PROTECTIVE VALUE OF VEGETATION ON TERTIARY TERRAIN BEFORE AND DURING CYCLONE BOLA, EAST COAST, NORTH ISLAND, NEW ZEALAND

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ABSTRACT

The effects of six vegetation types on landslide densities on Tertiary bedrock terrain were examined before and after Cyclone Bola struck the East Coast region of the North Island of New Zealand in March 1988.

Indigenous forest and exotic pine plantations more than 8 years old provided the best protection against the formation of shallow landslides, both before and during Cyclone Bola. Regenerating scrub and exotic pines 6–8 years old provided an intermediate level of protection. Greatest damage occurred on pasture and in areas of young (<6 years old) exotic plantations where canopy cover was negligible and root development limited.

Sites under older vegetation types with a closed canopy (indigenous forest and plantations of exotic pines >8 years old) were four times less susceptible to landsliding during Cyclone Bola than those under regenerating scrub and exotic pines 6–8 years old, and 16 times less susceptible than those under pasture and young exotic pines (<6 years old).

Keywords: East Coast region; Cyclone Bola; landslide densities; vegetation types.

INTRODUCTION

On 7–9 March 1988 Cyclone Bola, a cyclonic storm of short duration (72 hours), struck the East Coast of the North Island (Fig. 1). Rainfall intensities of 23 mm/h were recorded, with falls of 24 and 72 h duration measuring 346 and 917 mm, respectively. The heaviest falls were recorded in highly erodible hill-country areas. The East Coast region has a history of extreme rainfall events, largely of tropical origin, which since the turn of the century have had an average return period of 3 years (F.M.Kelliher, M.Marden, A.J.Watson, unpubl. data). Landsliding has been associated with many of these events.

Early reconnaissance flights over the storm-damaged region revealed that hill-slope damage by landsliding was widespread and severe, with the greatest densities on Tertiary hill country where shallow soils occur on steep slopes. It was also apparent that different vegetation types had afforded different levels of hillslope protection.

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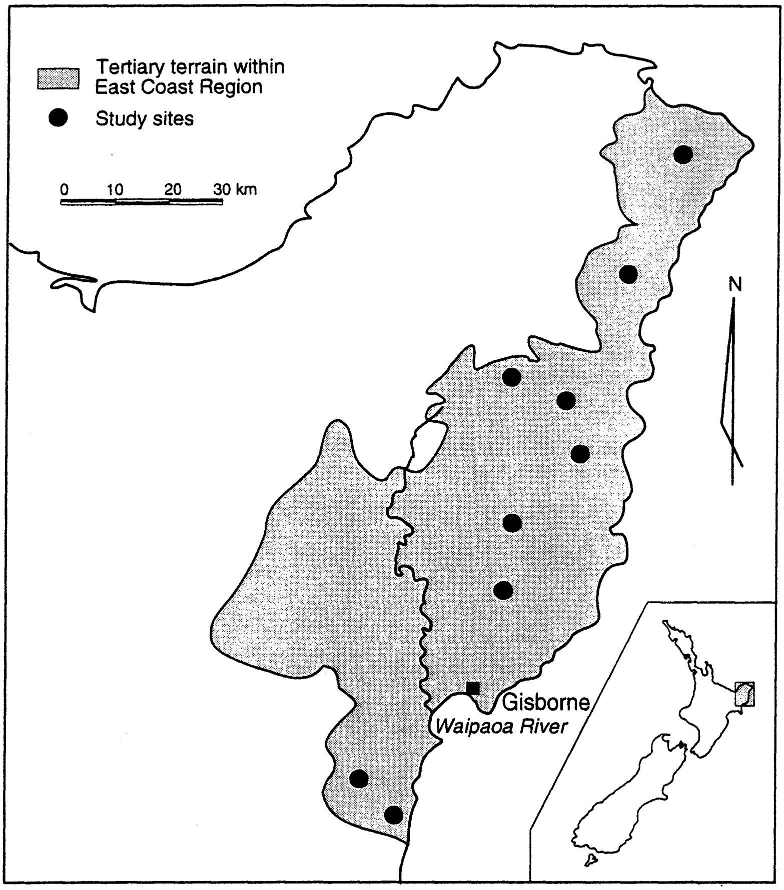

FIG. 1–Location and distribution of study sites on Tertiary hill country, East Coast region, New Zealand.

Initial assessments of the protective influence of different vegetation types were carried out shortly after Cyclone Bola (Marden & Rowan unpubl. data; Hicks 1991) and indicated that:

- Indigenous forest and areas of advanced regenerating scrub had provided the best protection against landslide initiation;
- Young exotic plantations (<6 years old) and pasture provided the least protection;
- Older exotic plantations (6–8 years old) gave an intermediate level of protection.

Sites with predominantly mature exotic forest and regenerating scrub for which aerial photographic coverage was not available at the time of the initial assessment have now been incorporated into the dataset. This paper presents the results of an extended survey aimed at assessing the susceptibility of sites under different types of vegetation (indigenous forest, regenerating scrub, exotic pines of various ages, and pasture) to landsliding* during a single intense rainfall event.

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* The term "landslide" is used throughout to refer collectively to all types of rapid mass movement.

Physiography of the East Coast Region

The East Coast region is divisible into two geomorphic terrains. The more erodible upper catchment reaches of the main rivers contain the highest (900–1400 m a.s.l.) and some of the steepest land in the district and are subjected to the heaviest annual rainfalls (2000–3800 mm). The area is underlain by inherently unstable rock types of Cretaceous and early Tertiary age that are predominantly fine-grained, clay-rich, and severely tectonically crushed. As a consequence these rock types are particularly susceptible to weathering processes and to the erosive action of running water. In addition, high groundwater pressures and numerous surface seeps keep large areas of the upper regolith perpetually wet. Present-day slope morphology reflects these influences. Tributary stream channels are deeply incised and mass movements, including earthflows and deep-seated slumps (Varnes 1978), dominate the slopes. Such slopes evolved over thousands of years by the same erosional processes evident today. Residual deposits of thick volcanic ash and fertile forest soil rich in humus from the once-extensive coverbeds are preserved only on narrow ridge tops or on high-level alluvial terraces.

To the east, steep hilly country is underlain by a sequence of competent sedimentary rock types of late Tertiary age (Fig. 1). These relatively competent rocks support steep valley slopes where shallow landslides are the dominant erosion type. Mass movements and gullying are often confined to areas where the rock sequence is dominated by mudstone that has been weakened by fault crushing. Coverbeds of volcanic ash and forest soils are deep (>1 m) and well preserved on localised gently-sloping dip slopes, but are shallow (<50 cm) and skeletal on the predominant steeper slopes.

Vegetation Erosion History

The clearfelling of vast areas of indigenous forest and its conversion to pasture 70–100 years ago escalated the rate of valley-slope erosion and the risk of damage to downstream areas by siltation and flooding. Despite early reports of increased damage from erosion as a direct result of deforestation (Henderson & Ongley 1920), the clearfelling of forest continued, and by the 1960s the erosion was sufficiently advanced to be viewed by some as the worst example of soil erosion on pastoral hill country anywhere in the world. The early 1960s saw the establishment of protection forests for erosion-control purposes. To date 80 000 ha of eroding land have been afforested, predominantly with exotic pines (*Pinus radiata* D.Don). Approximately 200 000 ha of eroding land remain under pasture.

Before Cyclone Bola 90% of the pastoral land area was considered capable of sustained production (National Water and Soil Conservation Organisation 1970). However, this cyclone demonstrated that extensive pastoral areas not previously considered susceptible are prone to erosion.

METHOD

The relative susceptibility of six different vegetation types to landsliding during a single cyclonic event was assessed by examining landslide intensity on aerial photographs taken before (1982) and after (1988) Cyclone Bola. Both sets of photographs were panchromatic at 1 : 25 000 scale. The post-Bola photographs were taken within 1 month of the event.

To minimise the inter- and intra-site variability caused by geomorphic and geotechnical influences, nine study sites (Fig. 1) were chosen for similarity of geology, aspect, altitude, and slope from the 1988 photographs, then identified on the 1982 photographs. At each site several vegetation types were present. For comparisons with the original dataset, landslide damage was estimated by landslide density counts.

Pre- and post-Bola landslide densities were determined by stereoscopically examining the photographs and counting landslide initiation points within defined areas of each vegetation type. Landslide density was expressed as the number of landslides per hectare. The areal extent of vegetation was measured with a digital planimeter.

The method worked satisfactorily for steep hill-country sites where thin soils overlying the impermeable Tertiary age lithologies rapidly became saturated during Cyclone Bola. Failure of these materials created sharp erosion scars clearly visible on the aerial photographs.

Not all the erosion scars within the areas assessed in this report were the result of Cyclone Bola. Several generations of scars were present on these slopes and most of those initiated by Cyclone Bola were on slopes that showed evidence of previous failures. We considered that new failures on existing erosion scars should be included in the count, because repeated collapse has been one of the major reasons why some areas were allowed to revert to scrub, were subsequently planted in pines, or were preserved as remnants of indigenous forest for protective purposes. Such slopes have been inherently unstable at least throughout historic times. All scars that had a fresh appearance were therefore counted. Details of erosion scar size, classification, position on slope, and age have not been included in this study.

The method proved inappropriate for assessing slope failures that were a result of mass movements on hill country underlain by Cretaceous lithologies. Horizontal displacements by earthflows and slumps, though widespread, were small, and these forms of displacement and the associated deep cracking were not visible on aerial photographs at 1 : 25 000 scale. Small areas of bare ground around steep-sided headwall and lateral scarps of earthflows and slumps were often the only visible signs of slope failure. As failure occurred below rooting depth, tall vegetation (forest and scrub) usually remained intact and collapse of the vegetation cover to produce an open distinct scar was rare. Consequently, an assessment of the protective influence of different vegetation types was not attempted for this terrain type.

Indigenous forest was defined as old (>80 years) closed-canopy secondary forest characterised by emergent broadleaved species, including kamahi (*Weinmannia racemosa* L.) and rewarewa (*Knightia excelsa* R.Br.). Scrub was identified as even-aged, closed-canopied stands of manuka (*Leptospermum scoparium* J.R. et G.Forst.) and/or kanuka (*Kunzea ericoides* (A.Rich.) J.Thompson) irrespective of stand age or height. Areas of scattered scrub on farmland were not included.

Areas of older (>8-year-old) exotic plantations were identified on the 1982 photographs as closed-canopied stands and their ages verified from forest stand records. Exotic pines 6–8 years old in 1988 were identifiable on the 1982 photographs as young plantings. The youngest (<6-year-old) plantings of exotic pines post-date the 1982 photographs. Consequently, the pre-Bola landslide density for these sites relates to the time when the land was in pasture.

The complex compartmental age-class distribution within exotic forests precluded any attempt to analyse differences in landslide densities attributable to initial stocking rates, tending, or final stand densities. Normal forest practice in this region is to establish between 900 and 1250 stems/ha, prune to 6 m in three lifts at ages 4, 6, and 8 years, and thin the stands at ages 4 and 7 to achieve a final stocking density of 250–300 stems/ha.

Statistical comparisons were made between pre-Bola landslide densities under the different vegetation types (Fig. 2). Differences between pre- and post-Bola landslide densities were compared by log-transformation of the data to stabilise variances, and by analysis of variance using the SYSTAT statistical package (Wilkinson Leland 1990). Site was not used as a factor in the analysis because differences in the number of landslides, before and after Bola, were consistent between sites. Confidence intervals (Fig. 2) were calculated on a log scale and back transformed, hence are not symmetric about the mean. All means reported were back-transformed values (Table 1). Statistical significance was assumed at $p<0.05$.

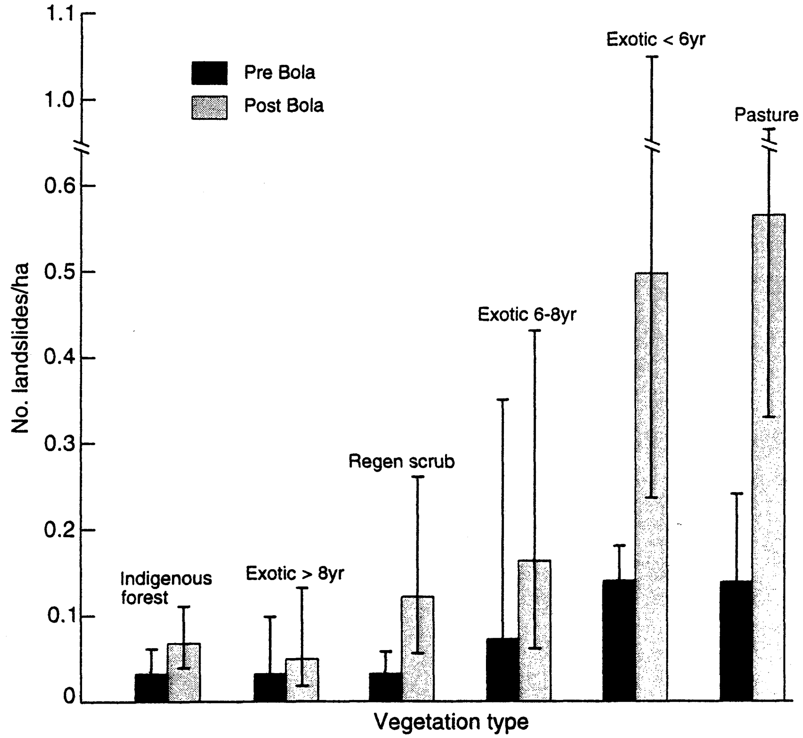

FIG. 2–Comparative pre- and post-Bola mean landslide densities for each vegetation type assessed in this study. Values plotted are the back-transformed means for the pre- and post-Bola landslide densities (Table 1). Error bars represent the 95% confidence intervals. These were calculated on a log scale.

RESULTS

Analyses of variance indicated that inter-site variations—including geology, aspect, altitude, slope, and rainfall—were not significantly different.

Pre-Bola Landslide Densities

The lowest pre-Bola landslide densities occurred in areas of indigenous forest (0.031 landslides/ha), exotic pines >8 years old (0.028 landslides/ha), and advanced regenerating scrub (0.029 landslides/ha) (Table 1). Densities for these three vegetation types were significantly lower ($p=0.003$) than for areas of exotic pines <6 years old (0.135 landslides/ha) and pasture (0.139 landslides/ha) (Fig. 2). Densities for areas of exotic pines 6–8 years old (0.070 landslides/ha) were not significantly different from those for any other vegetation type (Fig. 2).

TABLE 1–Landslide densities for different vegetation types assessed in this study (Note: all means are back transformed).

Vegetation type	Area assessed (ha)	Mean landslides/ha		Increase in landslide density after Bola
		Pre-Bola	Post-Bola	
Indigenous forest	4 600	0.031	0.066	0.025
Exotic pines >8 yr old	3 700	0.028	0.048	0.018
Regenerating scrub	4 250	0.029	0.120	0.099
Exotic pines 6–8 yr old	4 050	0.070	0.162	0.074
Exotic pines <6 yr old	6 070	0.135	0.496	0.292
Pasture	7 900	0.139	0.564	0.383
Total	30 570			

Effect of Bola

The relative effectiveness of vegetation types in preventing the initiation of shallow landslides remained largely unchanged after Cyclone Bola despite the overall substantial increase in landsliding initiated by it. Increases in landslide density were greatest in areas of exotic pines <6 years old (0.292 landslides/ha) and pasture (0.383 landslides/ha) (Fig. 2), which were not significantly different from one another in this regard. The pooled Bola landslide density for areas under these two vegetation types (0.675 landslides/ha) was significantly higher than the pooled density (0.043 landslides/ha) for indigenous forest and exotic pines >8 years old ($p<0.001$) and for regenerating scrub and exotic pines 6–8 years old (0.173 landslides/ha, $p<0.05$). Areas under indigenous forest and exotic pines >8 years old were collectively and individually 16 times less susceptible than both pasture and exotic pines <6 years old, and 4 times less susceptible than both regenerating scrub and exotic pines 6–8 years old, to landsliding during Cyclone Bola. The high susceptibility to landsliding, during heavy rainfall, of land under pasture and pines <6 years old is shown in Fig. 3 and 4.

DISCUSSION

The results of this study confirm a relationship between landslide density and vegetation type on East Coast Tertiary terrain where shallow soils exist on steep slopes, both before and after Cyclone Bola.

Before Cyclone Bola, landslide densities for sites of closed-canopy scrub were low and comparable with densities for areas of older exotic and indigenous forest. However,

FIG. 3–Contrasting landslide densities between pasture and indigenous forest on Tertiary hill country after Cyclone Bola.

FIG. 4–Extensive landslide damage to young exotic pines (2 years old) on Tertiary hill country after Cyclone Bola.

regenerating scrub was proportionately the most severely affected of the vegetation types assessed in this study, with >300% increase in landslide density after Cyclone Bola. Field observations showed that stands of young scrub less than 2 m high were more predisposed to landsliding than older taller stands of scrub, and that there was a likely relationship between the extent of damage and stand parameters such as age, density, and root development. Stand parameters were not available for these areas and no attempt was made to examine these relationships. However, another study confirmed that both stand age and stocking significantly influence the degree of erosion protection provided by regenerating scrub (Bergin *et al.* 1993).

Indigenous forest and exotic pines >8 years old afforded the best protective cover and were the least susceptible of the vegetation types assessed to landsliding. Exotic pines 6–8 years old and regenerating scrub (age unspecified) both provided an intermediate level of protection that was 4 times less effective than indigenous forest and exotic pines >8 years old, but 4 times more effective than pasture and exotic pines <6 years old. After Cyclone Bola, landslide densities under exotic pines 6–8 years old increased by ≈100%, proportionately greater than those recorded for indigenous forest (≈75% increase) and exotic pines >8 years old (≈60% increase), but less than those for pasture (>250% increase) and exotic pines <6 years old (≈200% increase).

Previous research has shown that, for exotic forests, interception of rainfall by the canopy, efficient use of soil-water (Pearce *et al.* 1987), and interlocking and overlap between adjacent tree-root networks (Forest Research Institute 1990) can modify the hydrological status of the slopes and reinforce the upper soil horizons. As a result, within 8 years of establishment a plantation can effectively reduce the likelihood of shallow landsliding during storm events. During Cyclone Bola 6- to 8-year-old exotic pines afforded a level of protection 4 times more effective than exotic pines <6 years old, supporting the observation that canopy closure and root development between years 6 and 8 can reduce the incidence of shallow landsliding during extreme rainfall events. However, vegetation cover and root reinforcement in pasture and exotic plantations <6 years old were not sufficient to enhance slope stability or reduce surface erosion during Cyclone Bola, confirming earlier research findings (Phillips *et al.* 1990; Marden *et al.* 1991).

Although canopy interception, soil-water utilisation, root biomass, and root development have been studied for *P. radiata*, there is little quantitative information available on these characteristics for indigenous vegetation. However, current research on stand diversity, age, density, growth rate, and root-biomass of regenerating scrub will permit a better understanding of its role and effectiveness in stabilising slopes and ameliorating the impact of storm events on steep Tertiary hill-country in the East Coast region.

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