PROTECTIVE VALUE OF REGENERATING TEA TREE STANDS ON EROSION-PRONE HILL COUNTRY, EAST COAST, NORTH ISLAND, NEW ZEALAND

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ABSTRACT

The effect of pasture reversion to tea tree communities (comprising manuka (*Leptospermum scoparium* J.R. et G.Forst.) and/or kanuka (*Kunzea ericoides* var. *ericoides* (A.Rich.) J.Thompson) of varying ages) on landslide damage resulting from Cyclone Bola was studied in hill country on the East Coast of the North Island, New Zealand. Eighteen sites containing areas of both pasture and regenerating forest aged 6–79 years were selected from areas of steep, colluvial-covered slopes prone to shallow landslipping. Vegetation composition and stand dynamics were ascertained from sample plots, and aerial photographs were used to measure landslide damage. Manuka dominated younger stands but within 20–30 years of establishment, kanuka had become dominant. Mean canopy height stabilised at 13 m by age 40, basal area reached 40 m^2/ha by age 30 years, and stand density reduced from 20 000 stems/ha at 10 years to 3000 stems/ha at 40 years. Landslide damage showed a rapid and highly significant reduction against increasing age of tea tree stands and was estimated to be 65% less than pasture at 10 years and 90% less at 20 years. These findings have implications for land-use options, including clearfelling of indigenous vegetation for planting of *Pinus radiata* D.Don.

Keywords: erosion; slope stability; vegetative protection; landslides; Cyclone Bola; East Coast; *Leptospermum scoparium*; *Kunzea ericoides*.

INTRODUCTION

Much of the hill country on the East Coast of the North Island of New Zealand is prone to serious erosion, particularly as a result of major storms such as Cyclone Bola which, on 5–9 March 1988, struck the northern part of the North Island bringing with it strong easterlies and heavy rain (New Zealand Meteorological Society 1988). It caused extensive landsliding on hill country sites, affecting pasture, reverting farmland, regenerating indigenous forest, and young pine (*Pinus* sp.) plantations (Phillips *et al.* 1990). Large volumes of sediment were transported downstream, which exacerbated damage by flooding and caused aggradation of silt on areas of productive alluvial land.

On steepland sites, shallow translational landslides of the debris-slide / flow-avalanche types are most common on hill country underlain by competent rock in the Tertiary terrain of the East Coast (Fig. 1). They were the most frequent among landslides initiated on Tertiary terrain during Cyclone Bola and had a measured mean depth of 0.96 m (Marden *et al.* 1991). Surveys of damage soon after Cyclone Bola indicated a strong relationship between vegetation cover and the degree of shallow landsliding, and showed that different vegetation types provided different degrees of protection from landsliding (Marden & Rowan 1993, and unpubl. data; Hicks 1989; Phillips *et al.* 1990;). The general conclusion was that slopes covered in young pine plantations and pasture had significantly more landslides than slopes with a cover of indigenous secondary forest, mature indigenous forest, or established exotic pine plantations over 8 years old.

On less steep slopes underlain by incompetent rock of late Cretaceous – early Tertiary age (Cretaceous terrain in Fig. 1), earthflows and slumps within deeply-weathered regolith were

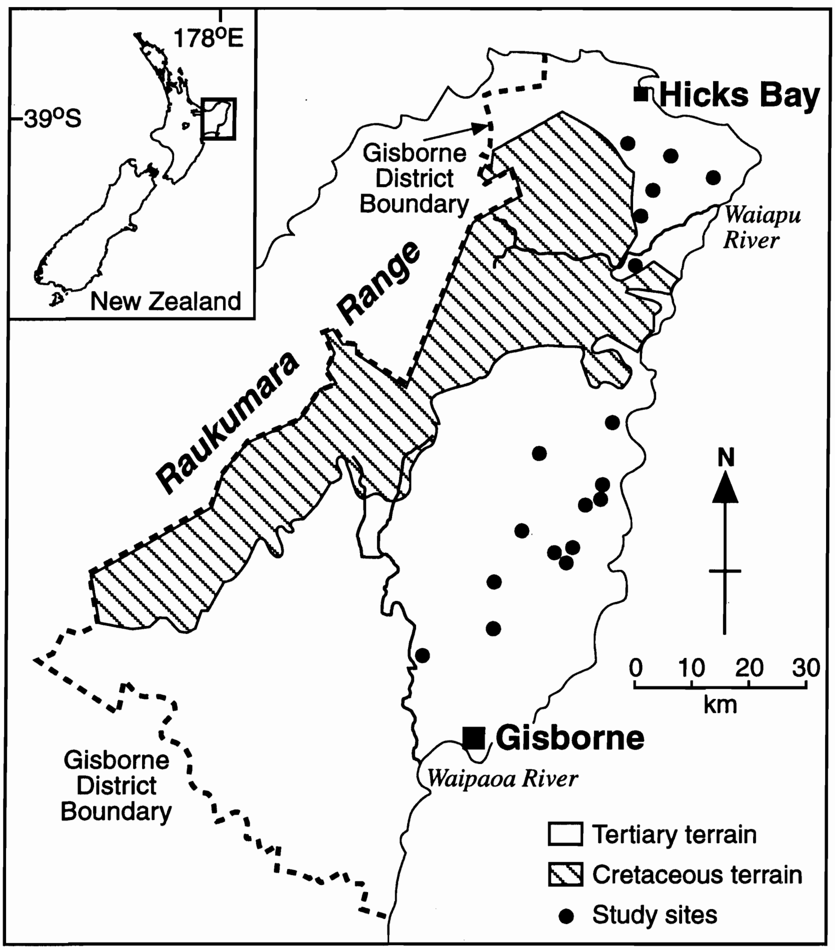

FIG. 1–Location of the 18 study sites in the Gisborne District, East Coast, North Island, New Zealand.

the predominant form of mass movement initiated by Cyclone Bola. Vegetation damage in these areas proved difficult to quantify (Marden & Rowan 1993) and has not been attempted in this study.

Recently, there has been increasing pressure to convert areas of regenerating forest to plantation forestry. In response to the magnitude of landslide damage to hill country throughout the East Coast region, the Government initiated a 28-year afforestation project aimed at converting marginal pastoral hill country to forest plantations, mostly of *Pinus radiata* (Ministry of Forestry 1994). Regenerating forest covers extensive areas of erosion-prone hill country that is being considered for exotic forest development. This has promoted considerable public debate about the relative merits of replacing areas of regenerating tea tree with exotic plantation or retaining scrub to allow full reversion to secondary broadleaved forest. There is also growing interest in managing areas of tea tree for wood production. However, there has been no comprehensive study of the age, composition, and structure of indigenous vegetation on the East Coast in relation to landslide damage resulting from Cyclone Bola.

The objective of this study was to determine the composition and structure of regenerating tea tree stands over a range of age-classes, and to assess the effectiveness of tea tree in reducing shallow slip erosion during major cyclonic events, based on damage caused by Cyclone Bola. A preliminary account of this study has been given by Bergin *et al.* (1993); the data and analysis are presented more thoroughly here.

STUDY AREA

Areas most severely damaged by shallow translational landslides during Cylcone Bola occurred on steep hill country underlain by a sequence of sedimentary rock types of late Tertiary age. These relatively competent rocks support steep valley slopes where coverbeds of volcanic ash and skeletal colluvial soils are shallow (<1 m).

Soils are Orthotic Recent Soils and their intergrades, Brown Soils on well-drained sites and Gley Soils on poorly-drained sites. These soils are typical of land that is being eroded or has received sediment deposited mainly as a result of slope processes (Hewitt 1992). They correlate with the Inceptisols of Soil Taxonomy (Soil Survey Staff 1992).

The climate of the East Coast region is warm temperate maritime, with moist summers and cool wet winters (Marden *et al.* 1991). Mean annual rainfall at lower elevations (e.g., Gisborne Airport, Station No. D87692, altitude 4 m) is approximately 1080 mm, increasing to 2100 mm at the higher elevations (e.g., Mt Arowhana, Station No. D87181, altitude 732 m) (New Zealand Meteorological Service 1984).

The region has a history of extreme floods, generally resulting from high intensity rainfall during occasional tropical storms. These storms have been a major feature contributing to the unstable nature of the hill country, east of the Raukumara Range. Although commonly considered to be infrequent, there were four East Coast rainfall events within the 1980s that resulted in considerable damage from landsliding (December 1980, 580 mm over 8 days; April 1982, 220 mm over 3 days; July 1985, 290 mm over 2 days; March 1988, up to 900 mm over 5 days (Cyclone Bola)) (Phillips *et al.* 1990). In the southern half of this region there have been 29 extreme floods during this century (Kelliher *et al.* 1995).

Areas of regenerating forest generally have similar disturbance histories. Podocarp-hardwood forest was clearfelled to create farmland around the turn of the century. After 70–100 years of intensive grazing, increased erosion coupled with productivity decline resulted in some of the poorer areas of farmland being afforested with exotic trees or abandoned. Much of the area now covered in indigenous vegetation was poorly utilised hill country farmland that, in part, had been allowed to revert. Areas of reversion which include secondary broadleaved forest and stands of manuka and kanuka total 60 000 ha and currently cover 7.2% of the land area within the East Coast region (Dymond *et al.* in press).

METHODS

Site Selection

Eighteen study sites containing areas of both regenerating forest and pasture were selected from parts of the East Coast region most severely damaged during Cyclone Bola between Hicks Bay in the north and Gisborne in the south (Fig. 1). Most were of northerly aspect. Because Cyclone Bola approached from the north-east, landslide damage was most severe on north-facing slopes. All sites were Category VI or Category VII of the Land Use Capability Classification (NWASCO 1975), but did not cover the full range of units within these classes. Care was taken to choose areas where tea tree stands and pasture occurred on slopes of similar gradient and aspect.

Sampling Methods

Field inspection and contemporary aerial photography were used to locate and select areas of homogeneous secondary forest types for separate sampling. Early aerial photography and local knowledge provided further information on the date of last clearing or burning, from which rates of reversion to secondary forest could be calculated. Sites chosen contained from one to four identifiably different age-classes of secondary forest as well as an area of pasture. In all, 36 stands from 18 sites were included in the study.

In each stand, two to five sample plots were established, 89 in total. Sampling intensity depended on the apparent homogeneity of vegetation and the total area of vegetation available for sampling. Most study areas were small (2–20 ha). Rectangular sample plots were located on mid-slopes, size being determined by the density of stems of the major species. To ensure that at least 15 individuals were included in each plot, dimensions were 5×2 m, 10×4 m, 20×8 m, or 40×16 m. Site factors were described using standardised reconnaissance plot methods (Allen & McLennan 1983). Additional information (landslide damage, description of the soil profile from auger samples, animal use, fire, or clearance history) was recorded.

Heights and basal diameters of all trees and shrubs within each plot were measured. Basal diameters were taken at or near ground level; where forking made this impossible, diameters were taken for all stems immediately above the fork. Where large shrubs or trees were the major component of vegetation, diameters and heights were recorded for stems down to a diameter of 2.5 cm. Where smaller shrubs were the major component, diameters of stems down to 1 cm were recorded. A measure of canopy height was obtained for each plot using the average height of all dominant trees.

In each plot, up to five discs were collected from stems of the dominant species (usually manuka and/or kanuka) for determination of establishment age. Representatives across the range of stem diameters in the stand were sampled. Discs were sanded and one ring was assumed to represent one year's growth. Because stands were sampled 2–3 years after Cylone Bola, ages were adjusted back to 1988 to give the age range of the stand at the time that Cyclone Bola occurred.

Stereo pairs of aerial photographs (1:25 000), taken immediately after Cyclone Bola, were used in conjunction with a dot matrix grid to estimate the percentage of surface area affected by recent landsliding in each area of tea tree stand and pasture at each study site. It is possible that vegetation in the tea tree stands could have obscured some of the landslide damage leading to some under-estimate of the damage.

Data Analysis

Since age and diameter of individual trees within a stand can be expected to be positively correlated, a value for the mean age of each stand was derived using regression estimates (Cochran 1977), i.e.:

$$A_T = A_I + b(D_T - D_I)$$

where, A_T = mean age of all trees in stand
A_I = mean age of individuals sampled by disc
D_T = mean diameter of all trees in stand
D_I = mean diameter of individuals sampled by disc
b = slope of age *v.* diameter regression equation.

A measure of the mean age of establishment in each stand was derived by obtaining an estimate for the upper ninetieth percentile of the age distribution. Assuming normality, this was represented by the equation:

$$A_E = A_T + 1.645 \times S_T$$

where, A_E = estimated age of establishment
S_T = standard deviation of age of all trees in stand.

The standard deviation of age (S_T) was estimated from the conditional distribution of the bivariate normal distribution using the following formula:

$$S_T = \sqrt{\frac{V_e\,(V_T(1 - r^2) + r^2 V_I)}{V_T(1 - r^2)}}$$

where, V_e = mean square error of the age *v.* diameter regression equation
r^2 = coefficient of determination of the age *v.* diameter regression equation
V_T = variance of the diameters of all trees in stand
V_I = variance of the diameters of individuals sampled by stem disc.

Log_e(stand density) was plotted against $\log_e$(individual tree mean basal area) (Fig. 2). According to the –3/2 self-thinning rule (Weller 1987), the relationship between average individual plant biomass and density is generally linear on a log/log scale. Points for fully-stocked stands should therefore lie within a linear band close to the theoretical line representing the relationship between stand density and basal area. Stands considered to be 50% or more under-stocked would be represented by a value $100.e^{-0.7}$% (0.7 units) below

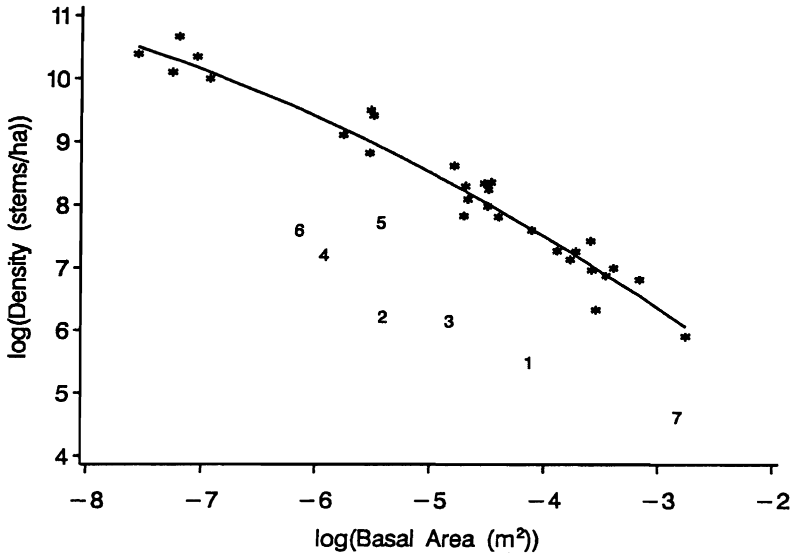

FIG. 2–Relationship between mean density of tea tree stands and mean individual tree basal area. Points representing under-stocked stands are indicated by the numbers 1 to 7. The regression equation for fully-stocked stands is $\log_e(\text{Density}) = 2.10 - 1.62\log_e(\text{BA}) - 0.0668\log_e(\text{BA})^2$ ($R^2 = 0.93$).

the line in Fig. 2. Under-stocked stands identified by this procedure were considered separately in subsequent analyses.

Diameters of multi-stemmed trees were combined using the square root of the sum of the squares of individual stem diameters. Trees with heights within 80% of the canopy height were assumed to belong to the canopy. Stand means for diameter, basal area, and stocking were obtained by averaging plot means of canopy trees. Relationships between these variables and establishment age were identified for fully-stocked stands using the programme FLEXI (Wheeler & Upsdell 1994) which determines the relationship between two variables using Bayesian smoothing techniques and provides 95% confidence intervals of the predictions.

To examine the effects of vegetation on land sliding, the proportion of the total area that had been recently damaged was calculated for each tea tree stand and for the area of pasture nearby. The percentage reduction in damaged area for each stand compared with the adjacent pasture was then calculated. Smoothed curves representing the effects on damage reduction of establishment age and basal area were then obtained, using FLEXI. It was assumed that at zero age and zero basal area, a site would be equivalent to pasture, and curves were therefore forced through the origin. The curves were also assumed to be asymptotic in character.

RESULTS

Site Characteristics

Rainfall received at each of the sample sites during the 5 days of Cyclone Bola varied between 350 and 850 mm (Table 1). Mean slope varied from 17° to 39°, with most within

TABLE 1–Site characteristics

	Mean	Minimum	Maximum	Std dev.
Cyclone Bola rainfall (mm)	594	350	850	144
Slope (°)	26	17	39	4
Damage to pasture (% area)	14	6	35	8
Altitude (m)	230	28	535	160

the range 18°–32°. Altitude of sites ranged from 28 to 535 m. Over half of the sites were located on slopes with a northerly aspect. Approximately equal numbers of the remaining sites were located on slopes facing east, west, and south. The percentage area affected by landslide damage on pasture varied from 6% to 35%.

Stand Characteristics and Composition

Seven stands were at least 50% understocked (*see* Fig. 2). Within stands, there was generally a positive relationship between tree age (A_T) and diameter, and the correlation coefficient (r) averaged 0.42. The standard deviation of age within stand increased with mean age, with a coefficient of variation averaging 27% remaining fairly constant across all age-classes. The considerable range in ages made it difficult to determine precisely the age of establishment, particularly in older stands.

Manuka dominated the canopy of fully-stocked stands in early years, but in the 20–30 years age-class kanuka had become dominant (Table 2). Beyond 30 years, manuka was virtually absent. Species other than manuka and kanuka appeared only in the 30–40 years age-class.

Table 2–Canopy species composition by age-class in fully-stocked stands.

Age-class (years)	No. stands	No. plots	Basal area by species (%)			Density by species (%)		
			Kanuka	Manuka	Others	Kanuka	Manuka	Others
0–10	6	16	36	64	0	8	92	0
10–20	4	10	32	68	0	17	83	0
20–30	4	12	74	26	0	49	51	0
30–40	8	17	86	4	10	88	2	10
>40	7	16	100	0	0	100	0	0

Stand Dynamics

Canopy height of fully-stocked stands increased steadily for the first 40 years, stabilising at approximately 13 m within 80 years (Fig. 3). Tea tree stands achieved a height of 2 m in 5 years, 4 m in 10 years, and 7 m in 20 years. Under-stocked stands did not deviate much from this trend. In contrast to height, stem diameter of canopy trees showed a more linear trend, although there was greater variation between stands (Fig. 4). Under-stocked stands tended to have above-average mean diameters at a given age.

Stand basal area increased rapidly over the first 20 years (Fig. 5), peaking at age 30 years at about 40 m^2/ha. Beyond 30 years basal area decreased, perhaps suggesting that kanuka has a lower basal area carrying-capacity than manuka. Under-stocked stands had lower basal

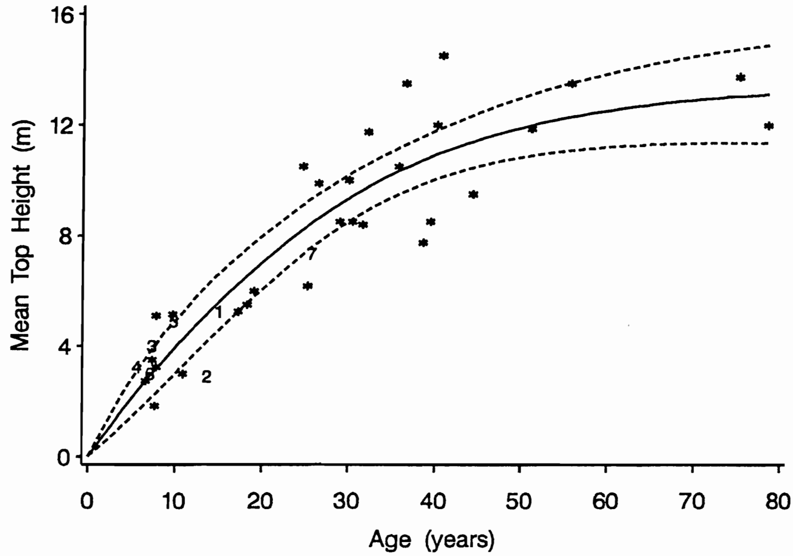

FIG. 3–Relationship between mean canopy height and establishment age. Solid line is a FLEXI curve fitted to fully-stocked stands; dashed lines indicate 95% confidence interval.

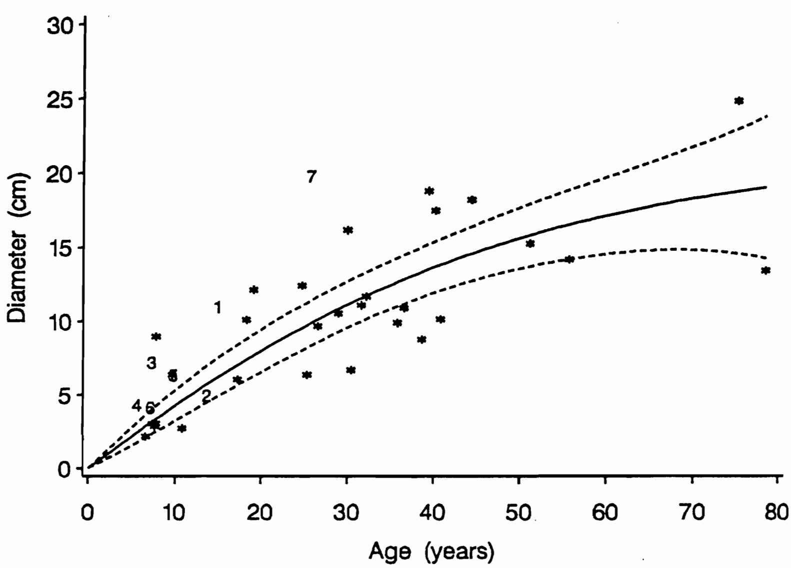

FIG. 4–Relationship between mean diameter of canopy trees and establishment age. Dashed lines indicate 95% confidence interval.

area than fully-stocked stands of similar age. Mean stand density of fully-stocked stands reduced rapidly with age from 20 000 stems/ha at age 10 years to less than 3000 stems/ha beyond 40 years of age (Fig. 6).

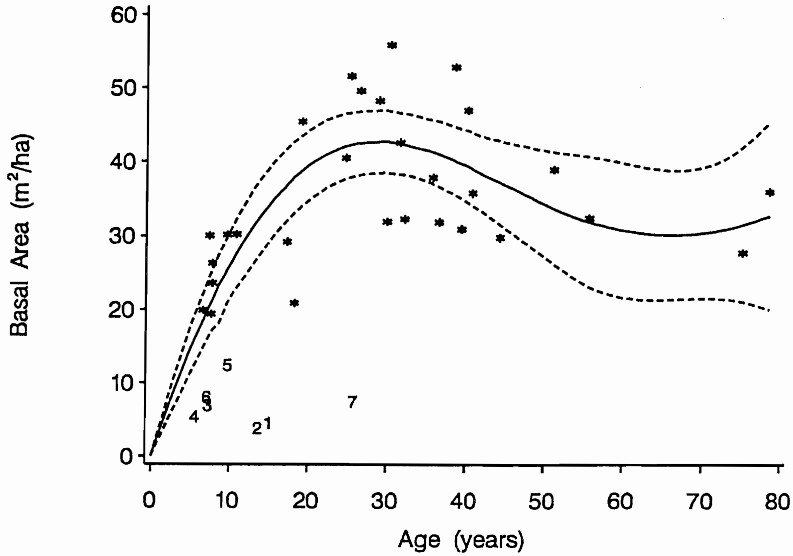

FIG. 5–Relationship between mean stand basal area and establishment age. Dashed lines indicate 95% confidence interval.

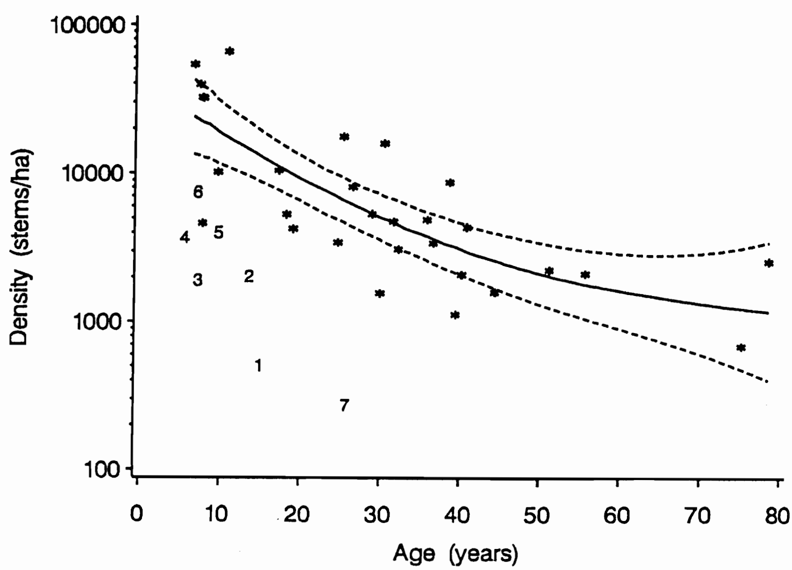

FIG. 6–Relationship between density of canopy trees and establishment age. Dashed lines indicate 95% confidence interval.

Protective Value of Vegetation

Slip damage showed a rapid and highly significant reduction with age. Predicted damage reduction with 95% confidence intervals was 65±10% at age 10 years and 90±9% at age 20 years (Fig. 7). Under-stocked stands tended to fall below the average for fully-stocked

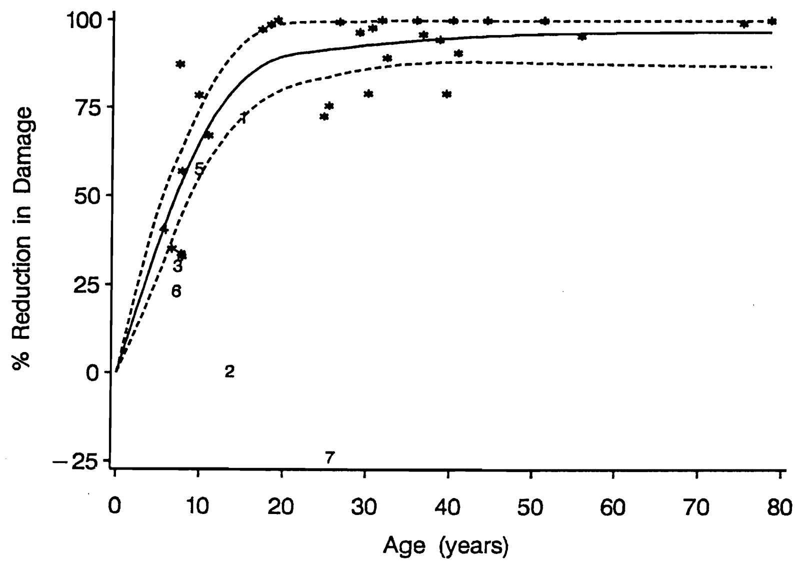

FIG. 7–Relationship between percentage reduction in landslip-damaged area and establishment age. Dashed lines indicate 95% confidence interval.

stands, but only two stands were well outside the range. Basal area in fully stocked stands was a less accurate predictor of percentage damage reduction than establishment age (Fig. 8). However, mean canopy height × basal area (Fig. 9), a broad indicator of stand volume, provided a better predictor of damage reduction than basal area alone.

Major site and vegetation variables are presented for each stand in Appendix 1.

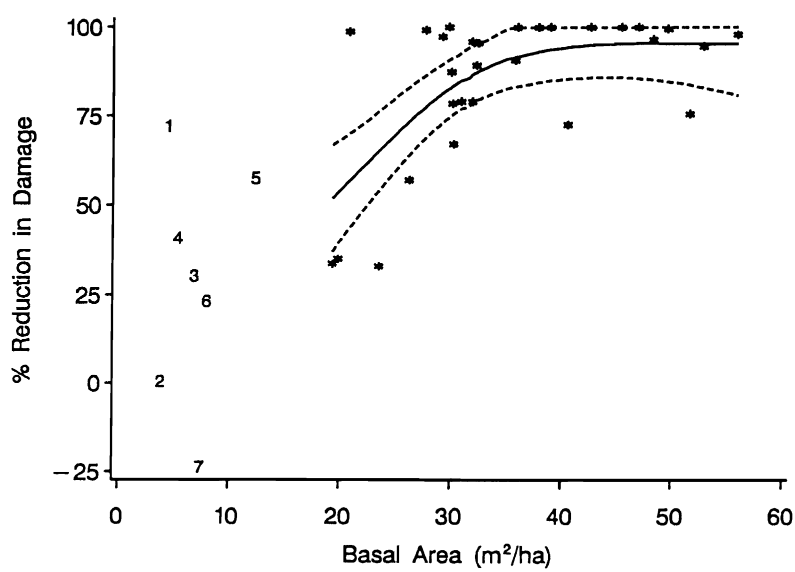

FIG. 8–Relationship between percentage reduction in landslip-damaged area and basal area. Dashed lines indicate 95% confidence interval.

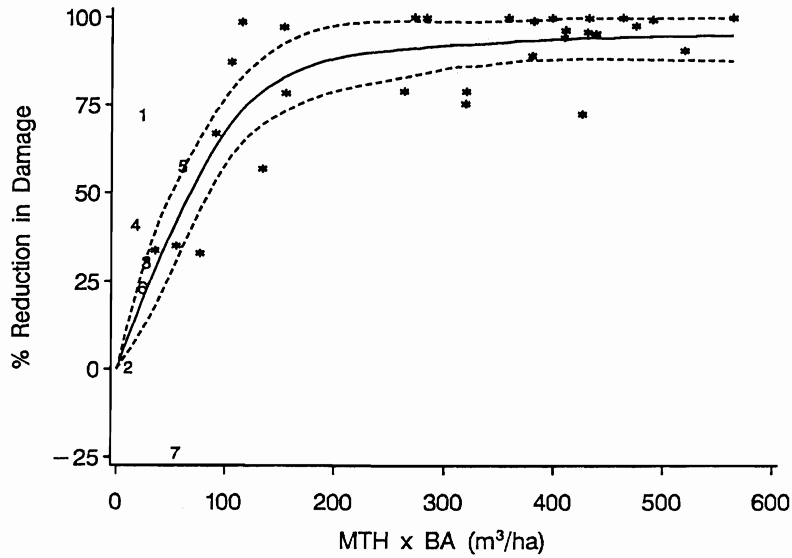

FIG. 9–Relationship between percentage reduction in landslip-damaged area and mean canopy height × basal area. Dashed lines indicate 95% confidence interval.

DISCUSSION

Manuka colonisation in reverting pasture on colluvial-covered slopes is rapid, and within 10 years of establishment, manuka-dominated stands typically contained more than 20 000 stems/ha. Although not surveyed in this study, tea tree stands less than 6 years old are likely to have a considerably greater density of stems. Esler & Astridge (1974) found a density of 80 000 stems/ha in the youngest stand of tea tree (6 years old) they surveyed in the Waitakere Range. Growth rates of tea tree on the East Coast appeared to be similar to that in the Waitakere Range survey.

On the East Coast, manuka was found to decline significantly after about 20 years, with stands then becoming dominated by kanuka. The oldest stands surveyed (79 years) were still dominated by kanuka with no indication of other species starting to replace kanuka forest. These findings are consistent with other studies. In a study of kanuka-dominated stands near Dunedin, Allen *et al.* (1992) found that manuka was replaced by kanuka about 30 years after the species established together. They found no evidence of replacement of kanuka by other species in stands up to 72 years old. Esler & Astridge (1974) observed that the growth of manuka in the Waitakere Range slowed at about 20 years whereas kanuka continued to grow for 50 years suppressing manuka. Esler (1967) found that manuka reached senility at 30–40 years on Kapiti Island whereas kanuka did not become decadent for 80 years or more. The ecological niches of the two species indicate that kanuka has a competitive advantage over manuka with time, growing faster and taller than manuka on good sites (Burrows 1973). Kanuka also has a greater resistance to the disease known as manuka blight (caused by the scale insect *Eriococcus orariensis* Hoy and its accompanying sooty mold *Capnodium walteri* Saccardo), and is more tolerant of shade and root competition, particularly on dry fertile sites (Burrell 1965). Manuka blight was common in stands surveyed on the East Coast and, as in other areas, it is clear that this and other factors have a role in determining the relative abundance of manuka and kanuka in the region.

In the Kapiti Island survey, Esler (1967) suggested that grazing had been a pre-determining factor in the development of manuka and kanuka. These species require high light levels which are available only when taller plants are absent. Reversion of grazed hill country on the East Coast to tea tree is a major management problem for farmers and where insufficient resources have been available for control, extensive stands are developing. Esler & Astridge (1974) indicated that in the Waitakere Range, the abandonment of previously-farmed land led to extensive stands of regenerating tea tree communities. Many sites in the Waitakere Range were affected by grazing and trampling associated with a noticeable absence of broadleaved shrubs and an abundance of the unpalatable shrub *Coprosma rhamnoides* A.Cunn. in the understorey. Similarly, most sites in our East Coast survey showed evidence of animal browsing and trampling with a dominant understorey of *C. rhamnoides* often present. For design reasons related to the landsliding objective, the stands were located mainly near pasture and would have included a greater proportion of sites affected by animals than if sampling was on a more random basis. Although grazing by cattle, sheep, and on some sites goats, may have favoured the initial establishment of tea tree communities, succession in older stands to other mixed species communities is likely to be slower than in either fenced or remote areas.

Forest vegetation is known to reduce erosion on steep hill country. Several studies have shown a clear relationship between the size and density of vegetation cover, and slope stability and sediment yield during major storm events (O'Loughlin *et al.* 1982). Forest vegetation reduces run-off and for most of the year keeps the soil profile substantially drier than under pasture, largely because of rainfall interception (Pearce *et al.* 1987). During periods of intense rain, the inevitable saturation of vegetation and soil is delayed under forest. Once the soil is saturated, the shallow regolith on steep slopes overlying relatively impermeable bedrock may be mobilised, leading to shallow landsliding. At this stage the reinforcement of the soil mantle by root systems contributes significantly to landslide prevention (O'Loughlin 1984; Forest Research Institute 1990; O'Loughlin *et al.* 1982).

Watson & O'Loughlin (1985) found that root systems of several manuka stands aged between 13 and 48 years growing in dense stands on shallow, stony, hillslope and terrace soils provided good protection against the formation of shallow landslides. Root systems of manuka in dense stands were concentrated in the top 50 cm of soil where they occupied approximately 5% of the soil volume. After measurement of root strength, they concluded that this level of reinforcement in young dense manuka stands was significant in maintaining stability on steep slopes susceptible to shallow translational landslides. Our study shows that within 10 years of establishment, manuka-dominated stands reduced erosion associated with Cyclone Bola by 65%. After another 10 years as kanuka became dominant, landsliding was reduced by 90%, with a near 100% reduction in landslipping in still older stands. This suggests that root systems in kanuka-dominated stands are more effective in preventing erosion than the root systems in younger manuka-dominated stands.

Somewhat surprisingly, most of the under-stocked stands in this study gave a reduction in landsliding comparable with fully-stocked stands of similar age. These under-stocked stands were mainly less than 15 years old, however, at which age only partial protection occurred, even in fully-stocked stands. The oldest under-stocked stand, consisting mainly of scattered 20- to 30-year-old kanuka trees, provided no protection.

For the East Coast and other regions throughout New Zealand where erosion is caused by combinations of factors such as cyclonic storms, steep slopes, and shallow soils overlying competent rock types, slope stability can be improved relatively quickly by planting fast-growing species such as *P. radiata*. At age 8, *P. radiata* root systems have a mean maximum depth of 1.8 m with structural roots concentrated in the top 40 cm of the soil profile, suggesting that trees of this age help maintain stability of slopes susceptible to shallow landslides (Forest Research Institute 1990). Direct comparisons between various East Coast studies assessing the effect of vegetation on erosion resulting from Cyclone Bola are difficult to make because of different parameters used to measure the degree of erosion (Phillips *et al.* 1990; Marden *et al.* 1991; Hicks 1991). However, all indicate that pines begin to increase slope resistance to shallow landslide failure between 6 and 8 years after establishment. More recently, landslide damage initiated by Cyclone Bola within 1-29-year-old *P. radiata* stands was analysed (Marden *et al.* 1995) using FLEXI. This permitted direct comparisons to be made of the relative effectiveness of kanuka and *P. radiata* in reducing landslides initiated during heavy rainfall events. The results showed that the two species afford similar levels of protection at age 10 years with *P. radiata* affording 75% protection (cf. 70% for tea tree) and 100% at 20 years, (cf. 90% for tea tree). *Pinus radiata*, however, achieved 90% protection by age 14 years indicating that near total protection occurs sooner with *P. radiata* and is a likely function of its faster root biomass growth rates (Watson *et al.* 1994). Both vegetation types ultimately provide a high level of protection.

A major implication of the results of this study is that on steep erosion-prone hill country the clearfelling of regenerating manuka/kanuka stands more than 10 years old will leave sites vulnerable to erosion by periodic storms until planted pines become established. The tensile strength of decaying manuka/kanuka roots is likely to be minimal after about 4 years (Watson *et al.* 1994). Pines require 6 to 8 years to make a significant contribution to slope stability, and there will be a period of at least 3 years during which slopes remain susceptible to storm-induced landslide damage. An analysis of storm frequencies based on historical discharge rates for the East Coast Waipaoa Catchment suggests that within any 3-year period, there is a 63% chance of a major storm event in the catchment area (Watson *et al.* 1994). The same analysis suggests that within any 6-year period there is an 87% chance of a major storm event with concomitant landslide damage (Kelliher *et al.* 1995).

In view of this risk, particularly for those land classes susceptible to storm-induced landslide damage, the rationale for promoting conventional plantation forestry establishment techniques on East Coast hill country currently under regenerating forest should be reassessed. Alternative land-use options to clearfelling and planting in *P. radiata* that are unlikely to lead to increased risk of erosion should be considered. The development of a productive land-use based on forestry which does not compromise conservation, cultural, and economic considerations for the East Coast region is a high priority for research (Herbert 1994). An enrichment scheme for tea tree-dominated hill country based on the establishment of high-value exotic and indigenous timber trees is currently being evaluated at the New Zealand Forest Research Institute in Rotorua. Trials have been set up to investigate performance of exotic species such as blackwood (*Acacia melanoxylon* R.Br.) or cypresses (*Cupressus macrocarpa* Gordon and *C. lusitanica* Miller), and indigenous tree species including totara (*Podocarpus totara* D.Don) and puriri (*Vitex lucens* Kirk) planted in lanes and gaps cut in the tea tree stands. As only a proportion of the scrub is required to be cleared, critical environmental values including soil and water conservation values, are left largely intact and consequently such a land-use is highly unlikely to lead to increased erosion of hill country.

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APPENDIX 1

MAJOR SITE AND VEGETATION VARIABLES LISTED BY STAND

Site			Landslip damage (%)		Age		Stand variables					
NZMS Grid reference	Rainfall (mm)	Stocking category	Scrub	Pasture	Mean A_T	Stand A_E	BA (m^2/ha)	Density of stocking (stems/ha)	Mean diameter of canopy (cm)	Canopy height (m)	Slope (°)	Altitude (m)
Z16/713164	560	Fully	0.0	10.5	35.6	51.2	39.0	1 422	17.5	11.9	31	154
Z14/854707	400	Fully	0.0	5.7	19.3	31.7	42.6	2 000	14.5	8.4	32	219
Y16/685130	580	Under	5.1	18.3	10.1	15.1	4.6	242	14.3	5.3	24	66
		Fully	0.5	18.3	14.9	17.3	29.2	9 000	6.3	5.3	27	85
Y16/701143	550	Fully	0.0	35.2	30.3	44.4	29.8	906	23.2	9.5	29	63
		Under	35.0	35.2	8.0	13.7	3.9	500	7.5	2.9	30	75
Z14/770790	550	Fully	5.7	8.6	5.1	7.7	19.4	24 333	3.0	1.8	29	111
		Fully	2.1	8.6	15.8	25.3	51.6	12 250	7.2	6.2	30	85
		Fully	0.8	8.6	23.8	40.8	35.8	563	19.2	14.5	29	45
		Under	6.0	8.6	5.4	7.3	6.9	469	10.1	4.0	29	28
Y17/640055	550	Fully	0.3	7.3	21.6	36.6	31.9	3 250	11.0	13.5	23	175
		Fully	2.0	7.3	18.1	24.7	40.5	2 906	12.0	10.5	22	190
Y17/660030	500	Fully	0.0	14.0	26.6	35.8	37.9	1 438	16.2	10.5	18	210
Z14/930730	400	Fully	1.0	9.3	19.3	32.3	32.3	2 469	12.5	11.8	25	110
		Fully	2.0	9.3	7.5	9.7	30.1	6 750	7.1	5.2	25	138
		Fully	4.0	9.3	5.0	7.8	26.3	2 500	10.8	5.1	28	135
		Under	5.5	9.3	3.9	5.6	5.4	1 344	5.8	3.3	28	73
Y17/385875	350	Fully	0.0	7.4	55.4	78.5	36.0	1 094	20.7	12.0	29	150
Z15/790530	610	Fully	0.2	8.9	21.6	30.5	55.9	13 333	7.1	8.5	27	237
		Fully	0.4	8.9	45.2	55.7	32.5	1 063	18.8	13.5	27	235
Y17/645038	530	Under	8.1	19.1	7.5	9.8	12.4	2 250	7.5	4.9	27	115

APPENDIX 1 cont.

Site			Landslip damage (%)		Age		Stand variables					
NZMS Grid reference	Rainfall (mm)	Stocking category	Scrub	Pasture	Mean A_T	Stand A_E	BA (m^2/ha)	Density of stocking (stems/ha)	Mean diameter of canopy (cm)	Canopy height (m)	Slope (°)	Altitude (m)
Z15/825695	600	Fully	0.0	12.2	16.0	19.1	45.4	4 250	12.1	6.0	25	177
Z16/735255	350	Fully	0.2	22.3	45.8	75.2	27.7	367	28.4	13.8	22	143
Y17/500970	750	Fully	5.9	9.1	5.2	6.6	19.9	32 500	2.6	2.8	28	530
		Fully	6.1	9.1	6.3	7.8	23.6	22 000	3.5	3.3	26	515
		Fully	0.5	9.1	27.5	38.6	52.8	4 000	10.8	7.8	26	475
Y17/555085	700	Fully	5.7	17.3	6.4	10.9	30.2	43 000	3.1	3.0	28	535
		Fully	2.2	17.3	5.1	7.4	30.0	31 000	3.3	3.5	21	363
		Under	13.3	17.3	4.2	7.1	8.0	2 000	5.2	3.0	26	380
Y16/600215	850	Fully	5.4	25.8	27.7	30.0	31.9	1 250	17.1	10.0	23	450
		Under	31.9	25.8	12.6	25.8	7.5	102	27.5	7.3	25	450
		Fully	5.4	25.8	30.4	39.4	30.9	969	20.1	8.5	21	433
		Fully	0.9	25.8	19.0	29.0	48.3	3 781	12.0	8.5	23	445
Z15/795650	700	Fully	0.1	7.6	7.6	18.3	20.9	4 172	11.8	5.5	23	145
		Fully	0.0	7.6	17.1	26.6	49.6	5 500	10.3	9.9	26	164
Y17/513907	570	Fully	0.0	16.3	26.8	40.2	46.9	1 688	18.7	12.0	29	380