Effects of topographic position on growth and form of Douglas-fir trees

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NZ Douglas-fir Cooperative

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ABSTRACT

The effect of topographic position on the growth and form of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) trees was investigated at two sites in the South Island. Transects of plots spanning a range of exposure levels were installed at each site, and the size and stem form of all trees within each plot were measured. At one site, stem form was assessed using the MARVL approach, while at the other site a stem form score was given to each tree within a plot. At both sites, stem volume was strongly related to TOPEX (a measure of exposure calculated as the sum of the angles to the visible horizon in eight equally spaced compass directions) with 66 percent of the variation in stem volume between plots explained by this variable. There was some indication that stem form was also related to exposure with a significant relationship found between the proportion volume within a plot in the straightest class (as measured using MARVL) and TOPEX. At more exposed sites, stem malformation appeared to be masked by the stunted nature of the trees, whereas in sheltered sites where height growth was greater, malformation was more apparent. While this study was preliminary in nature, results showed that there is considerable variation in the quantity and quality of trees within a stand and that this variation appears to be able to be predicted using a relatively simple measure such as TOPEX. Because TOPEX can readily be calculated from digital terrain models within a geographic information system, forest managers have the opportunity to site Douglas-fir where growth and form is least likely to be affected by exposure, and to model the variation in wood quantity and quality, so that material of similar quality can be segregated early in the wood chain.

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INTRODUCTION

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is the second most common plantation species in New Zealand, with a total planted area of approximately 112,000 ha (MAF, 2005). Nearly 75% of this area (73,000 ha) is in the South Island and the species appears well suited to the climate found in areas such as inland Southland, Otago, and Canterbury. However, the siting of Douglas-fir has a major impact on its survival and growth. In its native range in North America, the major site limitation is soil moisture availability, which is a function of soil characteristics, topography and regional climate (Revell, 1978). In New Zealand, exposure to strong winds appears to be a limiting factor for Douglas-fir growth. Spurr (1961) states that "Douglas-fir has proved very susceptible to damage by salt-laden sea winds and strong drying winds" and then went on to note that "siting with respect to wind appears to be of greater importance than any other single factor in limiting the distribution of commercial stands of Douglas-fir". As an example, Spurr (1961) noted that on greywacke-derived soils throughout the South Island, a reduction in tree height of 25% or more may be observed over a distance of several metres. In general there is a marked reduction in site quality going up a slope, or from a well-drained hollow to a nearby ridge site. It is not known whether this reduction in height growth is due to differences in exposure, differences in soil moisture or nutrient status, or a combination of the two.

Wind also appears to be the major site limitation to Douglas-fir in Great Britain, with trees suffering from both exposure to chronic winds and damage from acute winds. Darrah et al. (1965) noted that on exposed sites, drying winds caused severe burning of leaves and dieback, and that strong winds damaged terminal shoots, thus retarding height growth. Two previous attempts have been made to quantify the impacts of site factors on the growth of Douglas-fir in Great Britain. Dixon (1971) examined data from 93 plots in stands ranging from 20 to 80 years of age in Perthshire, Scotland, while Page (1970) studied stands growing in north Wales. Dixon (1971) found that growth was primarily limited by exposure as measured by the angle to the horizon. Approximately 60% of the variation in yield class (i.e., maximum mean annual volume increment) between the 93 plots could be accounted for by differences in exposure. Similarly, Page (1970) found that a multiple regression model which included elevation, soil texture, percentage slope, distance from ridge, soil series, bulk density and topography was able to explain approximately 75% of the variation in site index (mean top height at age 50 years) between the sites assessed in north Wales. Ledgard (1988) conducted a preliminary study in New Zealand to compare the relative productivity of Douglas-fir stands growing on ridge tops and slopes, and on northerly and southerly aspects in Ashley and Pomahaka Forests. He found that the mean annual volume increment was between 39% and 67% higher on sloping sites than on ridge top sites, and was 22% greater on a southerly (more sheltered) slope than on a comparable northerly slope.

The stem form of Douglas-fir on many sites is also a concern to forest managers. These undesirable form characteristics are often termed 'distorted growth' (Carter and Klinka, 1986) and are particularly apparent in younger trees. The same authors described many different types of distorted growth, plus the symptoms and presumed causes. They found that the three types of distorted growth that are probably of most concern to foresters are broken leaders, multiple leaders and sinuosity. Broken leaders are most common on high productivity sites where trees have large annual height increments, and the fault usually occurs while the leaders are succulent, with the resulting forks often having a "U" shape (Carter and Klinka, 1986). In North America the cause of broken leaders is usually animal damage (grouse, pigeons, crows and squirrels) or damage from wind or snow. The occurrence of animals capable of causing leader breakage is much less in New Zealand, so any damage is more likely to be the result of wind or snow, rather than animals.

The most common cause of forking and multiple leaders is lammas growth – an abnormal burst of late season shoot growth from the opening of recently formed buds, which is not expected until the following year (Carter and Klinka, 1986). Elongation of lateral buds at the base of the still inactive terminal bud often results in lateral branches that grow in an upward direction and compete with the leader. Lammas growth is most common in young trees and appears to be under strong genetic control. It is also strongly influenced by growing season soil moisture and nitrogen availability. Competition between laterals (lammas) shoots and the terminal shoot can result in many serious deformities, such as multiple leaders and forks in the main stem, ramicorn branches, acute angle branches and poor stem form.

Sinuosity is defined as stem crookedness or "waviness" that occurs entirely within an internode or interwhorl, rather than spanning several internodes (Campbell, 1965). According to Carter and Klinka (1986) sinuosity is a heritable trait which occurs most often in rapidly growing trees, especially those growing on moist sites. Similarly, Turvey et al. (1993) noted that sinuosity is under genetic control but speculated that wind supplies the destabilising force. Therefore, it would not be unreasonable to expect an increased incidence of trees with poor form on more exposed sites.

There is considerable anecdotal evidence of poor form in young Douglas-fir grown in New Zealand and the role of nutrition and genetics is currently being studied (Low et al., 2002; Murray Davis and Charlie Low pers comm.). A lack of boron has been suspected, but trials have not shown a boron effect (Murray Davis, pers comm.). The incidence of malformation in older trees has been investigated by Revell (1978) who quantified the proportion of malformed trees in 139 stands growing in the North Island ranging in age from 3 to 46 years. These sites were spread across three regions: northern North Island, central North Island and the east coast of the North Island. Revell (1978) found that in general there was an increase in malformation with increasing elevation and lack of protection from the wind.

Despite these observations on the effects of topographic position on the growth and form of Douglas-fir in New Zealand, few intensive quantitative studies have been carried out. In this study we test the hypothesis that the growth and stem form of Douglas-fir is related to the topographic location of a stand. Field trials have been established at two sites in the South Island (Okuku in Canterbury and Blackmount in Southland) to test this hypothesis. This report describes the results from these field trials and discusses how these results can be used by foresters to predict the variation in the quality and quantity of Douglas-fir wood across their estates.

METHODS

Study sites

Two sites were chosen for the study. The first site was in Okuku Forest, approximately 60 km northwest of Christchurch. It has an elevation range of 700-800 m above sea level, with a south-easterly aspect. Soils are classified as lowland yellow-brown earths belonging to the Hurunui series (NZ DSIR, 1968). The stand was planted in Douglas-fir in 1980 at a density of 1667 trees/ha (3m by 2m spacing). The stand has not been thinned since it was planted. The exact seedlot that was planted was not recorded, however adjacent stands planted in 1980 used 2/0 seedlings from seedlots CY/B/76/18 and CY/C/78/09. Both these seedlots were collected from Hanmer Forest (Vincent and Dunstan, 1989) and were of ex-Washington origin. Trees from this origin have a reputation for vigorous growth, often accompanied by poor stem form.

The second site was located in Blackmount Forest, approximately 30 km south of Manapouri. The stand had a lower elevation range than the Okuku site (300-430 m a.s.l.), but had a similar gradient in exposure. Soils are classified as lowland yellow-brown earths belonging to the Wairaki series (DSIR Soil Bureau, 1969). The stand was planted in 1979 at a density of 2222 trees/ha. Planted stock were 2/0 seedlings from seedlots S/67/919, S/69/1036 and SD/C/76/16. These seedlots were collected from Queenstown, Naseby and Beaumont Forest, respectively (Vincent and Dunstan, 1989) and are believed to be of ex-Washington origin. The lower part of the stand was thinned in 1996 to a density of 650 trees/ha, while the upper part of the stand was thinned in 2004 to a residual density of 627 trees/ha.

Field measurements

At both sites a series of fixed area plots were established along transects which were orientated parallel to the slope direction (i.e., there was a gradient in exposure within a transect). At Okuku Forest, a total of twenty 0.02-ha plots were established in the stand. These were located along four transect lines running parallel to the direction of the slope and also parallel to the direction of planting rows. Five plots were evenly spaced along each transect line, with approximately 50 m between plot centres. Some relocation was necessary in order to avoid wind-throw gaps.

At Blackmount Forest, the plot size was increased to 0.04-ha in order to obtain a suitable number of trees for assessment. A total of twenty-one plots were established in the stand and these were located along three transect lines running parallel to the direction of the slope. All plots within a transect were located in an area of the stand that had been thinned at the same date (i.e., either 1996 or 2004).

Within each plot, the diameter at breast height (DBH) and total height (H) of every tree was measured. The location of the plot centre was determined using a GPS to within +/- 10 m. Plot elevation was also measured using the GPS. The exposure of the site was assessed using TOPEX; a measure that has been shown to be well-correlated with windiness at a site (Quine and White, 1998). TOPEX was measured in the field using a compass and clinometer (Wilson 1984). The angle to the horizon at a distance of up to 1 km away was measured for each 45 degree sector (i.e., N, NE, E etc). Upward angles were recorded as positive and downward angles as negative. TOPEX was calculated by adding all these angles together. A high value indicates a sheltered site, while a low (or negative) value indicates that the site is exposed.

Two systems were used for assessing tree quality. At Blackmount Forest tree quality was assessed using the scoring system devised by Low et al. (2002) which uses a scale ranging from 1 (poorest form) up to 9 (best form). Trees with a quality score greater than 5 were considered merchantable, while those with a quality score less than 5 were considered non-merchantable.

At Okuku Forest a more detailed assessment of tree quality was performed using MARVL (Method for Assessment of Recoverable Volume by Log types; Deadman and Goulding, 1979). Each tree was cruised and the following user-defined codes were used:

Quality Code	Sweep (over 3 m length)	Other defect*
A	top-base coincident	Nil
B	SED/3	Minor
C	SED/2	Medium
P	> SED/2 but < 30 cm	Severe
R	n/a	Steep angled branch (ramicorn)
W	> 30 cm	Severe

*Other defect definitions
Nil – no or minor swellings, lightly branched
Minor – minor swellings, lightly branched
Medium – bumps, swellings, dense branching
Severe – many bumps, swellings, basket whorls

At both sites defects such as multiple leaders, ramicorns, broken tops and defective tops were noted.

Data analysis
Stem volume of each tree was calculated using the national volume equation for Douglas-fir, T136 (Katz, 1984). Total stem volume, basal area and mean top height were calculated for each plot. These yield data were then analysed using linear regression. Mean top height, basal area and volume at each plot were regressed against TOPEX. Data from both sites were pooled and an indicator variable was used to test whether differences existed between sites. The incidence of multiple tops (forks) and ramicorn branches were tallied for each plot and the proportion of trees with these characteristics calculated. Binomial logistic regression was then used to determine whether there was an association between the proportion of trees within a plot which have multiple tops or ramicorn branches and exposure as measured by TOPEX. Over dispersion (i.e., extra-binomial variation) was assessed using a chi-squared test, and where significant over dispersion was present the model was refitted using quasi-likelihood. Significance of variables in these logistic regression models was assessed using scaled drop in deviance tests.

At the Blackmount site the proportion of non-merchantable trees (i.e., those with a stem form score of less than 5) in each plot was calculated. Binomial logistic regression was again used to determine whether there was an association between the proportion of non-merchantable trees and exposure. At the Okuku site, the proportion of total standing volume in the A quality class was calculated using Atlas Cruiser (Atlas Technologies, Rotorua). Binomial logistic regression was used to determine whether there was an association between this proportion and exposure. As with the models fitted to the tree characteristic data, over dispersion was assessed using chi-squared tests and where necessary models were refitted using quasi-likelihood.

RESULTS

A total of 669 trees were assessed at the site in Okuku Forest and 498 at the site in Blackmount Forest. There was considerable variation in the mensurational characteristics of individual trees within each site. For example, at Okuku Forest stem diameters at breast height (DBH) ranged from 27 mm up to 343 mm, while heights ranged from 5.2 m up to 18.8 m (Table 1).

Table 1. Mensurational characteristics of the 669 trees assessed at Okuku Forest, and the 498 trees assessed at Blackmount Forest.

Characteristic	**Okuku Forest**			**Blackmount Forest**		
	Min	**Mean**	**Max**	**Min**	**Mean**	**Max**
DBH (mm)	27	195	343	37	280	495
H (m)	5.2	12.5	18.8	5.4	14.3	21.9
H/DBH (m/m)	29	64	153	29	52	146
Taper* (cm/m)	0.8	1.8	4.5	0.9	2.2	3.9
Volume (m^3)	0.005	0.21	0.75	0.003	0.46	1.66

*Taper is defined as DBH/(H-1.4)

The range in mean top height across plots was similar between the two sites, with the exception that trees on the most exposed plots at Okuku were shorter than those at Blackmount. In addition, trees on the most sheltered plots at Blackmount were taller than those on the least exposed plots at Okuku. Across both sites there was a strong linear trend of reduced mean top height with increasing TOPEX (Figure 1). A linear model containing TOPEX and an indicator variable for site was able to explain approximately 64% of the variation in mean top height. Higher order terms (e.g., $TOPEX^2$) were not significant and the effect of TOPEX on mean top height did not differ between sites (p=0.228). The mean top height of plots at the Blackmount site was on average 5.3 m taller than plots with the same level of topographic exposure at the Okuku site. While the trees growing at the Blackmount site are one year older, this age difference cannot explain a difference in mean top height in excess of 5 m. The difference in mean top height could be due to a number of soil and climatic differences between the two sites, but a possible explanation is that the elevation of the Okuku site is nearly double that of the Blackmount site. It is not unreasonable to expect that, in addition to temperature differences, the level of wind exposure for the same TOPEX score will be considerably higher at 700 m than at 350 m above sea level.

Basal area was significantly associated with TOPEX at both sites ($r^2 = 0.712$; Figure 2). The relationship between basal area/ha and TOPEX did not differ significantly between sites (p=0.564), nor were higher order terms significant (p=0.633). The lack of a difference in basal area between the two sites is a chance result rather than indicating a lack of difference in site productivity. The stand at Blackmount Forest had been thinned in two separate operations which have reduced basal area and total standing volume, whereas the stand at Okuku Forest is unthinned. However, this does not detract from the fact that, within a site, there is a significant reduction in basal area/ha with increasing TOPEX.

At the plot level, the ratio of height to DBH (where both height and DBH are in the same units) did not vary as much as at the individual-tree level. Across both sites there was a significant linear relationship between H/DBH and TOPEX (r^2=0.754; Figure 3). With increasing exposure (i.e., as TOPEX becomes lower) trees tend to become more tapered. This effect was stronger at the Okuku site than the Blackmount site as evidenced by the larger coefficient on the TOPEX term (c.f. 0.202 *vs*. 0.073).

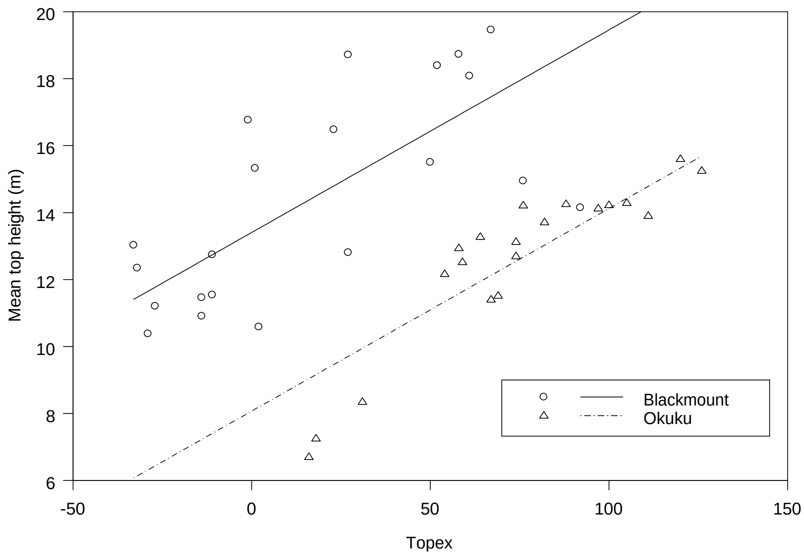

Figure 1. Relationship between mean top height (m) and TOPEX for the 21 plots measured at Blackmount Forest and the 20 plots measured at Okuku Forest. Low TOPEX values indicate exposed sites while high TOPEX values indicate sheltered sites.

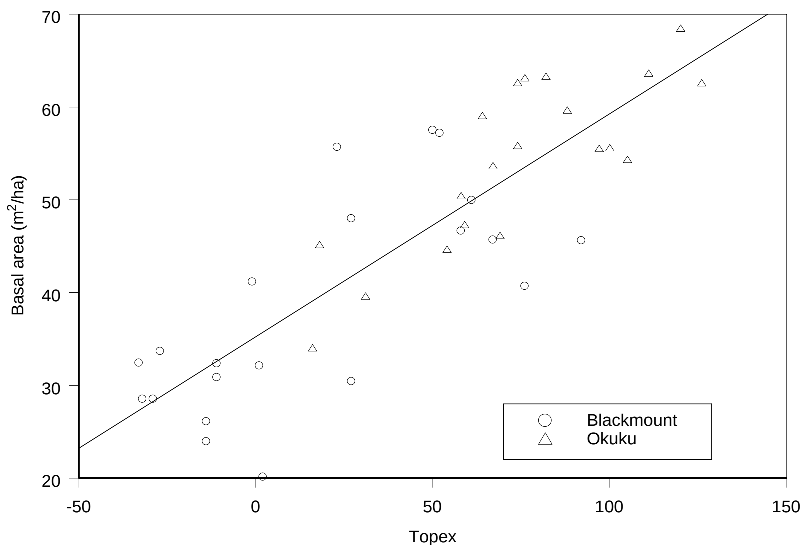

Figure 2. Relationship between basal area (m^2/ha) and TOPEX for the 21 plots measured at Blackmount Forest and the 20 plots measured at Okuku Forest. Low TOPEX values indicate exposed sites while high TOPEX values indicate sheltered sites.

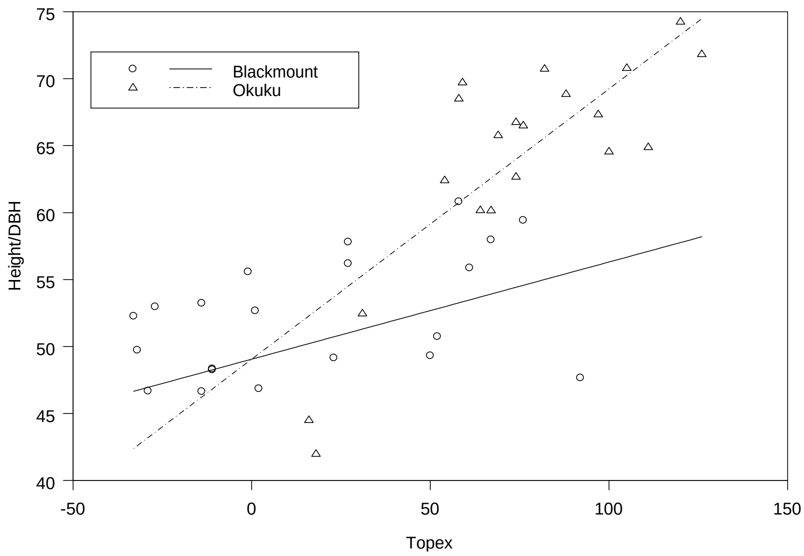

Figure 3. Relationship between H/DBH and TOPEX for the 21 plots measured at Blackmount Forest and the 20 plots measured at Okuku Forest. Low TOPEX values indicate exposed sites while high TOPEX values indicate sheltered sites.

There was considerable variation in stem volume with the highest yielding plot at Okuku Forest containing nearly four times the volume of the lowest yielding plot at the same site (522 m^3 ha^{-1} compared to 112 m^3 ha^{-1}). A similar situation was found at the Blackmount site. Total standing volume was strongly associated with TOPEX at both sites ($r^2 = 0.664$; Figure 4). The relationship between stem volume and TOPEX did not differ significantly between sites ($p=0.224$).

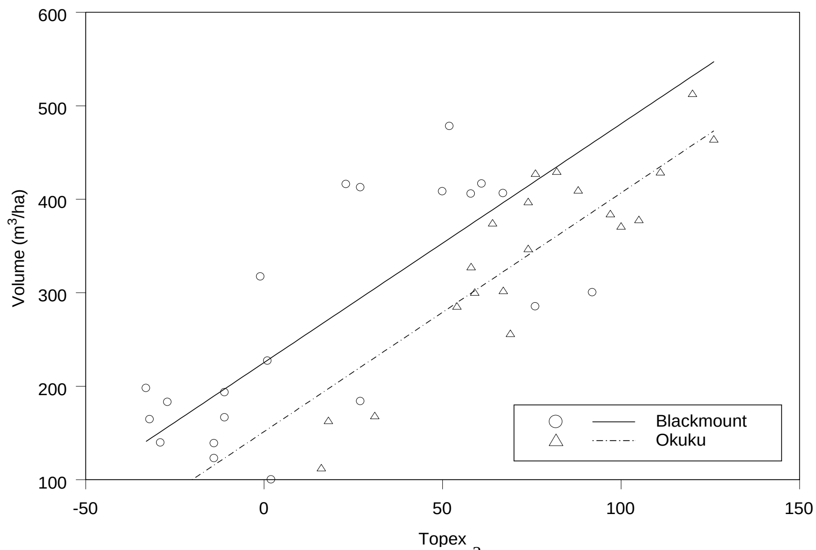

Figure 4. Relationship between volume (m^3/ha) and TOPEX for the 21 plots measured at Blackmount Forest and the 20 plots measured at Okuku Forest. Low TOPEX values indicate exposed sites while high TOPEX values indicate sheltered sites.

The proportion of trees in a plot with ramicorn branches ranged from 0 up to 0.56 (i.e., 56%) while the median across all plots and both sites was 0.22. There was considerable variation in this proportion and it did not appear to be related to TOPEX. The binomial logistic regression model (fitted using quasi-likelihood due to the significant over dispersion) showed that there was suggestive, but inconclusive evidence of an association between TOPEX and the proportion of ramicorn branches (p=0.158). The result is even less clear cut as the sign of the relationship differs between the two sites. At Blackmount there is some suggestion that the proportion of trees with ramicorn branches increases with increasing topographic exposure, while there is some suggestion of the opposite trend at the Okuku site (Figure 5).

There was no relationship between the proportion of multi-leadered trees in a plot and TOPEX (p=0.700). However, there was a significantly greater proportion of multi-leadered trees in plots at Okuku Forest than at Blackmount Forest (p<0.001; Figure 6). These differences could be due to a range of site factors such as elevation, aspect, windiness and rainfall which differ between the two locations, or it could be due to genetic differences between the tree stocks which are planted at the two sites.

The proportion of non-merchantable trees in a plot at the Blackmount Forest site ranged from 0 up to 0.67 (i.e., 67%), with a median value of 0.21 (21%). There was no significant relationship between the proportion of non-merchantable trees in a plot and TOPEX (p=0.916; Figure 7). However, the proportion of non-merchantable trees in a plot differed significantly between transects. Plots located on transect 3 contained few if any non-merchantable trees, while those in transect 1 contained a large number. These differences are due to factors other than TOPEX and could reflect different tree selection practices in different parts of the stand during the thinning operations.

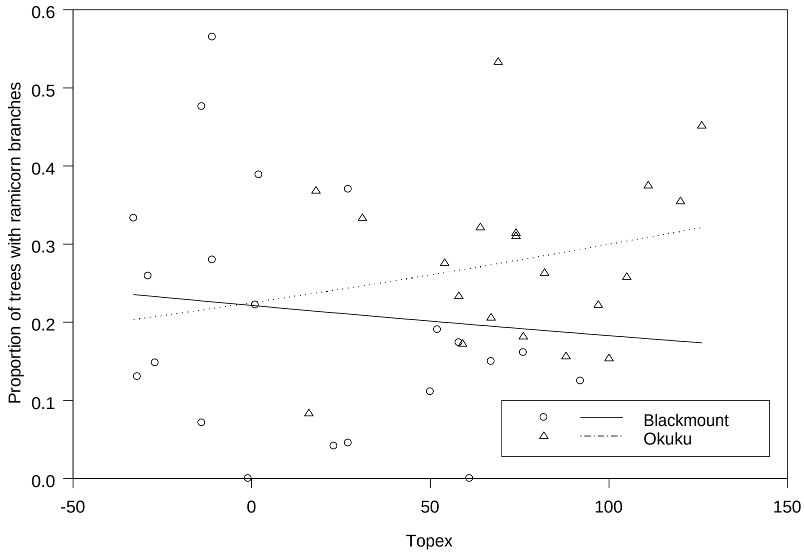

Figure 5. Relationship between the proportion of trees in a plot which have ramicorn branches and TOPEX for the 21 plots measured at Blackmount Forest and the 20 plots measured at Okuku Forest. Low TOPEX values indicate exposed sites while high TOPEX values indicate sheltered sites.

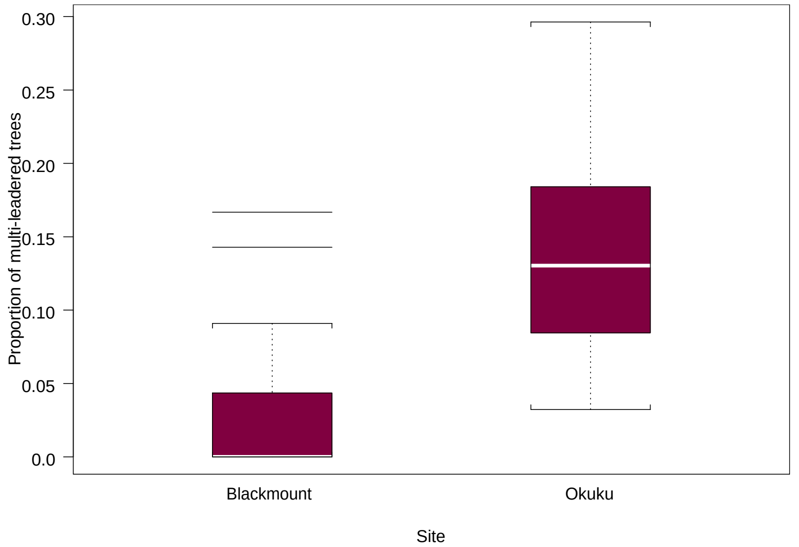

Figure 6. Comparison between Blackmount Forest and Okuku Forest of the proportion of trees in a plot with multiple leaders.

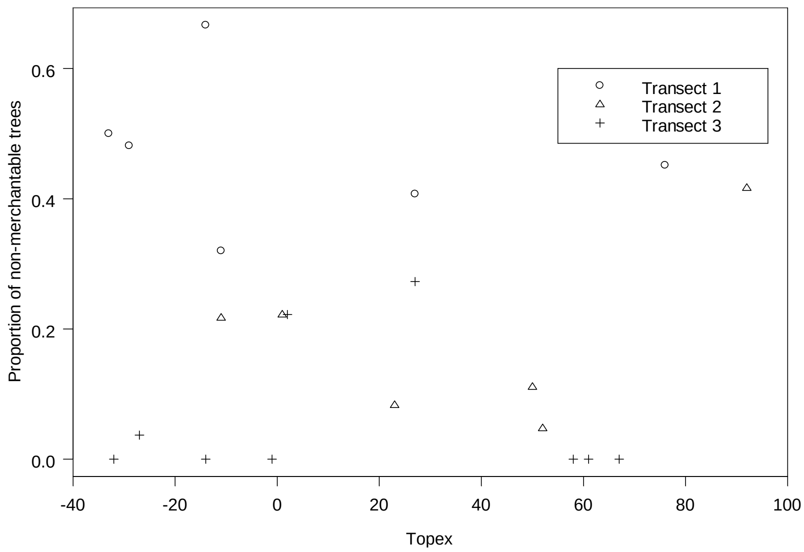

Figure 7. Relationship between the proportion of non-merchantable trees in a plot and TOPEX at the Blackmount Forest site.

At the Okuku Forest site a significant relationship was observed between the proportion of total standing volume in the A quality class and TOPEX (Figure 8). As a site becomes more sheltered there is an increase in the proportion of total standing volume in the A quality class, up until a TOPEX score of 90 after which point there is a decrease in this proportion. However, this result is strongly influenced by the two plots which have very high TOPEX scores and a low proportion of their volume in the A quality class. An indication of the leverage these points exert can be seen when the model is refitted after they are removed. In this case the quadratic term (i.e., $TOPEX^2$) is no longer significant (p=0.913) and there is a linear relationship between the log odds (i.e., logit) of the proportion of volume in the A quality class and TOPEX.

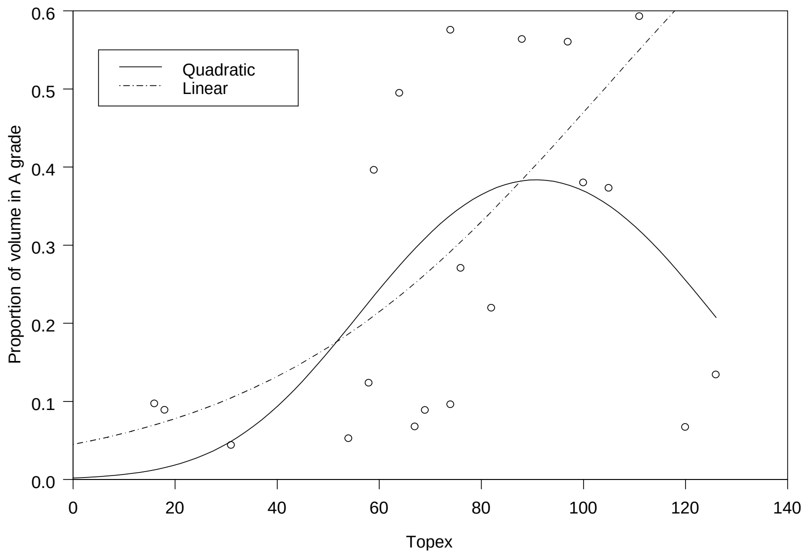

Figure 8. Relationship between the proportion of volume in the A quality code in a plot and TOPEX at the Okuku Forest site.

DISCUSSION

Based on the data from the two sites investigated here, increased exposure as measured by TOPEX appears to have a large effect on yield and a lesser effect on stem form or log quality. There was some evidence to indicate that there is a reduction in the proportion of stem volume contained in straight logs (quality code A) with increasing exposure. However, the two most sheltered plots according to TOPEX had a similar proportion of volume in straight logs as the two most exposed plots. This could be explained by the fact that on the more exposed sites, any malformation appeared to be masked by the stunted nature of the trees, whereas in sheltered sites where height growth was greater, malformation was more apparent.

The systems used to assess stem form differed between sites and the lack of any relationship between exposure and malformation at the Blackmount site may have been due to the system used to assess malformation. At this site a single score was assigned to each tree rather than dividing each tree into a series of sections of different quality under the MARVL approach. Ideally, the two systems would have been tested at each site to determine if the simpler whole-tree scoring system could provide similar results to the more detailed MARVL approach.

The effect of exposure on yield was very pronounced and the proportion of variation in yield explained by TOPEX was very similar to that found in the studies conducted in the United Kingdom by Page (1970) and Dixon (1971). When reviewing these earlier studies from the UK, Revell (1978) suggested that because New Zealand was a relatively narrow country orientated at right angles to the prevailing west to south-west airflow, most localities can expect stronger winds than are experienced in the native range of Douglas-fir, and similar effects to those reported in Britain could be expected.

There are a number of possible explanations for the pattern of variation in stem volume observed. While there is a strong correlation between TOPEX and yield, there is a considerable degree of uncertainty as to what TOPEX is actually measuring. Quine (2000) found a strong correlation between TOPEX and wind speed, while McNab (1993) suggests that it is likely to be correlated with other environmental factors including rainfall and soil moisture status. Previous research has shown that soil moisture availability is a major factor limiting the growth of Douglas-fir in North America and it is likely that soil moisture availability is reduced on ridge top sites (i.e, those sites with a low TOPEX score). Further measurements should be carried out to estimate plant available moisture for each of the plots used in this study. It is also possible that height growth is directly affected by wind exposure through damage to the terminal shoot. Previous studies in Otago Coast Forest (Kershaw, 1969) found a relationship between the level of exposure and the proportion of Douglas-fir trees which had lost their terminal leader. Such terminal loss would be expected to show up as either reduced height growth and/or increased levels of malformation. It was assumed that trees would respond to leader loss by leader replacement which would in turn result in multi-leadered trees. However, there was no apparent relationship between TOPEX and the proportion of multi-leadered trees in a plot. This may be explained by a study at Mt Barker, near Lake Coleridge, where leader deformation and subsequent stem straightening within a block of trees was quantitatively assessed and photographed for over 3 years (during years 4-6 after planting) (Ledgard and Low, 2003). Repeat photographs showed leaders bent horizontally in year 1 'straightening' markedly by year 3. The authors recorded that "It is likely that after another 5 years very few trees will show any external sign of malformation on this portion of the stem." More conclusive data on the effect of wind on terminal shoot growth could be provided through destructive sampling which would involve sectioning the tree stem longitudinally so that the pith is clearly visible.

In addition to the effects of topographic position on yields found in this study, it is possible that wood quality may also be affected. Data from the Okuku Forest site already indicate that the proportion of straight logs is lower in stands which have higher TOPEX scores. In addition, branch size may also increase with increased levels of wind exposure. Watt et al. (2005) found a strong relationship between TOPEX and both branch index and maximum branch diameter for radiata pines trees growing in the Wairarapa region. Similar effects may occur in Douglas-fir stands, and further research should investigate whether differences in branch size do occur between plots, as this attribute is one of the key determinants of log quality. Wind exposure has also been identified as having an effect on the amount of compression wood in a tree and also on the modulus of elasticity (MOE) of wood. Compression wood in coniferous trees is often produced in response to tree lean and its function is to return the apical meristem to the vertical position. In many cases, the process of returning the apical meristem to the vertical position occurs as a series of over-corrections which results in stem sinuosity and the presence of compression wood at different locations up the stem (Spicer et al., 2000). Compression wood has higher density than "normal wood", but generally has higher microfibril angle, lower modulus of elasticity and poorer dimensional stability when dried; all these traits make it less desirable to wood processors. Several studies (see Telewski (1995) for a review) have also found that at wind exposed sites, swaying of trees can result in wood which has a lower modulus of elasticity. With the use of machine strength grading of structural timber, a reduction in MOE could have negative consequences for sawmill operators if its magnitude is significant. Preliminary investigation to test whether there is an effect of wind exposure on MOE could be made using one of the standing tree acoustic tools which are available to estimate dynamic MOE.

While this study was preliminary in nature, results indicated that substantial differences in the growth and form of Douglas-fir trees exist within a stand and that these can be predicted from topographic location. In this study, an index of topographic exposure (TOPEX) was calculated in the field using a compass and clinometer. However, it can also be calculated directly from digital terrain models (DTMs). This would allow forest managers to determine areas of high exposure where Douglas-fir performance could be limited due to low volume yields and poorer quality wood. It would also allow logs to be segregated at an early stage in the wood chain to enable their more optimal allocation to appropriate end uses, which in turn will improve the efficiency and profitability of operations.

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