MANAGEMENT OF EUCALYPTS COOPERATIVE

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Soil A Horizon Development Beneath *Eucalyptus regnans*.

B. D. Murphy, T.W. Payn and S. Rofe

NZFRI

Report No. 29 August 1996

PROJECT RECORD NO. 5430

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EXECUTIVE SUMMARY

Variation in growth patterns of Eucalyptus regnans *(F. Muell.) on sites in the central North Island led to examination of the A soil horizon within a Kinleith Forest block, as depth of the topsoil appears to have a negative correlation with growth. To better understand this relationship, A horizon soil depth and* E. regnans *stocking were mapped over landform and aspect combinations. Depth of the A horizon relates weakly to aspect, landform and predominant understorey vegetation. Deeper A horizons are found on eastern and southern slopes, in particular on toeslope and basin landforms, suggesting influence of soil temperature, moisture and colluvial modification. Evaluation of solar radiation interception for the site reveals that relatively lower insolation on east and south slopes of major landforms appears to contribute the development of deeper horizons on those aspects, particular in the winter period. It may also affect root development of* E. regnans *in the growing season by warming soil temperatures to allow early root expansion in spring on better insolated sites.*

INTRODUCTION

The suitability of *Eucalyptus regnans* (F. Muell.) for short-fibre pulp plantations in New Zealand, combined with its outstanding growth rates on optimum sites had led in recent decades to the planting of over 8,000 hectares by various forestry interests (Bathgate *et al* 1993). However potential of the species has not been fully realised in the field. Of particular concern has been the apparent microsite effect on growth, with clusters of large trees located amongst trees of poorer growth. This is particularly disconcerting for forest managers, the within stand variability unacceptable to any pulp regime programme.

This led to research to attempt to identify the causal elements, concentrating on environmental factors as the source of variation. This had the assumption that the problem is not caused by inherent genetic variability, over which these projects have no control. Development of multiple-regression growth models to help explain this microsite effect on growth yielded some clues to the problem. Of particular concern was the apparent negative effect on growth with increasing depth of the A soil horizon on Kinleith sites (Payn & Oliver 1994). Increasing the scale of the study to the central North Island region confirmed this relationship (Murphy 1996). This is an apparent anomaly, as often this horizon is important as a source of nutrient cycling in eucalypts. Frederick *et al* (1985) found that leaf fall for *E. regnans* averages about 5.2 tonnes/ha/annum, and that leaves were the major source of all nutrients (except for copper) returned to the soil.

The hypothesis under study is that a thicker A soil horizon progressively develops in lower quality sites (ie gullies, colder aspects) over the course of the crop rotation, due to slower organic cycling in those microsites. This may have a two-fold effect, 1) by disturbing the normal nutrient-recycling processes associated with species such as *E. regnans*, and 2) creating soil conditions that are unsuitable for the growth and survival of the root systems. Gully bottoms in particular have been noted for their very poor *E. regnans* growth, to the extent that Bathgate *et al* (1993) described them as 'extreme sites' where few live trees existed. This contrasts with Booth and Pryor (1991) who state 'where the species is successful, it is often restricted to particularly favourable microsites, such as gullies with sheltered conditions and deep soils.' The apparent contrast in these statements might be tempered by the difference in soil moisture conditions found in gullies typical of Australian and New Zealand sites.

An examination by Guo (1993) on the effect of microsite factors on *E. regnans* in the Kinleith region concluded that topography and understorey had no apparent effects on tree growth, and that the recent Taupo soils had relatively low inorganic phosphorus concentrations. Fine roots and mycorrhiza did correlate with soil types and topography, and were absent in wetter environments.

Therefore the aim of this project was to examine the depth of A horizon across different landform and aspect combinations, in an attempt to determine where and why the depth was varying. It was hoped these variables could be used to explain how growth of *E. regnans* may be affected, and if possible, conclude which microsites are unsuitable for the species.

METHOD

Site Description

The study site was the Jeff Road forestry block (owned by Carter Holt Harvey Ltd) in Kinleith Forest, about 5 kilometres north of Tokoroa (Figure 1). This block contains 14-16 year old *E. regnans* of Franklin (Tasmania) seed source. These were originally planted at 1152 - 1496 spha, and subsequently thinned to between 650 - 712 spha by age three. Fertilisation was believed to include 30 g of Urea per tree, with another 60 g between planting lines at establishment, followed by an aerial application of 250 kg Urea ha^{-1} in the second growing season. Site preparation included V-blading and mounding where vehicle access was possible (Payn & Oliver 1994).

The Jeff Rd block is a cutover site, previously planted with *P. radiata*. Payn and Oliver (1994) described the area as mainly rolling with short slopes of about 20 degrees. Altitude is roughly 260 m.a.s.l and the region has an annual rainfall of approximately 1500 mm, with a tendency towards winter maxima.

The most recent soils in this area are derived from air fall tephra of Taupo origin. The B horizon typically consists of Taupo pumice overlying Rotorua ash. The thickness of Taupo pumice can be affected by topography, with upper slopes sometimes missing Taupo ash, and relatively thicker layers deposited at the bottom of slopes and in basins (Guo 1993: Payn & Oliver 1994). The suitability of the block for this study included its variable topography (landform and aspect combinations), being relatively free of blackberry (*Rubus fruticosus*) enabling suitable access, and existence of the topographical data in a GIS database (courtesy of Carter Holt Harvey Ltd.)

Landforms and Transects

The Jeff Rd block was surveyed using topographical maps and aerial photos to determine areas of terrain that would allow for examination of a variety of landform (see below) and aspect combinations. Aerial photos were also useful in that they indicated areas with poor stocking, hinting at areas unsuitable for *E. regnans*. In particular, the major hill and basin systems were investigated as these often contained suitable combinations, ie moving from the top of a hill site downwards in any compass direction usually yielded several landform types.

Desirable terrain contained some or all of the following landforms: flat, crest, topslope, terrace, midslope, toeslope and basin (defined in Appendix 1). At the approximate centerpoint of each site, transect lines were run along the four main compass bearings, attempting to cover as many landforms as possible along individual transects. In cases where the surface of a major terrain form continued for several hundred metres, a central transect was run across that surface and transects running at right angles to this plane were then taken at 50 m intervals (for an example see Figure 6). Using marker pegs and string to delineate the transects, spade sampling was used to measure the A soil horizon at 10 m intervals along each transect, or over 5 m where landforms changed over short distances. A total of 190 depth samples were taken over 30 transects. Two sets of transects covering major terrain features were later chosen for a GIS treatment (see below).

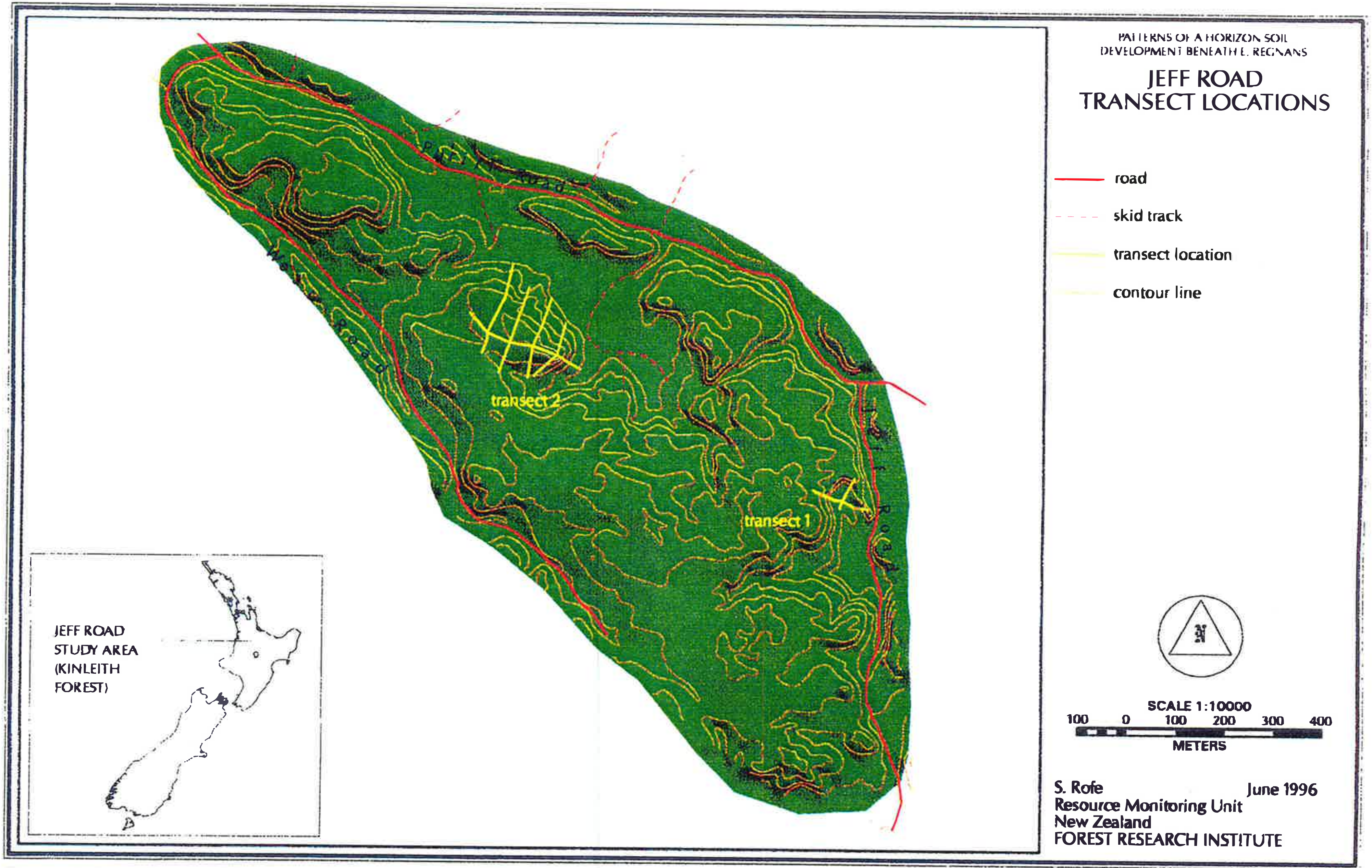


Figure 1: Location and topographical map of Jeff Road study block.

The A Horizon

For the purposes of this project, the A horizon was defined as the depth of mineral soil material (at or adjacent to the surface and consisting predominantly of mineral particles intimately mixed with a greater or lesser amount of humified organic matter; Macvicar *et al* 1977), excluding fresh litter (L horizon, as described by Hewitt 1993). Sampling consisted of a soil pit deep enough to determine the depth of the A horizon, with the four sides of the pit measured to gain an average horizon depth for that pit. A horizons that continued below 20 cm in depth were recorded as 20+ cm, due to difficulty in measuring accurately any deeper. Where a buried A horizon occurred, it was added to the surface A horizon to give an overall composite depth. The buried litter layer would still remain available as a source of nutrients for feeder roots, so it is necessary to include it as part of the overall A horizon depth. Where possible sampling for A depth directly over V-blade mounds was avoided as the A horizon was disturbed.

Plot Description

Soil depths were recorded on field sheets, along with dominant vegetation types for each point, landform type, aspect and slope. Living *E. regnans* (defined as any *E. regnans* with visible live leaves) within a 5 m radius were counted and recorded as a measure of stocking. Notes were also made of unusual features, such as whether the A horizon was buried due to cultivation, or disturbed due to pig browsing. Although preferable to have height and dbh measurements of the trees to enable evaluation of growth for each subplot, this was not possible due to time restraints.

For ease of analysis, dominant understorey vegetation types were divided into five broad groups. These were bracken (*Pteridium aquilinum* var. *esculentum*), tree-fern or Ponga (*Cyathea dealbata* and *Dicksonia squarosa*), ferns (*Blechnum* spp.), grasses (including *Cortaderia toetoe*) and herbaceous shrubs (including tree species), ie Himalayan Honeysuckle (*Leycesteria formosa*), Manuka, *Coprosma* spp. and *Buddleia davidii*.

Geographical Information System (GIS)

Two major terrain areas were chosen in the field for further treatment utilising GIS and contour coverage. These terrain locations (referred to as Transect one and Transect two) were georeferenced using a Global Positioning System (GPS). These points were then converted to New Zealand Map Grid (NZMG) coordinates for use in a GIS then overlayed onto ARC/INFO contour coverage of the study area. Topsoil depth information was attributed to the points to produce a map of approximate topsoil depth variation over two sites chosen for the GIS treatment (S. Rofe *pers comm.*).

Point location data were collected using a *Trimble GPS Pathfinder Basic + GPS* unit. Positions were taken at the centre point and end of each transect. Where transect length exceeded 50 m, a further point was taken half way along the transect. Determination of point location consisted of taking the average of three differentially corrected position readings from the GPS unit. Tolerances for position fixing were set quite strictly to facilitate accurate positioning.

The accuracy of the points collected in the field was refined using Post-Processed Differential Correction to yield an accuracy of approximately ± 5 meters. Points were then converted to New Zealand Map Grid coordinates and imported into the ARC/INFO GIS environment. Once in the GIS, the points were overlayed on to a contour coverage of the study area, and A horizon soil depth was layered on the resulting maps in increments, ie 0-4.9 cm, 5.0-9.9 cm.

Solar Radiation

The GIS map of the Jeff road block was analysed for solar radiation interception for the months of June and December using the *Solarflux* insolation model (Rich *et al* 1995). This was done in attempt to indicate the difference in solar radiation between winter and summer and also to describe whether any of the build-up in topsoil could be due to poor insolation of some aspects and landforms. Low insolation levels could a) inhibit soil processes due to insufficient surface warming and b) be unsuitable for growth of *E. regnans* in terms of receipt of direct solar radiation.

Statistical Analysis

Percentages were calculated for vegetation type by aspect, landform and depth of A horizon. Class variables of aspect, landform, and vegetation type were tested using Duncan's Multiple Range Test for Variables (SAS Institute 1985), against the dependents of A depth and stocking.

RESULTS

Aspect

The mean influence of aspect on depth of A horizon and stocking is shown in Table 1. For the A horizon significant differences exist between west and the east/south aspects, with west slopes on average showing the shallowest A horizons. For stocking, north facing slopes have a significantly higher stocking than other aspects.

Table 1. Effects of aspect on depth of A horizon and stocking.

Aspect	Depth of A horizon (cm)	Stocking (stems per 5 m radius)
N	8.2ab	3.7a
E	10.3a	2.8b
S	9.4a	2.8b
W	6.4b	3.0b

Note: numbers in any column followed by the same letter are not significantly different at $p<0.05$

Table 2 shows that bracken is the most dominant vegetation type on north and west aspects (~50%). Cockayne (1967) suggests that bracken cannot grow in full forest shade, but is tolerant of dry conditions. It is also tolerant of slightly infertile and repeatedly disturbed sites. Ashton (1958) described the understorey of *E. regnans*, and concluded that some 30% of available light is not intercepted by the canopy and is available to the understorey. Thus, available light underneath *E. regnans* stands may be sufficient to support bracken, particularly on aspects that receive relatively high irradiance. The predominance of bracken on north and west aspects suggests that they receive adequate solar radiation for that species.

Table 2. Percentages of dominant vegetation type by aspect.

Aspect	Bracken (%)	Tree-ferns (%)	Ferns (%)	Shrubs (%)	Grasses (%)
N	49.2	12.3	20.0	6.2	12.3
E	19.2	25.5	31.9	6.4	17.0
S	15.2	37.0	32.6	6.5	8.7
W	53.1	12.5	9.4	18.7	6.3

In contrast the eastern and southern slopes are dominated by tree-ferns and ferns, together comprising 55-70% of the understorey. This suggests these aspects are wetter and receive less light than the north and west facing slopes, as most fern species are constrained to areas of shade and moisture (Crooker & Dobbie 1963). Tree ferns such as *C. dealbata* and *D. squarosa* can tolerate full sunlight, but only if constant moisture is available (Heath & Chinnock 1974). West facing slopes contain the greatest percentage of shrub species, indicating that they might receive more solar radiation or that those slopes have a superior nutritional status. In the same region, Payn and Oliver (1994) found significant differences in growth with respect to aspect; eastern aspects performed the poorest, northern and western sites were preferred.

Considerable differences exist between the dominant vegetation types by landform (Table 3). Bracken appears as the dominant species on flats, crests and topslopes. Ferns dominate on terraces and combined with tree-ferns they have a similar if not greater presence than bracken in mid and toeslopes. Basin landforms are characterised by grasses, ferns and shrubs dominating, with bracken not present.

Table 3. Percentages of dominant vegetation type by landform.

Landform	Bracken (%)	Tree-ferns (%)	Ferns (%)	Shrubs (%)	Grasses (%)
Flat	54.3	11.4	22.9	5.7	5.7
Crest	45.4	9.1	36.4	9.1	0.0
Topslope	46.7	26.6	16.7	3.3	6.7
Terrace	30.8	15.3	38.5	7.7	7.7
Midslope	36.2	34.0	21.3	6.4	2.1
Toeslope	21.4	25.0	25.0	14.3	14.3
Basin	0.0	11.5	26.9	15.4	26.9

The dominance of bracken in the upper landforms may be related to its need for relatively high light levels. Establishment of bracken is dependant on a 'complex interaction of favourable microsite, microclimate, and competition from other vegetation' (Beveridge *et al* 1968), while Cochrane (1969) described *P. esculentum* as 'a rapid and aggressive initial colonizer (sic) of bare, forest-fired areas'.

Tree-ferns and ferns become dominant where light levels are lower and soil moisture is probably higher. The absence of bracken in basin landforms, despite apparent high light levels may be due to increasing soil moisture and soil organic content, or that other species find the site conditions more suitable and out-compete bracken, ie exotic grass species.

Bracken species have been noted for their allelopathic effects on some other herbaceous species, particularly of the *Rubus* family (Tolhurst & Turvey 1992). This suggests that in areas where large masses of bracken have accumulated, germination and survival of other species could be reduced by phytotoxic effects. In the field this was supported by the presence of large areas of bracken on north and west facing slopes, where few other understorey species were apparent.

Table 4 shows what appears to be a good relationship between the depth of A horizon and some of the major understorey groups - as the A depth increases, the percentage of bracken declines. At depths less than 5 cm, the percentage is 50.8% which declines steadily to 8.1% at the deepest level of A horizon. Cochrane (1969) described the distribution of *P. esculentum* as closely related to precipitation totals and A horizon depth, which seems to be the case here.

Tree-ferns display an opposite relationship, associating little with the shallow A horizon depths, and gradually increasing in presence with greater depths. Presence of ferns remains relatively constant; no apparent pattern exists with shrubs (possibly due to different shrub types associating with different topsoil depths). The abundance of grass species appears to be unrelated to A horizon depth, and is more likely to be related to the quality of light and fertility present.

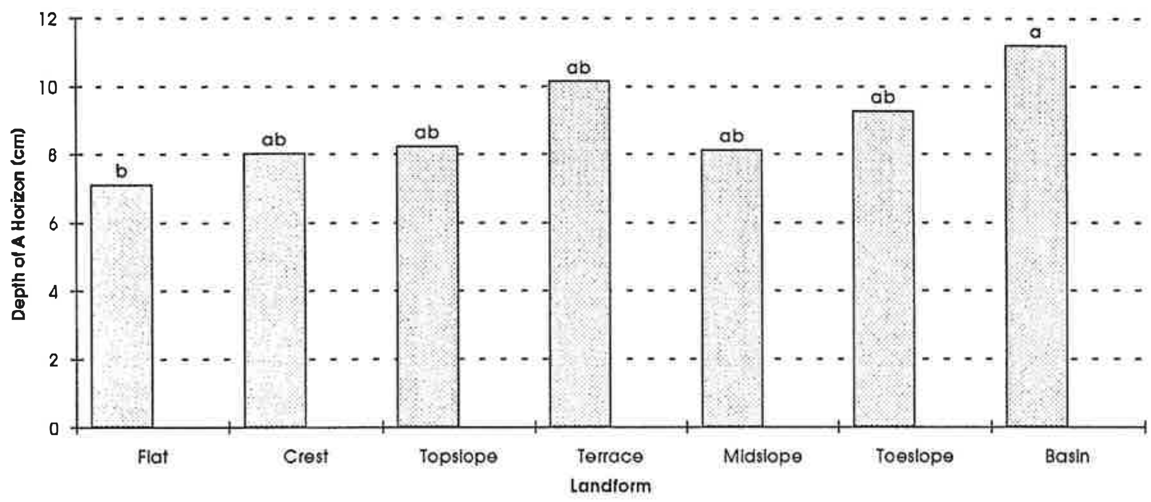
Table 4. Percentages of main understorey species associated with A horizon depth.

A Depth (cm)	Bracken (%)	Tree-ferns (%)	Ferns (%)	Shrubs (%)	Grasses (%)
0 - 4.9	50.8	9.5	22.2	9.5	8.0
5.0 - 9.9	35.2	18.5	31.5	1.9	12.9
10.0 - 14.9	30.6	27.8	22.2	11.1	8.3
15.0 - 20+	8.1	40.6	18.9	13.5	18.9

Landform

Mean depths of A horizon associated with landform type are shown in Figure 2. There is a significant difference between the depth of A horizon on flat landforms (ie the tops of hills) and that of basins. Other landforms were not significantly different. An apparent pattern occurs with shallowest topsoils on flats which then increase slightly on the topslopes and terraces. This might suggest that topsoil material has moved down from the flat and topslopes of hills by gravitational processes accompanied by rainwash (ie colluvial processes), accumulating on terrace landforms which act as a catchment area. From the midslope, depth of the A horizon then increases towards the toeslope and basins, again suggesting colluvial relocation of A horizon material. However this is likely to have been a modifying effect on the depth of A horizon that has already built up due to interactions of vegetation, temperature and aspect, which appear to be the major causes of the A horizon build-up.

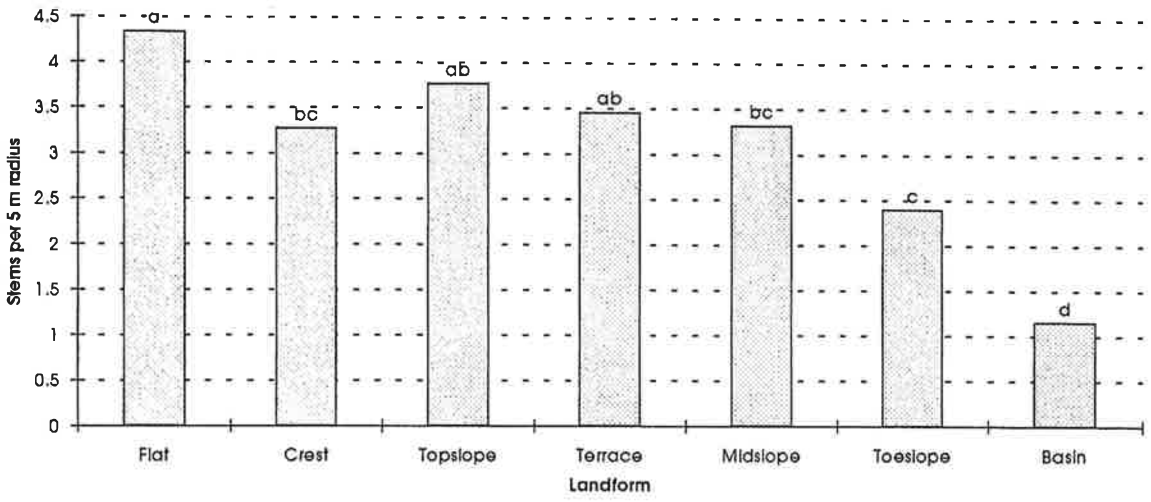
Figure 2. Depth of A Horizon Related to Landform.



Note: Bars with common letters are not significantly different at $p<0.05$

Figure 3 shows the stocking levels of *E. regnans* related to landforms. Main points are that flat landforms have significantly higher stocking than crest, midslope, toeslope and basin landforms, and that stocking in basins is significantly lower than any other landform type. Topslopes and terraces have slightly higher stocking levels than crest or midslope landforms, although the difference is not significant.

Figure 3. Stocking Related to Landform



Note: Bars with common letters are not significantly different at $p<0.05$

It can be difficult to determine the effects of landform on the growth of *E. regnans*. Guo (1993) suspected that the effects of slope and aspect might affect seedlings, causing some mortality, but by 11.5 years, larger trees would be unaffected. A similar pattern may emerge with landform, in that some landforms that are not optimum for the species may affect growth and survival of seedlings, if for instance, direct solar radiation was very low.

The apparent superiority of stocking on flat landforms may be attributable to several factors, such as better insolation, protection from frosts, good drainage and perhaps better site preparation due to ease of access. Topslopes also appear to contain relatively higher stocking levels, which decrease downslope.

Guo (1993) described gully bottoms and toe slopes as always poor for tree growth, and that they should be avoided when planting *E. regnans*. Reasons for this were suggested as the low available phosphorus and compacted structure of the soils in these sites, resulting from re-deposition of fine Taupo tephra from up-slope landforms. This study confirms the unsuitability of basins and gullies for growth of *E. regnans*, as the stocking factor was just over 1 stem per 5 m radius.

As the site was planted with a range of stockings and then underwent thinning to variable levels, the measure of stocking used in this project can only be a rough guideline as to suitability of different landform/aspect combinations for growth and survival of *E. regnans*. Therefore not too much emphasis should be placed on these stocking figures, except in cases where the mortality has been obvious, as in some basin landforms.

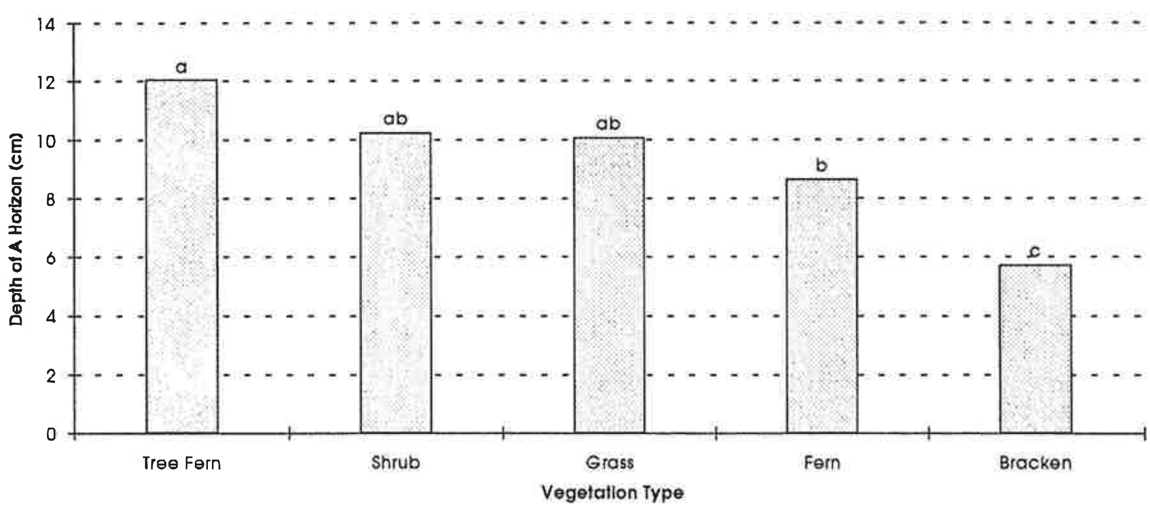
Soil Horizons

Underlying horizons typically consisted of depths of Taupo tephra underlain by Rotorua ash. Occasionally Taupo tephra was not evident, with the A horizon leading directly to ash layer. Absence of the Taupo tephra on microsites appears be due to the nature of the landform, direction of deposition, and subsequent weathering, rather than removal by cultivation practices. Boundary layers between the A and B horizons often varied between abrupt and diffuse (as defined by Milne *et al* 1991).

Vegetation Cover

A relationship between depth of the A horizon and dominant vegetation type was visible in the field. Where bracken was dominant, it came to be expected that the A horizon depth would be relatively shallow, or non-existent. However where tree-fern species were the principal cover type, dark, moist and relatively deep A horizons were common. The data supported these observations, as seen in Figure 4. A horizon depth under tree-fern vegetation is significantly deeper than under fern or bracken vegetation. That shrubs and grass also appear to have a relationship with relatively deep horizons is most likely because they occur most frequently in toeslope and basin landforms (see Table 3), landforms that appear to have deep A horizons due to colluvial processes.

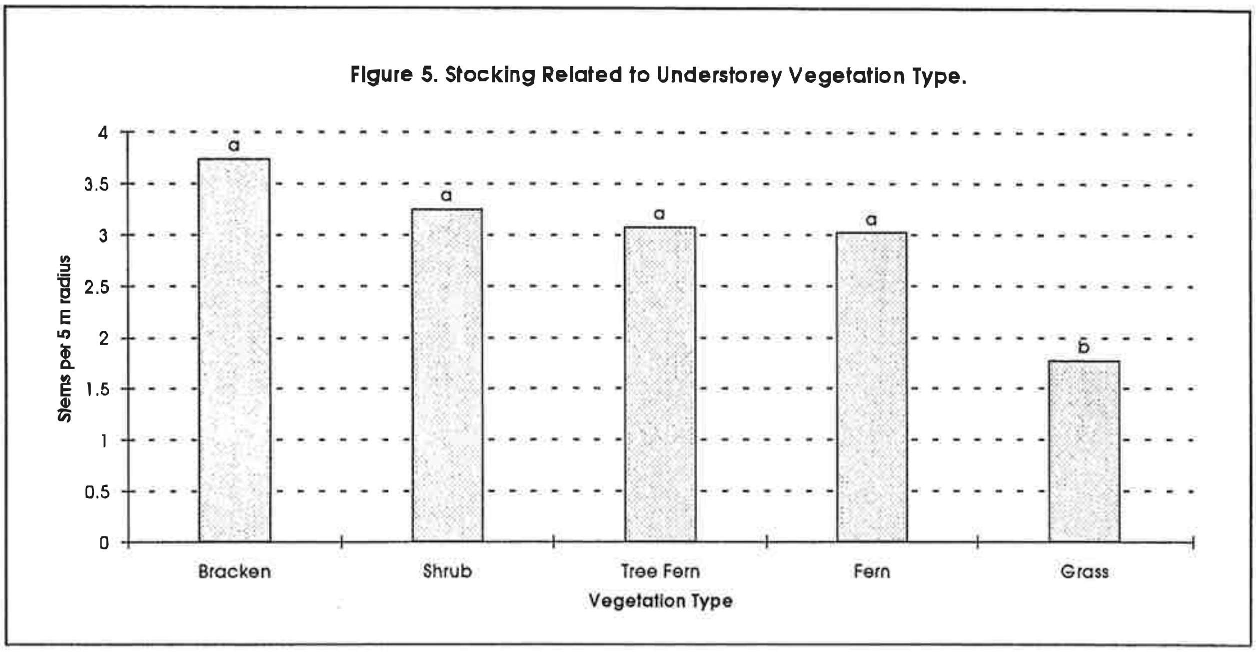
Figure 4. Depth of A Horizon Related to Understorey Vegetation Type.



Note: Bars with common letters are not significantly different at $p<0.05$

The association of bracken with shallow soil horizons raises several hypothesis. One is that it is the coloniser species where sites have been disturbed by activities such as mechanical cultivation or pig rooting, processes that are known to disturb the A horizon by either burial or re-distribution. The likely alternative is that the aspects on which bracken predominantly occurs (see Table 2) are also relatively warm and receive higher insolation, so it is likely that organic cycling is rapid, not allowing for the large build-up as occurs on the wetter/colder sites. Bracken possibly contributes relatively little litter to the soil for recycling, thus does not influence the depth as much as tree-fern litter appears to.

Figure 5 shows stocking levels related to the dominant vegetation type. Only grass vegetation shows a significant difference in stocking levels to the other vegetation types. Although bracken has the highest stocking score, it is not significantly different from that of shrub, tree-fern or fern. The apparent relationship between bracken and highest stocking levels is most likely explained by the fact that bracken is found predominantly on the better insolated (see below) north/west aspects and landforms.



Note: Bars with common letters are not significantly different at $p<0.05$

GIS and DTM Treatment.

The two terrain areas of the Jeff Rd site used in the GIS analysis are shown in Figures 6 and 7. These are the digital terrain models (DTM) of Transect two and Transect one respectively. The general pattern of A horizon development is shown clearly in Figure 6. The flat of the hill has generally rather shallow A depth coverage, which increases in the mid and toeslopes. On the northern side of the hill can be seen an area of increasing A depth, which is where a terrace landform is located. To the south of the hill a gully is also indicated by A horizon levels over 20+ cm. There is some indication of slightly deeper horizons developing in an area just south of the top of the flat, but no obvious signs of excessively deep A horizons are occurring on the western slopes.

Figure 7 is predominantly a basin landform, surrounded by steep slopes to the north and west. The DTM shows that the flat top of the east facing slope has moderately deep A horizon soils, which increase in the crest/topslope area. Midslope A horizon depths are shallower than that of the preceding landforms. At the toeslope and beginning of the basin the A horizon increases to greatest depth, supporting the theory of deeper horizons occurring on these landforms. However in the basin it appears that the A horizon is very shallow. Unfortunately, as the basin area itself was V-bladed during pre-planting cultivation, the results are affected by disturbance of the A horizon. Some of this area was also modified by removal of vegetation for other experimental work (J. Bathgate *pers comm*). The short slope to the east of the basin (that is, the west facing slope) has relatively shallow topsoil. This could be due to the superior solar radiation interception, shallowness of the slope, or that across the top runs a haul track resulting from removal of the previous crop, which would have compacted the soils.

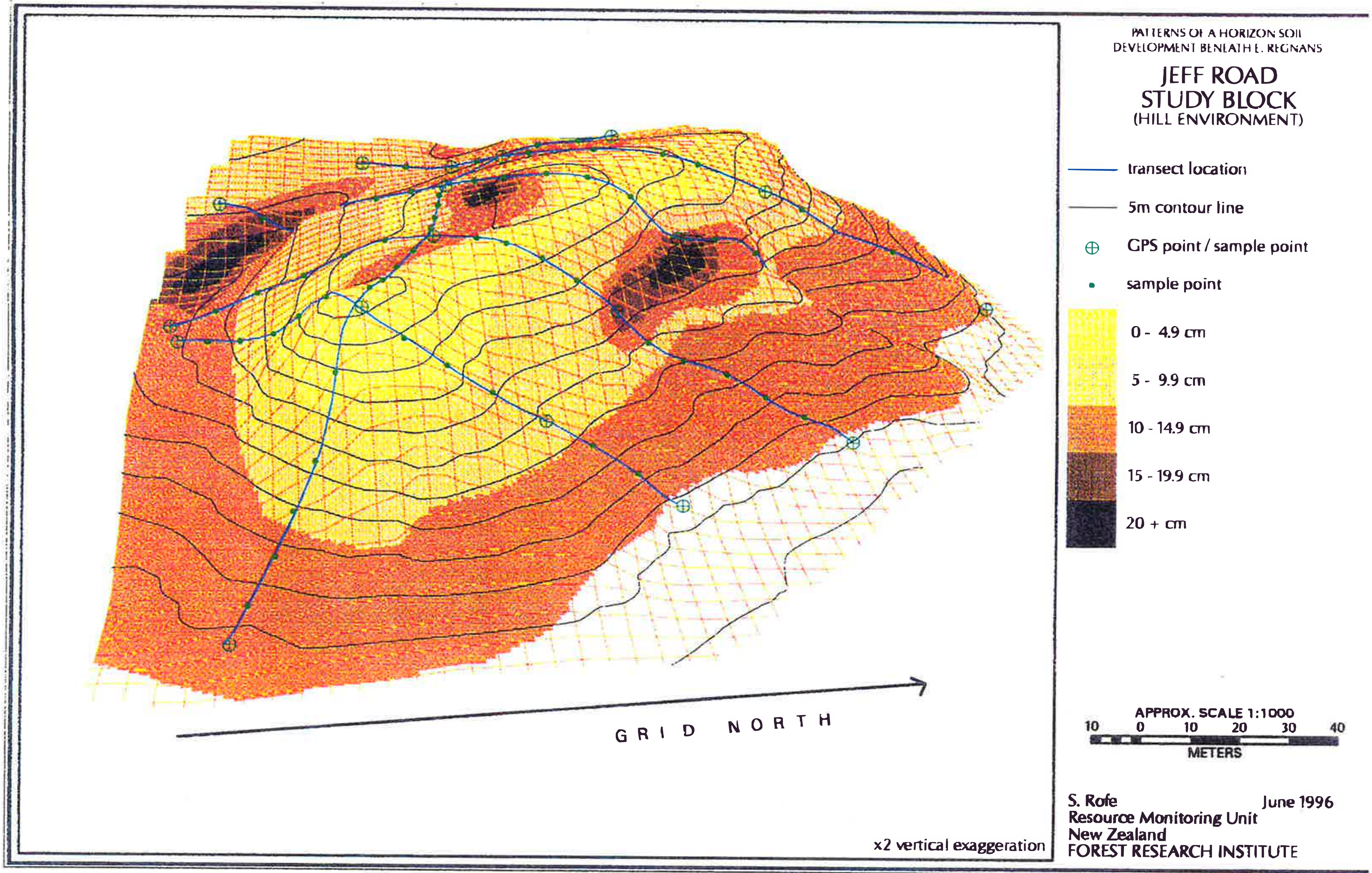


Figure 6: Digital Terrain Model showing A horizon soil over hill landform.

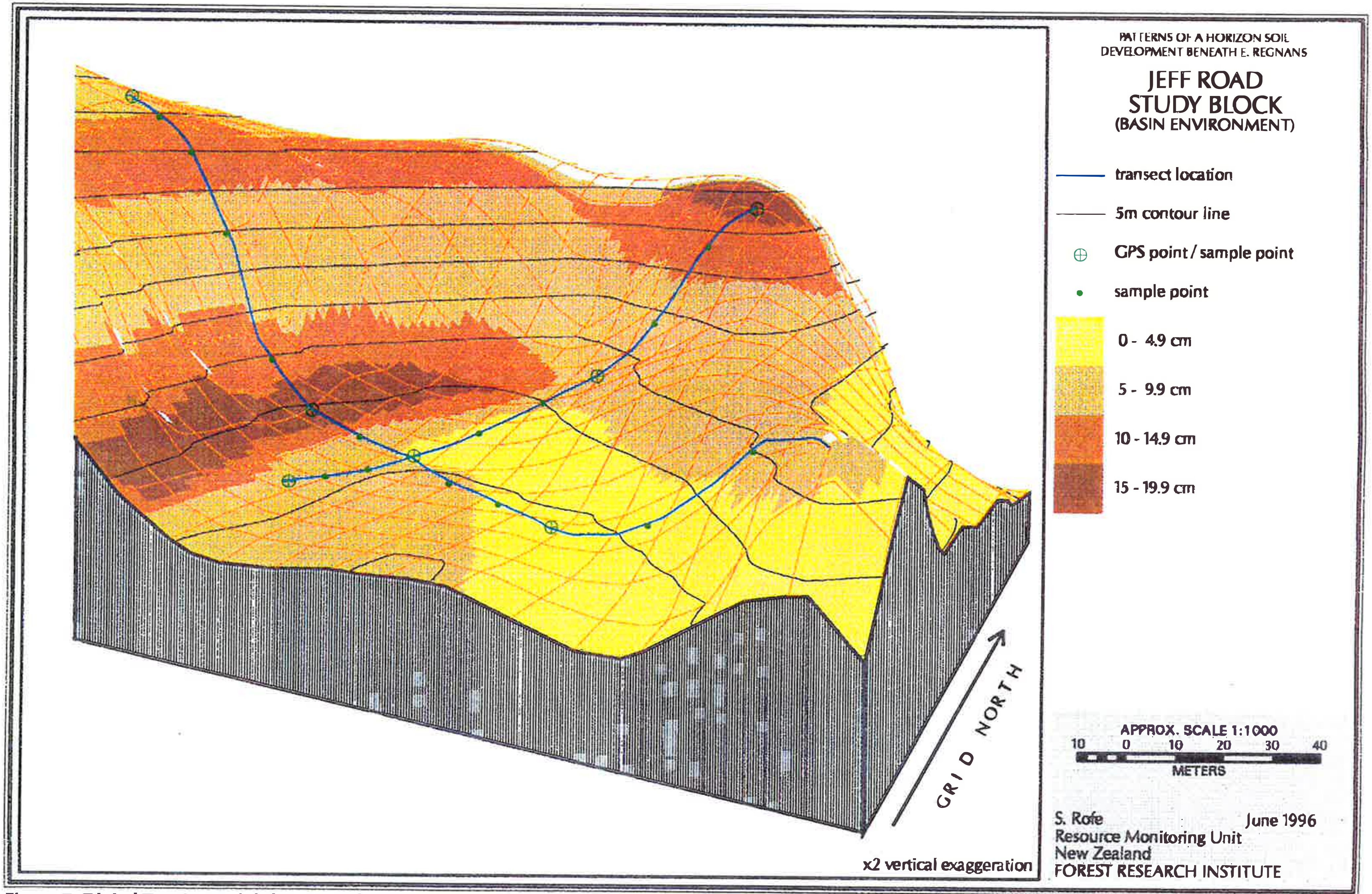


Figure 7: Digital Terrain Model showing A horizon soil depth over basin landform.

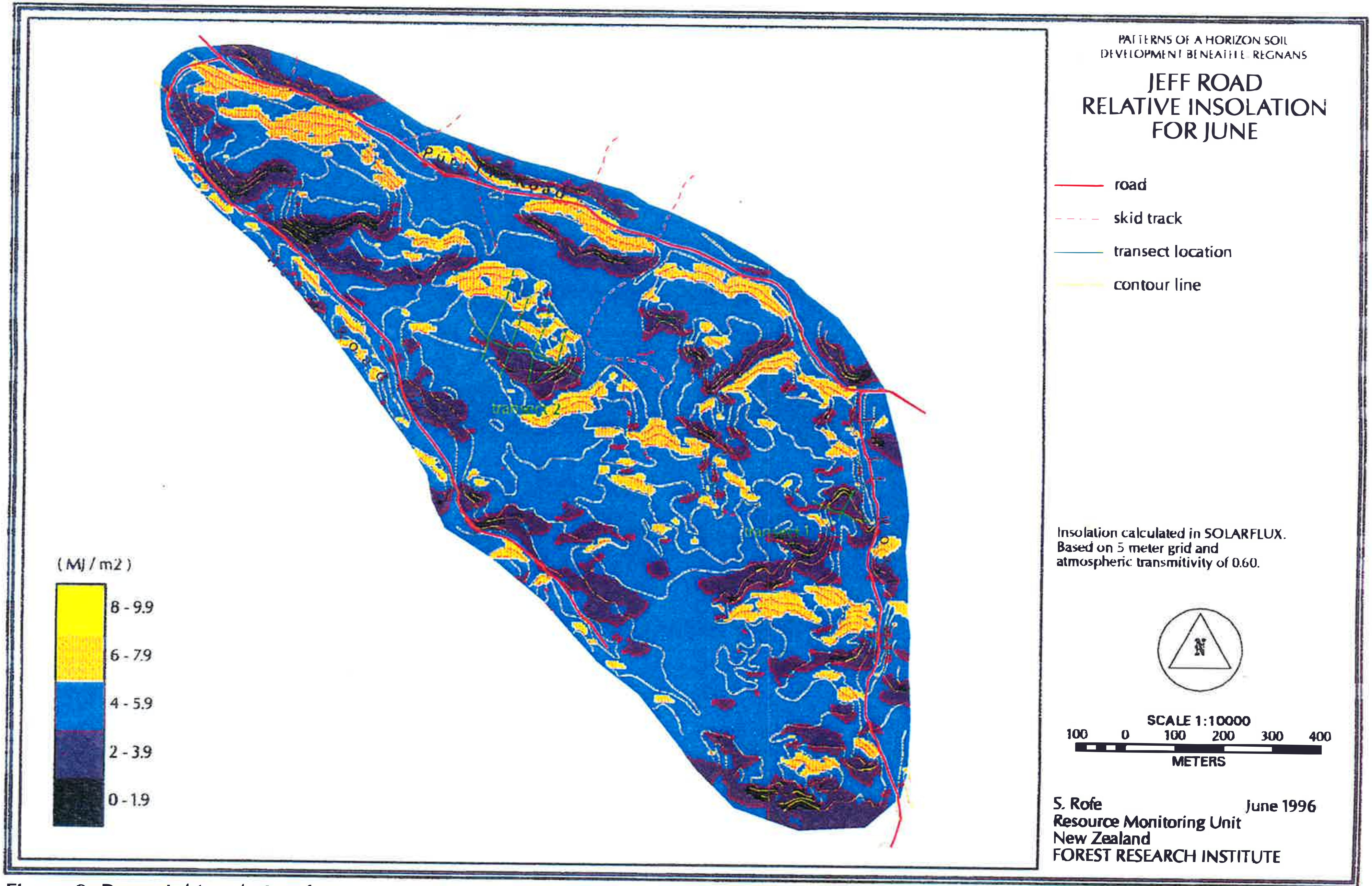


Figure 8: Potential insolation for June at Jeff Road study block

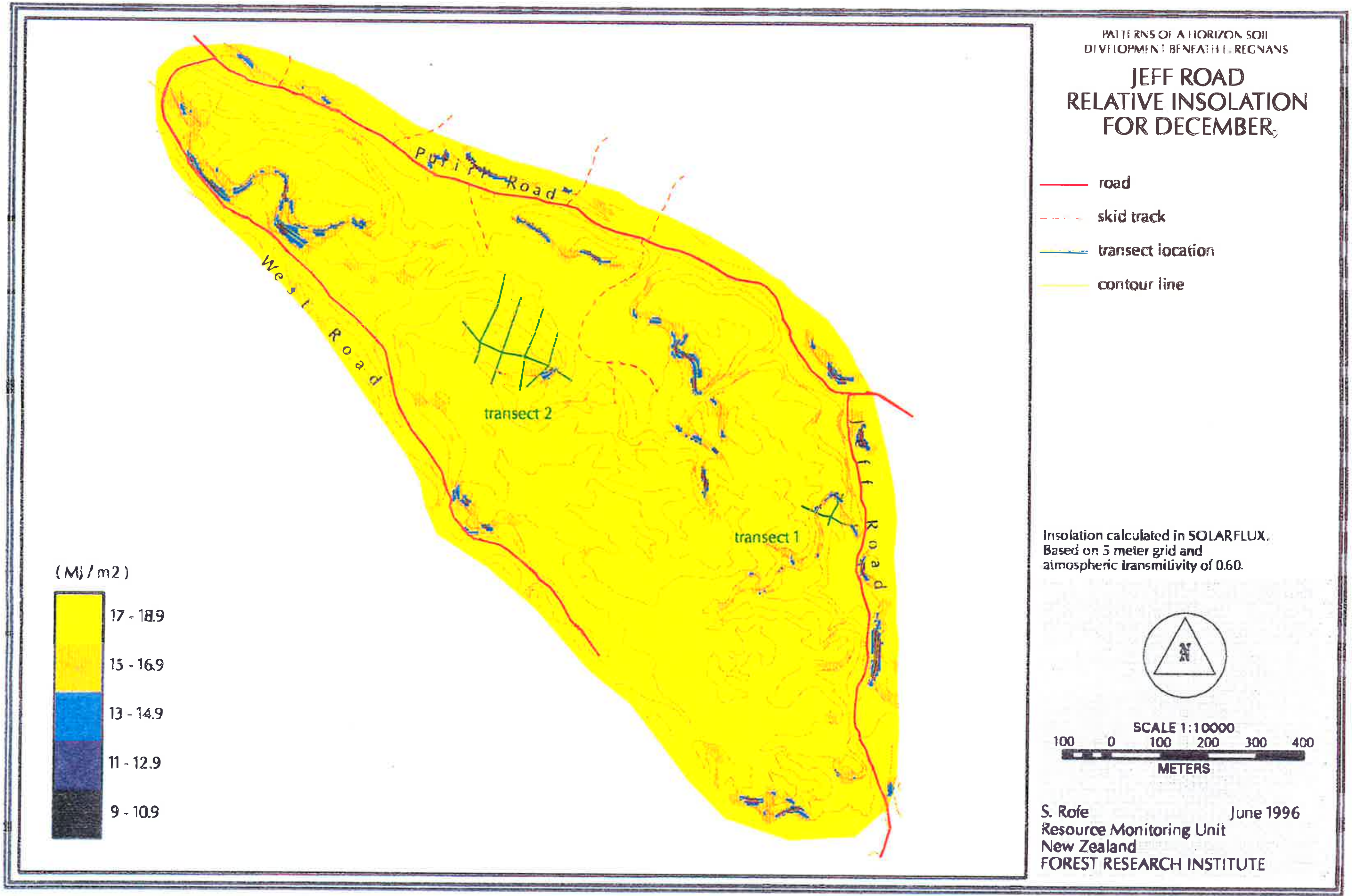


Figure 9 Potential insolation for December at Jeff Road study block.

Solarflux Interpretation.

Figures 8 and 9 show the potential insolation for the Jeff road block in June and December respectively, and also show the areas of Transects one and two used in the DTM treatment above. Interpretation of the insolation conditions suggests that on many hill terrain landforms the south and east facing slopes receive relatively less solar radiation than other aspects. This is particularly so in June, where the difference is accented by shading effects with the sun relatively low in the sky. This supports the hypothesis that some of the build-up in A depth is occurring in those areas where the winter or spring soil surface temperatures may be less than in better quality sites. This can also be seen clearly in Transect 2, where the southern and eastern aspects of the hill receives relatively low radiation (dark blue) than the north and west facing aspects (orange). This may explain some of the deep soil horizons occurring on the southern aspect of Transect 2 as seen in Figure 6.

The importance of the differences in relative insolation may not be important in summer, when all areas appear to receive an even dosage of solar radiation, but may be critical in early spring. Even by June, differences in insolation at ground level suggest that the north and west facing slopes may have slightly warmer soil temperatures than the cooler east and south aspects. This could become critical in spring, when activation of the expansion of feeder roots of *E. regnans* is related to the soil temperature (J. Bathgate *pers comm*). Hence, trees located on better insolated sites will initiate root growth earlier in spring and encourage a similarly expanding canopy, while trees on poorer sites will remain quiescent until their soil temperatures rise.

DISCUSSION

McNab (1989) quotes several examples of correlations of tree growth with different definitions of landform. Inconsistencies with definition have led to differing results, depending on whether land surface geometry is divided into discrete classes, or whether the position on the slope has been used to describe the site. Realising that landforms are continuous, and that preceding landforms (ie the landform directly up-slope of the site measured) have a direct effect on subsequent landforms, by way of litterfall, moisture and soil properties, it is believed that the class definitions used here provide a meaningful description of the nature of the topography of a given microsite. Whereas simple terms such as convex or concave may be used to describe a site, our definitions such as topslope, midslope or basin give a better indication as to the nature of a given location.

The main point of conjecture is whether the negative correlation of depth of A soil horizon on growth of *E. regnans* is a direct effect (ie the increasing depth of this horizon is physically affecting plant growth?) or whether the less direct effects of unsuitable moisture, temperature and other environmental conditions (ie solar radiation) lead to build-up of organic material and incidentally create conditions unsuitable for the growth of *E. regnans*? Clearly it is the latter. It appears that deep A horizons are occurring where soil conditions are cold and moist, and are then compounded by associated vegetation types that further modify conditions until they are marginal for *E. regnans*.

Clearly noticeable in the field were the effects of site cultivation and understorey vegetation type on A horizon depth. On the flatter, more accessible sites, V-blading had buried the previous A horizon, which was either visibly intact and buried at depths of up to 20 cm, or mixed with other soil horizons. Presumably the buried horizon is the remnant of the A horizon formed under the previous *P. radiata* rotation. Variability in the depth of the A horizon occurred over very small distances, even down to scale of the four sides of a soil pit, eg 13-34 cm.
Landform has been shown to affect the soil moisture content and physical properties of soils (McNab 1993). Rab (1994) investigated the effects on growth of *E. regnans* on a site that had previously been logged. A large percentage of the site had been modified by compaction and movement of soils. There was also a strong correlation between bulk density of the soils and growth, with both height and diameter growth of *E. regnans* reduced with increasing bulk density. Logging also decreased total porosity of the soils, with the author suggesting that the soil compaction may reduce macroporosity to such an extent that root growth is limited by oxygen availability. As this site has been previously logged, some of the soils may be compacted, creating conditions that are less favourable for *E. regnans*' seedling survival and growth.

Guo (1993) found that understorey competition did not appear to have an effect on tree growth of 11.5 year old *E. regnans*, but may have been important before the seedlings were able to grow above the understorey canopy. Competition for nutrients and moisture, if present, would be concentrated in the A horizon, where understorey root mass and feeder roots of *E. regnans* are concentrated. The largest effect of understorey plants may not in fact be direct competition, but the altering of the soil to a status that is unsuitable for *E. regnans* root development. This includes shading of the soils which lowers their temperature (and hence reduces mycorrhizal development; J. Bathgate *unpublished data*), retention of moisture that may not allow crop roots to breathe, and development of thick organic A horizons, that contain large quantities of carbon but may not provide balanced nutrition for feeder roots of *E. regnans*.

Distribution of tree-ferns was clearly restricted predominantly to the moister, less exposed aspects (principally east and south slopes). These conditions, when combined with heavy litterfall from tree-fern and fern species appears to lead to build-up of organic material because decomposition is slow. Most of the light that reaches these sites appears to be intercepted by the large tree-fern fronds, so very little direct light reaches the soils to warm them.

On several occasions when soil pits were dug in tree-fern dominated sites, a rotten smell was present, suggesting anaerobic conditions in the soil. These soils, with relatively poor nutritional status (these soils appear to have an extremely high C:N ratio, J. Bathgate *pers comm*) are probably highly unsuitable for *E. regnans* to be grown as a short rotation species.

Adverse conditions such as poor drainage, low nutritional status and other soil conditions can impair the physiology of forestry trees. Maguire (1955) showed that the presence of soil moisture can lower the temperature by significant amounts. This, when combined with soils that receive relatively little direct solar radiation due to shading from understorey species, may result in soil temperatures that are prohibitively low for the efficient uptake of nutrients and vigorous expansion of *E. regnans*' roots.

The relationship between the understorey vegetation and A horizon depth provides us with the classic 'chicken and egg' scenario, that is to say, is the understorey vegetation type directly responsible for the depth of the horizon, or is the horizon itself affecting the vegetation type present? It is likely that it is a combination of both. There is little doubt that tree-ferns modify the A horizon with the large amount of organic matter they discard, and this probably benefits these species by creating a suitable soil microclimate, hindering competition from other species that find the conditions intolerable. But to germinate in the first place, these ferns need moist soil conditions, limiting the range of their distribution. Tree-ferns probably thrive on sites that would have the climatic potential to develop deep A horizons anyway.

For *P. esculentum*, its association with relatively shallow A horizons stems from its need for nearly full light intensity. Such environments tend to have dry and warm topsoil conditions, and hence rapid recycling of the litter layer. As a coloniser, bracken appears where A horizons are disturbed and vegetation has been cleared. For these two reasons, bracken is associated with relatively shallow depth of A horizon. If the site is continually disturbed bracken will remain the dominant species, regenerating quickly from underground rhizomes, but in absence of disturbance over 10-20 years, bracken may act as a nursery crop for angiosperm species if seed banks are present. Thick bracken beds are an effective barrier to browsing animals and protect the seedlings (J. Bathgate *pers comm*).

Frederick *et al* (1985) found that in the understorey beneath *E. regnans*, native woody species and ferns increased with stand age while the presence of herbaceous species declined. Thus age of the stand when measurement of understorey is taken may be important, as transitional stages may occur. For example, after clear felling of the previous crop and site cultivation, coloniser species such as *P. esculentum* may gain temporary dominance on many sites. The first effects of shading and changing of microsite conditions may occur several years later as the *E. regnans* crop establishes a canopy above understorey vegetation, and other species might advance on sites too cool and shaded for *P. esculentum*. At the current age of the crop, the dynamic of understorey vegetation may be changing relatively slowly, but in the future the presence of small angiosperm shrubs and trees may become more intense.

In a study of *P. radiata* and *E. regnans* of a similar age to the trees in this study, Jurgensen *et al* (1986) found that the litter component under radiata pine was double that of *E. regnans* up to at least age 17 years. Decomposition rates under *E. regnans* appear to be faster than under *P. radiata* (James 1986), and litterfall shows a distinct summer maxima (Frederick *et al* 1985). This suggests that *E. regnans* relies more on the rapid re-cycling on nutrients from litterfall than does *P. radiata*. This is a typical trait of the *Eucalyptus* genus, evolved for mature soils with low available nutrients.

Visually, there were differences between the suitability of different landforms on the growth of *E. regnans*. Gullies often contained remnants of trees that had reached a reasonable size, and then died. This suggests that some sites were marginal for *E. regnans* for a period, but at some later stage mortality occurred due to a shift in site conditions which exceeded the biological limits of the crop species. This appears to be similar to the Baron Road syndrome, where trees initially established and grew, but unexplained mortality occurred when the trees were older. Although as yet no definite disease has been identified with BRS, the possibility exists that climatic conditions, such as increased summer rainfall maxima, are involved with triggering the disease. Marks *et al* (1973) suspect that soil pathogens such as *Phytophthora cinnamomi* may activate against eucalypt species with changes in soil temperature (above 15º C) and moisture. They also found that addition of fertilisers increased the incidence of root rot caused by *P. cinnamomi* in susceptible eucalypts. This supports theories that the appearance of dieback in *E. regnans* stands occurs in times of high summer rainfall, as soil temperatures would be warmer, and usually occurs in basins where soil moisture levels can be high year-round.

Recently some of these Jeff Road sites have experienced a return to suitability for *E. regnans*, with previously affected trees returning to a healthy status. This might suggest that a slight change in climatic conditions has lead to a return to more favourable conditions in spring/summer for these gully microsites.

At the current age of the crop, tree canopies are tall relative to the short steep slopes, so are beyond landform effects on insolation. *Eucalyptus regnans* seedlings reach maximum photosynthetic activity within an hour of full sunlight, and then gradually taper off productivity (J. Bathgate *pers comm*), so that even trees in relatively poorly sited areas may still receive enough light in the afternoon to attain the full photosynthetic potential for the day. However the soil surface is still affected, and may provide conditions unsuitable for *E. regnans* with regards to soil temperature and moisture.

Soil temperatures may be most important at the beginning of spring, with the associated flush of new foliage and root growth. Slight soil temperature differences that occur between the warmer and cooler sites may be sufficient to stimulate root growth in some sites and not in others. This in turn could mean the difference between the amount of new foliage produced on trees (J. Bathgate *pers comm*). Subsequently, trees with the larger canopies are likely to gain more growth over the growing season than the trees which have relatively smaller canopies. Analysis of the potential solar radiation received on different aspects showed that the east and south aspects can receive less radiation (at ground level) than the west and north sites, suggesting that those soils may take longer into the growth season to reach the temperature required for root expansion and associated foliage flush. Soil temperature conditions in areas such as basins may also be maintained below the required threshold by the high moisture conditions. This may have a regulatory effect, as cold wet sites may prevent the development of expansive *E. Regnans* root systems, whereas in better quality sites, large root systems develop that can pump out excess moisture and regulate the soil conditions, and may go some way to explaining the clumping effect exhibited by *E. regnans* in New Zealand conditions.

CONCLUSION

Development of A horizon in a *Eucalyptus regnans* plantation appears to be influenced by landform, aspect and understorey vegetation. Deeper horizons occur on east and south aspects where litter decomposition and nutrient recycling appear to be slowed by cold and moist soil conditions. Landform is a modifier, with the shallowest depths occurring on the tops of hills, generally increasing in depth down-slope. Deepest A horizons occur on toeslopes and in basin/gullies, suggesting influence by colluvial processes. Understorey vegetation may modify the depth of A horizon, in particular tree-ferns which appear to enhance conditions that prohibit rapid recycling of litter. Most favourable sites for the growth of *E. regnans* appear to be north to west facing, either on the top of hills or on topslopes where better insolation occurs, whereas toeslopes and basins should be avoided when siting this species. Bracken may be a useful indicator species for suitable conditions.

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APPENDIX

Appendix One. Definitions of Landform Types.

Flat. (Hilltop). Smooth or even surface, accepted here as the flat surface at the top of a hill or rise, which enters into crest landforms at the sides.

Crest. The peripheral edge of a flat landform from which the surface slopes downwards into the toeslope; especially the highest line of a range of mountains or hills.

Topslope. Upper part of a slope immediately below a flat or other surface of low relief where present, or immediately joining a crest or summit and not occupying more than 30% of the total vertical height of the slope.

Terrace. A relatively flat or gently inclined surface, bounded on one edge by a steeper ascending slope, and along the other by a steeper descending slope.

Midslope. The middle part of a slope without reference to profile shape, bounded at its base by a toeslope, and bounded at its top by a topslope.

Toeslope. The lower part of a slope, bounded by a valley floor or nearly flat landform at its base and by the midslope at its top. Defined as separate from the midslope as a line defining the basal 30% of vertical height of a slope.

Basin. Predominantly deep-sided erosion channel at the foot of slopes, includes gullies.

Definitions modified from Milne *et al* (1991) and Payn and Oliver (1994).