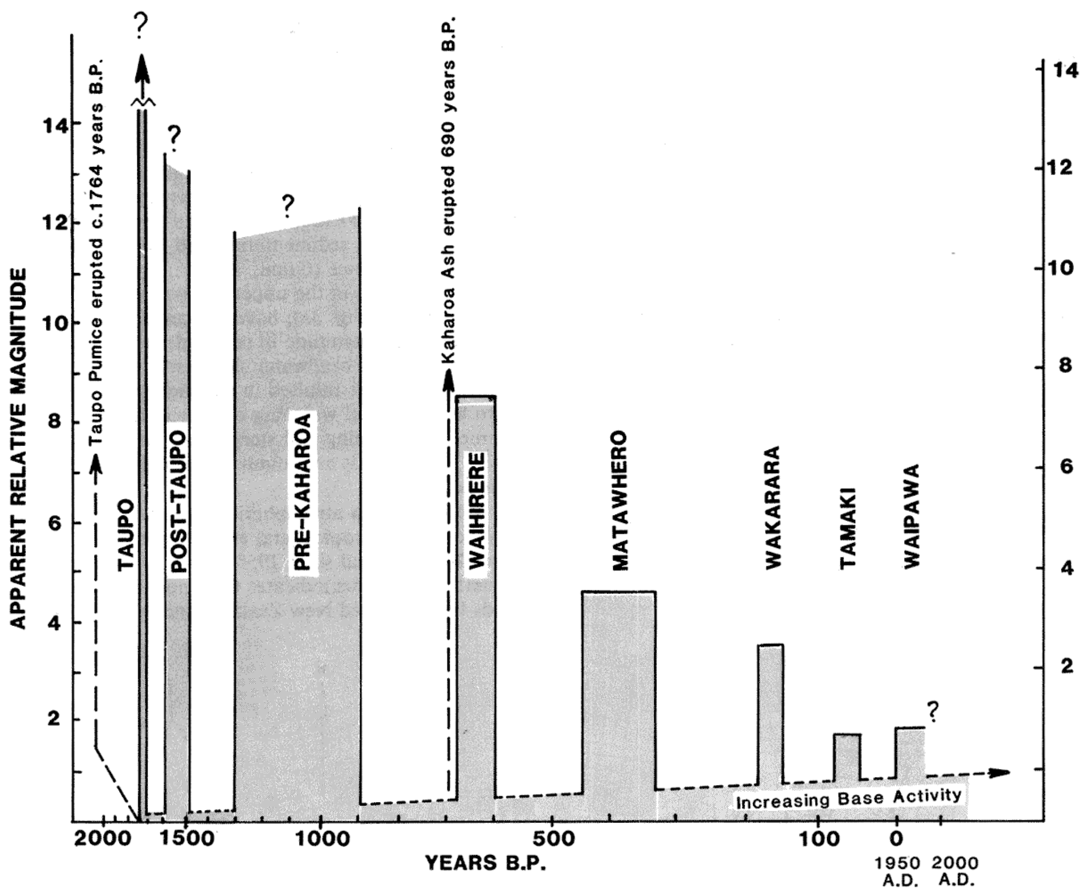

Figure 2: *Relative magnitudes of sedimentation in the eight erosion periods and their chronology since c.1764 years BP. The two ash showers used as statigraphic markers are shown. The trend line of increasing base activity, or hydrological instability, is oversimplified (from Grant, 1985).*

regardless of the presence of large numbers of people in the area. This agreement in the evidence from these two different environments Ö inland and coastal Ö strongly suggests that the cause is independent of cultural influence; otherwise trends are impossible to understand. Moreover, numerous phases of major alluviation have been dated during the millenia preceeding the arrival of the Polynesians in New Zealand (see Grant, 1985).

Buried in the alluvium of every erosion period are the remains of indigenous vegetation, ranging from leaves and fruit, to large tree trunks with intact root discs (Grant, 1985). The same types of vegetation relics are still being transported, and deposited, from forested wilderness regions in major floods. Today in the Waipawa Period, vegetation including mature forest, is being destroyed on alluvial surfaces, and on riparian and upper slopes by pluvial and fluvial processes. Compared with earlier periods the scale of sedimentation of the present Waipawa Period is small (Fig. 2). Therefore I deduce that the damage to vegetation during those greater periods must also have been greater. Already some vegetation, including tree species, is colonising fresh Waipawan surfaces. Much of this young vegetation may yet be destroyed by continuing erosion and alluviation, but ultimately plants will re-establish on most sites. Likewise, in preceeding erosion periods, vegetation re-established on bare surfaces and developed to maturity during ensuing tranquil intervals.

This paper discusses the effects on the vegetation of increased rates of slope erosion and alluviation in erosion periods. Some other agents of an erosion period, which also damage the vegetation, are mentioned as a reminder that there are many physical factors operating independently of humans and animals.

Modern Erosion - The Waipawa Erosion Period

Period changes

The current Waipawa erosion and sedimentation period began about 1950 AD (Fig. 1). Since then, over the North Island, air temperatures have increased 0.8∞C in summer, 0.7∞C in autumn, 0.4∞C in winter, and spring has warmed erratically (Grant, 1983). Similar warming has been recorded over South Island (Salinger, 1979).

At three widely separated locations in North Island, summer-autumn storm rainfall maxima increased after 1950 by 26-29%. This represented increments of 16-37 mm - sufficient to produce increased erosion, sedimentation and flooding of practical significance (Grant, 1983).

Major floods in the upper Waipawa River, Ruahine Range (Fig. 3a), have increased in both frequency and magnitude in recent decades. The increased rates of headwater slope erosion and coarse sediment transport resulted in channel aggradation of up to 8 m, channel widening of up to 146%, and channel straightening and steepening (Grant, 1977; 1982). These trends are common throughout New Zealand.

Together with atmospheric temperature rises there have been more tropical and extra-tropical cyclones about New Zealand since 1955 (Grant, 1981a, 1983; Barnett, 1938). This indicates that more high-force winds have affected New Zealand since the 1950s.

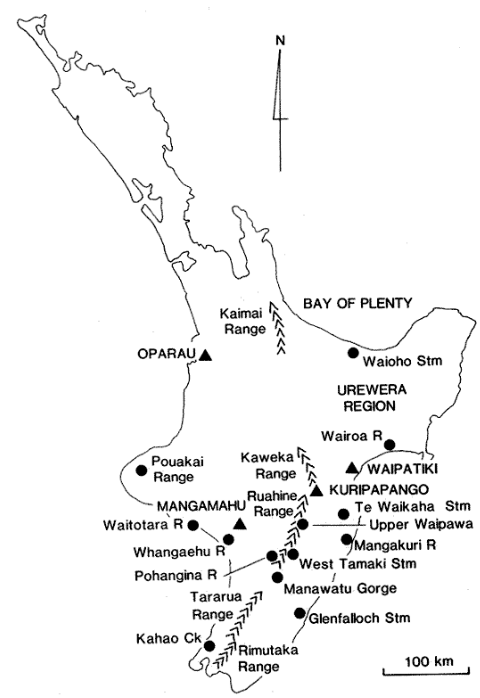

Figure 3a: *Locations in the North Island.*

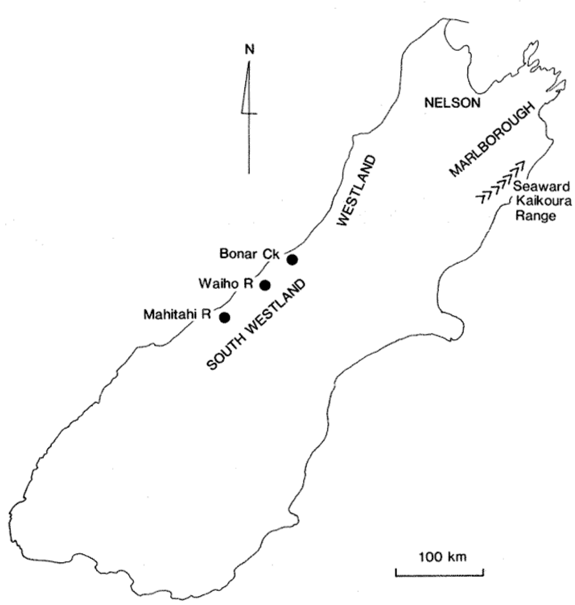

Figure 3b: *Locations in the South Island.*

This general change is likely to have had several adverse effects on vegetation, especially at higher altitudes (Grant, 1983). For instance, drought seems to have increased in the latter part of this century (Grant, 1968; 1969; 1983; 1984); and snowfalls heavy enough to damage vegetation (Elder, 1958, 1965) may be more common because at higher temperatures snow contains more water which makes it heavier. A more subtle consequence is that the average level of the winter snowline is higher and snow lies on the ground for less time (Burrows and Greenland, 1979). Together, this gives mammals and herbivorous insects a longer period to attack more montane vegetation than earlier this century (Batcheler, 1967; Grant, 1983).

Earthquakes and volcanic eruptions may also destroy vegetation. However, these are outside the scope of this discussion because there is no evidence linking them in time with the climate-controlled increases of erosion and alluviation (Fig. 1). The following discussion is restricted to the total or partial destruction of vegetation by slope erosion and alluviation.

Devegetation by erosion

In the Waipawa Period, vegetation has been destroyed when the regolith has eroded during storm rainfalls. Increased rates of erosion have affected many forested wilderness areas. Some of these in the North Island (Fig. 3a) are the Kaimai Range (Griffiths, 1969; Jane and Green, 1983a, b); the Urewera region (Jones, 1966; Wallis and James, 1972); the Ruahine Range (Cunningham and Stribling, 1978); the Pouakai Range (Fletcher, 1978); the Tararua Range (Hollowayet *al.*, 1963); and the Rimutaka Range (Cunningham and Arnott, 1964). In the South Island (Fig. 3b), Robinson and McSaveney (1980) noted increased erosion associated with heavy rain in South Westland, and so did Wardle (1971) on the Seaward Kaikoura Range. I have observed in the Nelson, Marlborough and Westland regions and in the North Island, that most river beds have widened in recent decades. Taken together this indicates increased erosion, coarse sediment transport and progressive devegetation, throughout most of New Zealand. This can be seen on aerial photographs but the rates of devegetation cannot, and they have been estimated for only a few basins.

In the upper Waipawa Basin, central Ruahine Range (Fig. 3a), the vegetated area on upper slopes decreased 2% during 1950-1982, at an annual rate of 0.06070. This resulted from heavy rainstorms (Grant, 1983). In the Pohangina Basin of the southern Ruahines, the vegetated area decreased I % from 1946 to 1963, or 0.06% per year, probably as a result of increased storminess (James, 1973). In three nearby basins, the vegetated area decreased 2.8% during 1946-1974, or 0.10% per year. "Intense rainstorms have probably had the most significant effect. . ." (Stephens, 1977). In eight other basins of the southern Ruahines the average decrease of vegetated area during 1946-1974 was 1.6%, or 0.06% per year, ". . .in response to the occurrence of storms. . ." (Mosley, 1978). The annual maximum rate of devegetation was 0.17% in Raparapawai Basin and the annual minimum rate was 0.03% in Mangatewainui Basin.

In the Pouakai Range (Taranaki) (Fig. 3a) the vegetated area decreased from the 19505 to 1971 in all 12 basins studied. The mean annual rate of loss for all basins was 0.09%, the mean annual maximum (in Oakura Basin) was 0.30%, the mean annual minimum (in Mangorei Basin) was 0.01%, and the mean for the three most rapidly changing basins was 0.21 %. These values refer to basin areas above 760 m in altitude where all the mass movement erosion exists and where ". . . most erosion is triggered by high intensity rainstorms." (Fletcher, 1978).

From 1948 to 1980 the vegetated area of Bonar Creek basin, South Westland (Fig. 3b), decreased by 11 %, an annual loss rate of 0.34%. The "progressive increase in size of erosion activity. . . with progressive failure of the vegetation. . ." was associated with sustained heavy rainfalls (Robinson and McSaveney, 1980). They pointed out that other basins in the area were also severely affected by two major storms in 1958 and 1979, and that many more mountain basins of South Westland have probably had a similar history.

In the following discussion annual rates of devegetation are applied to the 36-year Waipawa erosion period (1950-1986) to obtain standardised values for the area devegetated since 1950.

The 12 basins examined by Fletcher (1978) essentially covered the entire Pouakai Range, so that during 1950-1986, rangeland devegetation by erosion was 3.2% of the 1950 vegetated area. The most affected basin (Oakura) lost 10.8% of the 1950 vegetation and the least affected (Mangorei Basin) lost 0.4% .

On the Ruahine Range, 2.6% of the vegetated area was lost by erosion from 1950 to 1986. Maximum devegetation (Raparapawai Basin) was 6.1 % of the 1950 vegetated area; and the minimum

(Mangatewainui Basin) was 1.1%.

It is quite striking that in both the Pouakai and Ruahine ranges the respective average devegetation rates (3.2%, 2.6%) and the maximum rates (10.8%, 6.1 %) are close. And there is no real difference in minimum values (0.4%, 1.1%) because many Ruahine basins have been less eroded in the period than the Mangatewainui (1.1 %).

If the devegetation in Bonar Creek basin during 1950-1986 (12.2%) is taken as a maximum value for South Westland, it is similar to the maximum values on the Pouakai and Ruahine ranges (10.8% and 6.1 % respectively).

Devegetation by Waipawa alluviation

The area directly affected by alluviation processes generally increases downstream. Alluvium of the Waipawa Period is still accumulating (in 1987) on lower slopes, in stream channels, on flood plains and in lakes. It mantles the width of streambeds which have been active in sediment transport and deposition since c.1950. Uninterrupted soil development is impossible on most of these new surfaces. The present increased rates of sediment supply and transport have produced wider active river beds, higher river bed levels, steeper channel slopes, and an increase in the size and frequency of riparian landslides (Grant, 1977). These trends are nationwide. Hydraulic, hydrologic and geomorphic processes involved in channel sedimentation, and their effects on the vegetation bordering the channels, were discussed by Grant (1977, 1983, 1985).

Downstream sites bordering channels, and flood plains, generally carry little indigenous vegetation today. Locally, as in South Westland, podocarp forest which established on older alluvium is now being partially or totally destroyed by alluviation (Wardle, 1974). Along upstream forested channels the greatest damage to indigenous vegetation results from the destruction of older alluvial terraces by fluvial processes. Good examples come from the upper Waipawa River where measurements were based on aerial photographs and surveyed ground control (Grant, 1977). A 630-m long channel reach had an average bed width of 35.1 m in 1950. By 1975 this had widened to 59.4 m and the beech forest on the terrace had been destroyed. That is, 24.3 m of the 1975 bed width, or 40% by area, carried forest in 1950. Further upstream on two different reaches, forest which in 1950 occupied 42% and 53% respectively of the 1975 river bed areas had gone by 1975 (Fig. 4). About 3 km downstream of these three reaches, on a 583-m reach, forest on older alluvial terraces which in 1950 occupied 59% of the 1975 river bed area had gone by 1975. By 1986, the channels of all four reaches had got even wider at the expense of bordering forest.

Along the four reaches sampled, whose total length was 1.8 km, a forest area of 5.5 ha was lost between 1950 and 1975. Today, this area would exceed 6 ha, which is 0.6% of the upstream drainage area of 10 km^2. Moreover, the total area of riparian forest destroyed from 1950 to 1975 along the drainage network is probably at least 1 % of the drainage area.

Increased transport of coarse sediments in channels results in more fresh landslides on riparian bedrock slopes (Grant, 1977; 1983; Keller, 1970), which inevitably destroy vegetation (Fig. 5). In 1975, I tallied 47 riparian landslide scars along a 3-km channel length of the upper Waipawa. Nine scars were old (pre-1950) and had revegetated; 11 were old and had revegetated but since 1950 had been partially reactivated; and 27 were fresh active scars since 1950 from which the vegetation had gone. The area of vegetation lost from these scars between 1950 and 1975 was about 3.5 ha; and subsequent losses have probably increased it to about 4 ha, which is 0.4% of the drainage area (10 km^2). However, I estimate that at least 1 % of the basin was affected by riparian landslide scars and devegetation from 1950 to 1986.

The total impact of the Waipawa Period

To place in better perspective the effects on vegetation area of slope erosion and alluviation processes I summarise here the probable overall effects of the Waipawa erosion period on the vegetation of the Waipawa Basin from 1950 to 1986.

Slope erosion destroyed vegetation on 2% of the basin area, riparian terrace damage accounted for at least 1%, and riparian bedrock erosion about 1%. To this total of about 4% must be added about 1% for windthrow by gales and the more insidious death caused by wind-rocking (Grant, 1983); damage from heavy wet snowfalls; and the dieback from recent droughts (Grant, 1984). Unseasonable heavy frosts have damaged beech canopies, and icy wind blasts have desiccated and caused one-sided dieback of podocarp heads. Although it is not possible to refine these estimates, it is obvious that partial and total damage to the vegetation of the upper Waipawa Basin since 1950 has affected more than the 2% of the basin area lost by erosion of the upper slopes. The estimates above indicate that upper slope erosion accounted for only about 40% of all vegetation loss. Similarly, in other basins covered in indigenous vegetation, the

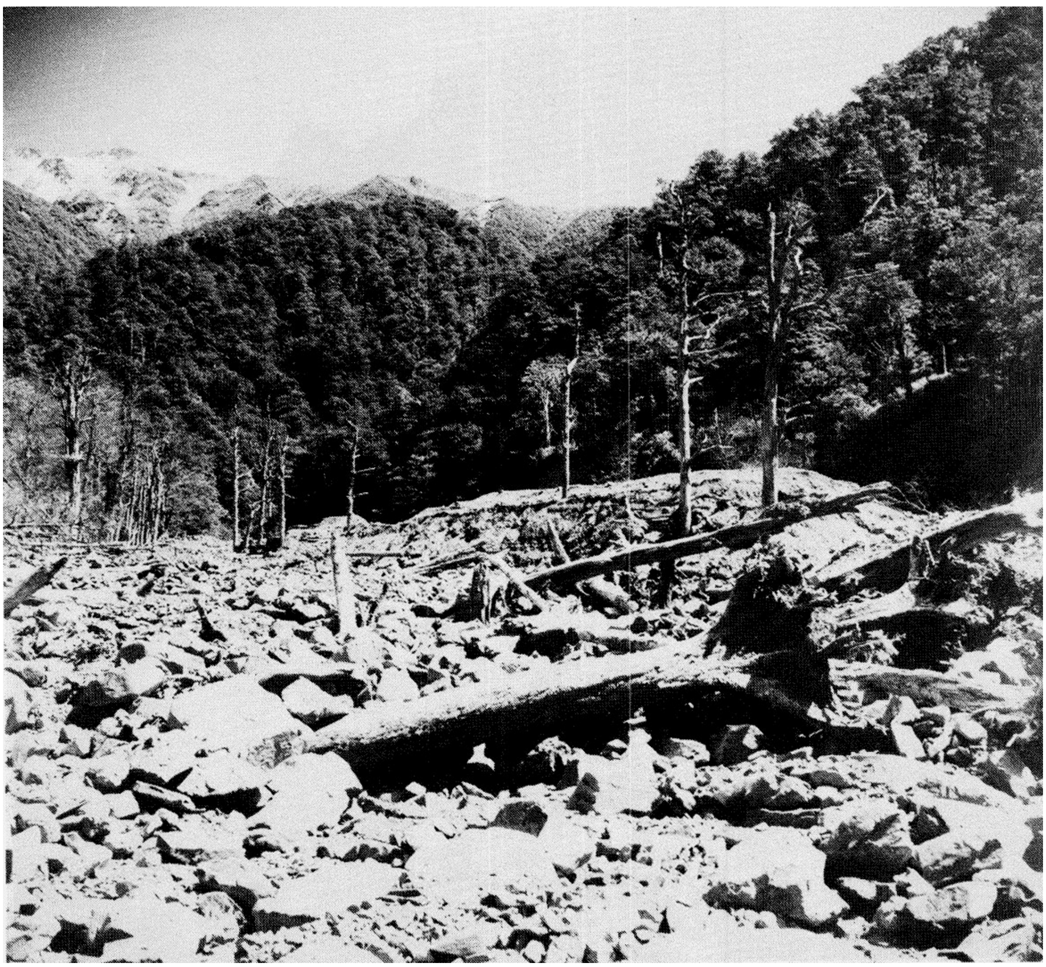

Figure 4: *Increased alluviation since 1950 has destroyed large areas of red beech forest* (Nothofagus fusca) *on older alluvium in the upper Waipawa River basin, Ruahine Range (photo, 1975).*

total impact of the Waipawa erosion period on the vegetation is certain to have been much greater than that attributed to upper slope erosion. In the upper Waipawa, the total effect of the present erosion period on the vegetation is 2-3 times that contributed by upper slope erosion alone. These ratios can be used with caution as a guide for other basins in New Zealand.

Vegetation destruction since 1950 is widespread in New Zealand, and it is still active, though irregularly, in response to heavy storm rainfalls, large floods and the transport of large quantities of coarse sediment through channels. I have been unable to estimate the national extent of this vegetation loss since 1950, but it should be possible for many areas using aerial photographs taken since the 1940s.

Figure 5: *Increased transport of coarse sediments since 1950 has resulted in increased erosion of riparian bedrock and further destruction of forest in the upper Waipawa River basin, Ruahine Range (photo, 1975).*

Earlier Periods of Devegetation

During the Waipawa erosion period, the amount of vegetation destroyed by upper slope erosion in the upper Waipawa Basin was as little as 40% of that lost under the overall impact of this erosion period. If we can estimate the relative magnitudes of the impacts on the vegetation of other erosion periods (Fig. 1), then we may assess the likely effect that each period had on the vegetation of selected areas. The following discussion outlines an approach, and presents estimates for the Ruahine and Pouakai ranges.

Alluviation magnitudes

Relative magnitudes of periodic sedimentation, expressed proportionally to the present Waipawa period alluviation, are approximate averages for large basins (Fig. 2). In the headwaters of some basins, Waipawa alluviation to date appears to greatly exceed that of the Tamaki, and even Wakarara, periods (Fig. 1); but in downstream zones it is generally smaller.

In the last 700 years Waihirere sedimentation was the greatest (Fig. 2). Since then, period magnitudes have generally decreased. Post-Taupo and Pre-Kaharoa sedimentation almost certainly exceeded that of the Waihirere, and the Taupo Alluvium Period was the greatest of the eight (Fig. I). However, Taupo alluviation, unlike the others, was restricted to a large central zone of North Island.

If the present Waipawa alluviation is scaled at 1.0, the relative magnitude for Tamaki is 0.8, Wakarara is 2.7, Matawhero is 4.0 and Waihirere is 8.0 (Fig. 2). Pre-Kaharoa, Post-Taupo and Taupo sedimentation are taken as greater than 8.0. The magnitude of sedimentation in an erosion period is not necessarily a reliable index to its relative effect on the vegetation because that depends on the rate of accumulation and on how long the period lasts. Also, beyond certain thresholds of surface denudation, progressive supply of sediment results from deepening of areas which are already bare, rather than from expansion of them (Grant, 1983). The greater sedimentation in earlier periods was probably the effect of more intense rainstorms and flooding then than later (Grant, 1985). If that was so, devegetation by erosion was probably greater then too. The approximate sedimentation magnitude indices above are all we have at present for making practical comparisons over time.

Erosion effects in two areas

Estimates of the mean amount of vegetation destroyed by slope erosion in the Waipawa Period were given above for 13 basins on the Ruahines (2.6%) and 12 basins on the Pouakai Range (3.2%). The products of these mean percentages for each range, and the sediment magnitude indices, yield approximations of the effects of slope erosion on vegetation area in each erosion period (Tables 1 and 2).

The Ruahine Range is about 1110 km^2 (Cunningham and Stribling, 1978). I have given estimated areas (km^2) affected (Table 1) because they convey more graphically the likely extents of vegetation lost in each erosion period. In the upper Waipawa Basin, the total effect on the vegetation is at least two and a half times that caused by upper slope erosion alone. To estimate the likely area of the range affected by all erosion period factors I have applied a factor of 2.5 to the areas devegetated by erosion alone (columns C and D), to produce columns E and F. The estimates indicate extensive vegetation damage in all erosion periods except the Tamaki (Table 1). Independent evidence from the age structures of today's forests tends to support these deductions (Grant, in prep.).

On the Pouakai Range, the vegetation is generally more stunted and probably less susceptible to damage by gales and heavy snowfalls than in the Ruahines. Nonetheless it would be affected by drought, unseasonable frosts, and other associated climatic factors. Therefore, to estimate the likely areas of vegetation affected by all erosion period influences I have applied a lower factor of 2.0 to the areas devegetated by erosion alone (Table 2).

The averages (column C), and basin maximum values, for the two ranges are similar. This may be because the current rainfall intensity- duration pattern is much the same on these ranges (Tomlinson, 1980).

Table 1: *Possible areas of vegetation lost from erosion on the Ruahine Range (1110 km^2), and the likely overall areas devegetated by all factors, during the last six erosion periods (based on 13 basins).*

	Area devegetated by erosion				Likely area affected by all factors	
Erosion period (AD)	A Sediment magnitude	B Basin maximum (%)	C Range average (%)	D Range area (km^2)	E Cx2.5* (%)	F Dx2.5* (km^2)
Waipawa 1950-1986	1.0	6.1	2.6	29	6.5	73
Tamaki 1870-1900	0.8	4.9	2.1	23	5.3	58
Wakarara 1770-1800	2.7	17	7.0	78	18	195
Matawhero 1500-1620	4.0	24	10	115	26	288
Waihirere 1270-1350	8.0	49	21	230	52	575
Pre-Kaharoa 650-1050	>8	>49	>21	>230	>52	>575

* Factor of 2.5 is explained in the text.

Table 2: *Possible areas of vegetation lost from erosion on the Pouakai Range (30 km^2), and the likely overall areas devegetated by all factors, during the last six erosion periods (based on 12 basins).*

Erosion period (AD)	Area devegetated by erosion			Likely area affected by all factors
	A Sediment magnitude	B Basin maximum (%)	C Range average (%)	D Cx2.0* (%)
Waipawa 1950-1986	1.0	11	3.2	6.4
Tamaki 1870-1900	0.8	8.6	2.6	5.2
Wakarara 1770-1800	2.7	29	8.6	17
Matawhero 1500-1620	4.0	43	13	26
Waihirere 1270-1350	8.0	86	26	52
Pre-Kaharoa 650-1050	>8	>86	>26	>52

* Factor of 2.0 is explained in the text.

Figure 6: *Pre-Kaharoa Alluvium dated by radiocarbon forms a terrace 4.6 m above the Glenfalloch Stream (Fig. 3a). It contains frequent wood remnants and occasional prostrate logs - one is visible. A t its base there is older alluvium with in situ podocarp stumps, one of which is at the right-hand toe of the terrace rise.*

Alluviation effects

At Kahao Creek (Fig. 3a) where Post-Taupo Alluvium (1600-1500 years BP) covered a layer of logs, ". . . a phase of forest vegetation. . . was terminated catastrophically by the onset of a phase of aggradation. . ." (Brodie, 1957).

Near the mouth of the Waitotara River (Fig. 3a), Pre-Kaharoa Alluvium (1300-900 years BP) had inundated and killed *in situ* pre-existing forest. The alluvium itself contains abundant tree remains from the destruction of upstream forest. In the Pre-Kaharoa Alluvium along the Glenfalloch Stream (Fig. 3a) there are abundant plant remains, including logs (Fig. 6), and buried *in situ* podocarp stumps rooted in earlier alluvium (Grant, 1985).

At the foot of the southern Kaweka Range, near Kuripapango (Fig. 3a), Waihirere Alluvium (680-600 years BP) has been deposited in a large depression drained by the Waikarokaro Stream (Grant, 1985). The alluvium overwhelmed a forest containing kahikatea *(Dacrycarpus dacrydioides)* and matai *(Podocarpus spicatus),* and it had itself transported numerous tree trunks from upper drainage areas.

Matawhero Alluvium (450-330 years BP) at Waipatiki (Fig. 3a), which now carries a stand of kahikatea and matai, has transported large numbers of podocarp trunks from earlier forest in the basin, and many of these are now exposed in the bed of the stream (Fig. 7).

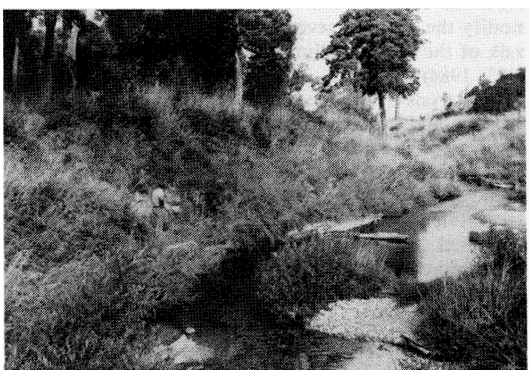

Figure 7: *At Waipatiki (Fig. 3a) numerous podocarp logs from upstream forest destruction are exposed near the base of Matawhero Alluvium. A stand of kahikatea and matai now grows on the surface of the Matawhero sediments.*

Wakarara Alluvium (180-150 years BP) commonly occurs as a deposit, 0.5-2 m thick, on the Matawhero alluvial surfaces. Where podocarp-beech forest grew on the Matawhero surface, the Wakarara sediments buried the butts of the trees. The podocarps usually survived this alluviation, but the beech succumbed, and their decayed stumps remain today. Most understorey plants would have been annihilated. Consequently, today, many such sites in mountain areas may carry podocarps of Matawhero-age, beech of Wakarara age, and an understorey which originated either after Wakarara sedimentation or even after Tamaki alluviation (80-50 years BP) where this affected the site (Grant, 1981b). As usual, abundant vegetation remains were transported in Wakarara sediments. Bordering the Manawatu River, upstream of the gorge (Fig. 3a), great quantities of podocarp and hardwood relics exist in Wakarara sediments. Many matai trunks have intact bark and fairly complete root systems. The effects of Tamaki alluviation (1870-1900 AD) in the West Tamaki Basin, southern Ruahines (Fig. 3a), were discussed (Grant, 1981c) for several types of vegetation. The present cover on the Dry Creek fan of mahoe *(Melicytus ramiflorus),* lemonwood *(Pittosporum eugenioides),* pate *(Schefflera digitata)* and pigeonwood *(Hedycarya arborea),* colonised after the Tamaki alluviation ceased in the 1890s. On the Hut Creek fan, nearer the head of the Tamaki Basin, red beech *(Nothofagus fusca)* grows on the surface of Tamaki Alluvium.

Smale (1984) described the same general history beside the Waioho Stream, eastern Bay of Plenty (Fig. 3a) where the present kahikatea stand". . . may have established three or more centuries ago on a post-Kaharoa alluvial surface. . .", which was almost certainly either the Waihirere or Matawhero (Fig. 1). In South Westland, alluviation destroyed podocarp forests but they subsequently re-established and developed on the new surfaces (Wardle 1974; 1980). Likewise, alluviation seems to have damaged the vegetation in nearly all of the 90 Post-Taupo sites dated in the North Island and 19 in the South Island (Grant, 1985).

These examples represent but a small fraction, from the last 1800 years, of countless sites telling the story of periods of alluviation and vegetation destruction separated by longer tranquil intervals when new vegetation grew and soils formed. Indeed, this periodic pattern goes back a long time before Taupo Pumice (1764 years BP). In the North Island I have dated alluvium containing numerous tree trunks in the Mangakuri Valley, c.2200 years BP; along the Wairoa River, c.3000 years BP; and in the Te Waikaha Stream, c.3900 years BP. At Oparau the basal sediments, c.6000 years BP, contained fine organic materials (Grant, 1985). In the South Island, an example of this older alluviation is evident in the Waiho valley c.2400 years BP (Wardle, 1974). This event may have been contemporaneous with the massive alluviation in the Mahitahi valley (NZ 5589A, 2560 ± 100) containing' abundant forest remains (Fig. 3b).

A complete set of post-Taupo Pumice alluviation phases is rarely seen at a single site. The most complete earlier stratigraphy that I have examined is near Mangamahu, Whangaehu valley (Fig. 3a) where younger alluvia have accumulated on older and each is separated by a paleosol (Campbell, 1973). He identified five soils which correspond with my soils 1-5 (Fig. 1). The last of the 'great' sedimentation phases was in the Matawhero Period and this alluvium forms the present valley floor. Later sedimentation was probably confined to the river trench and subsequently transported down stream. Campbell's sequence from Taupo Alluvium (1764 years BP) to the surface of Matawhero Alluvium (330 years BP) is 13.5 m thick. It shows that forest on the Pre-Kaharoa valley surface, 4 m above Taupo Alluvium, was destroyed *in situ* by Waihirere Alluvium. I estimated that the exposed, erect matai and totara trunks had been 350-450 years old when killed (680-600 years BP). Another podocarp forest established on the Waihirere surface, 4.5 m above the Pre-Kaharoa surface, only to be destroyed by Matawhero Alluvium (450-330 years BP). The lower Whangaehu valley floor, commonly 1 to 1.5 km wide, is chiefly Matawhero Alluvium at the surface. Hence most of the forest on the valley floor at the time of European settlement must have been younger than 450 years (Fig. 1). Likewise, on large areas of valley floors and flood plains in both islands the ecological status of the vegetation when Europeans arrived was linked closely to the alluvial history of the sites. This still applies to vegetation which has survived essentially unchanged by cultural impact. Some idea of the great extent of forest on Late Holocene alluvium in Nelson and Marlborough land districts was presented by Park and Walls (1978).

Discussion

In the last 1800 years, seven periods of increased storminess, erosion and alluviation have damaged or destroyed large areas of vegetation throughout New Zealand. Another, the Taupo Pumice eruption and alluviation, devastated a large expanse of the central North Island. The hypothesis proposed is that there have been periods of increased erosion and alluviation alternating with longer soil-forming intervals (Grant, 1985). It explains the physical processes, linked to global changes of atmospheric circulation, by which major changes to the vegetation could take place periodically and rapidly. Moreover, there have been similar periods of vegetation destruction in earlier millenia. Hence, the periods discussed here represent only the tail-end of a very long-term natural pattern which has affected New Zealand's biota, regardless of the presence or absence of humans and browsing mammals. The first Polynesian settlers probably arrived during the Pre-Kaharoa period, 1300-900 years BP (McGlone, 1983), but numerous erosion periods had preceded them. Subsequent periods began and ended and new vegetation and soils developed, unaffected by their increasing population.

Exotic animals could not have contributed to the Wakarara and earlier erosion periods, and there is no basis for thinking that Tamaki and Waipawa alluviation arose from any loss of vegetation which they might have caused. Besides, from c.1950 to 1984 the impact of the Waipawa Period generally increased, while populations of browsing mammals declined greatly under intensified control measures (Thomson, 1972, Conway, 1978). Reduced animal numbers should, after a lag time, result in increased vegetation density within browsing reach. However, this beneficial effect on the vegetation is unlikely to modify the areas of severe erosion which supply the bulk of the coarse sediment to the channels (Grant, 1983, 1984).

Analysis of previous periods indicates that, on the Ruahine and Pouakai ranges, 10-13% by area was devegetated in the Matawhero Period, by slope erosion alone, and that all factors combined possibly damaged 26%. In the Waihirere Period, 21-26% was devegetated by erosion alone, and 52% by all factors combined. In earlier even more severe periods these values were greater again. However, even in the Matawhero and Waihirere, the estimated effects were extremely damaging by any standard, especially in some basins where maximum devegetation was probably much greater than the average for the range (Tables 1 and 2). In each erosion period, alluviation processes must also have affected large areas of vegetation bordering the channels and on the flood plains, but the extent cannot be estimated. In the mountains of western South Island, the effects of erosion periods on the vegetation and fauna probably exceeded those on the Ruahine and Pouakai ranges, because rainfall norms there have almost certainly always been greater.

In terms of erosion and sedimentation processes the Matawhero (450-330 years BP) was the last of the 'great' periods, although much vegetation was damaged in Wakarara times. The present national forest estate is dominated by stands which became established during the last 400-500 years and large areas have also developed since the Wakarara Period, 180-150 years BP (Grant, in prep.). Therefore much of the vegetation is relatively young and still developing towards some condition of quasi-equilibrium. Even in the absence of humans and animals, this vegetation would be in a dynamic state of imbalance and change. This has many implications for management of forest and range (Grant, this volume). Each period of vegetation destruction, and subsequent re-establishment, allowed many different plant species to invade the sites, resulting in increased diversity and many apparently anomalous mixtures of major species.

Local animal populations, of the land, rivers, small lakes, and coastal estuaries, are greatly affected by periods of vegetation destruction, and increased erosion and alluviation. Some species may have become extinct, or greatly reduced, as a result. And what was the impact on forest bird species, including the moas, at times when great tracts of forest were destroyed?

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