The effects of a crown lightening technique on growth and form, and topple in two-year-old *Pinus radiata*

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Abstract

Toppling is recognised as an increasing problem in *Pinus radiata* plantations, particularly on fertile farm sites. Toppling can be costly to forest and woodlot owners due to the loss of value of the final crop, arising from poor stem form, and reduced selection ratios. Crown lightening, the reduction of a tree's "sail area" by shortening branches, is one method being applied to reduce the likelihood of topple. In June 1996 a trial was installed near Whangarei, New Zealand, to assess the effects of a crown lightening technique called "windproofing" on the growth, form and topple of two-year-old radiata pine. Two days following trial installation the trial was subjected to a storm event with high rainfall and winds gusting to 95 km/h. Assessment of the trial two years after installation shows no affect of windproofing on height or diameter. No windproofed trees toppled, while 50% of control trees toppled. The difference in topple resulted in better stem straightness in the windproofed trees. The relatively low cost of applying windproofing, no significant loss of growth, and the reduced chance of topple, suggest that windproofing is a useful tool for forest managers to increase the likelihood of achieving a high value tree crop at rotation end.

Introduction

Juvenile instability, or "toppling", is the overturning of young trees (2 to 3 years old) just below ground level due to either, soil failure around the roots of the tree (Telewski 1995), or root fracture at the root or base of the stem just below ground level (Lines 1980; Coutts 1983; Burdett *et al.* 1986). Trees affected by topple are often not uprooted, but continue to grow resulting in stem sinuosity as the tree struggles back to the vertical (Burdett 1979; Cremer 1998; Telewski 1995).

It is claimed that toppling has serious economic implications for forest and woodlot growers throughout New Zealand (NZ Forest Research Institute 1987; Mason 1989). Toppling results in stems having butt sweep (Mason 1985; Burdett *et al.* 1986; Cremer 1998) so reducing potential volume recovery of valuable clearwood (Cown *et al.* 1984; Gosnell 1987), increasing quantities of compression wood (Harris 1977; Nicholls 1982; Cremer 1998), reducing selection ratios at time of thinning, and reducing the possibility of achieving an acceptable final crop stocking (Mason 1985; Burdett *et al.* 1986). A further cost of toppling is the increased susceptibility of older trees to windthrow due to poor root architecture (Burdett 1979; Burdett *et al.* 1986).

In a static model of tree failure a tree is likely to topple when the overturning moment[4] caused by the wind exceeds the maximum resistive moment that the tree roots can provide (Figure 1) (Petty and Swain 1985; Moore and Somerville 1998). The maximum resistive moment is the maximum resistance offered by the stem-root connection, and/ or root-soil cohesiveness (Moore and Somerville 1998). The overturning moment in young trees is predominantly the force applied to the tree crown by the wind (Moore and Somerville 1998). The level of force applied by the wind is determined by the wind speed, crown frontal area, and drag coefficient of the crown (Moore pers comm.).

Crown lightening, or reduction of a tree's "sail area" by shortening the laterals of rising two-year-old trees (Turner and Tombleson 1997), is one method of possibly reducing the incidence of toppling by reducing the crown frontal area, and hence, the overturning moment caused by the wind. While the application of crown lightening

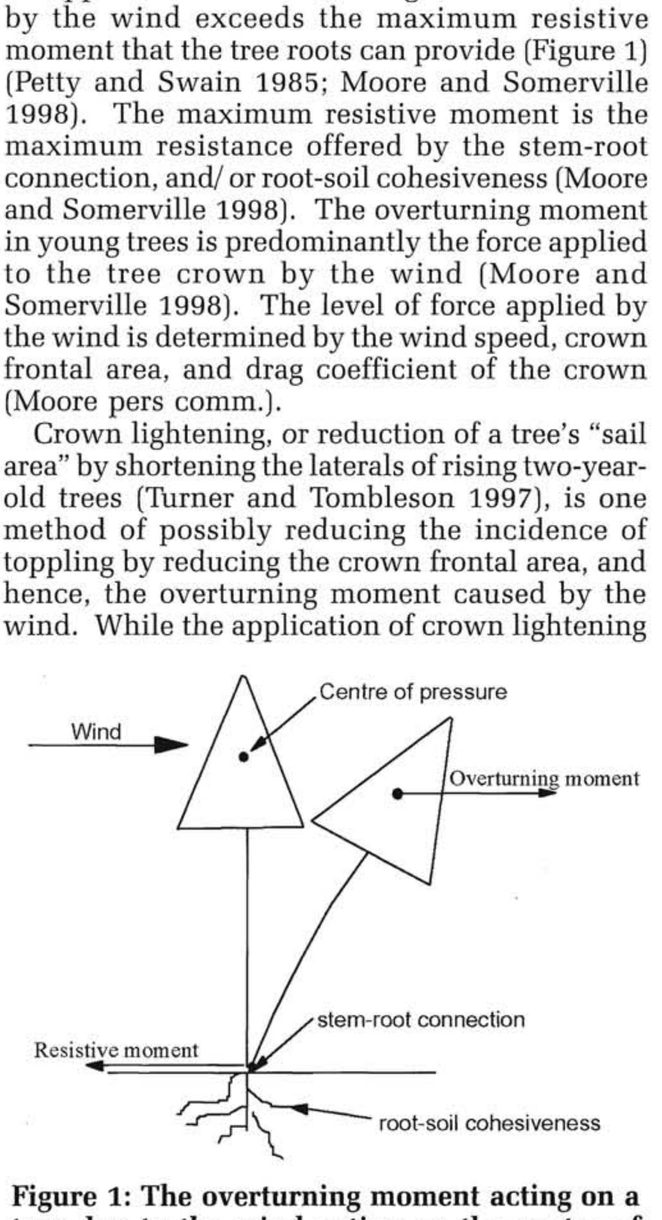

Figure 1: The overturning moment acting on a tree due to the wind acting on the centre of pressure of the tree crown (adapted from Papesch *et al.* 1997).

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3 A moment (m) is a "turning agent" and is defined as M = rF, where r is the perpendicular distance of the line of action of the applied force, F, from the base of the tree (Halliday and Resnick 1988).

is becoming increasingly common (Turner and Tombleson 1997), the name used to describe the technique, and the methods of application are extremely varied. Turner and Tombleson (1997), and J.P. Maclaren (pers comm.) have installed a number of trials, replicated across New Zealand, evaluating a crown lightening technique which aims to remove approximately one-third of the crown area, via shortening of the laterals using secateurs, to form a cylinder. Barton (1995) documented results from a trial in which three levels of sail pruning were applied to *Cupressus* species. A "mid prune" which involved removing 75% of branches from the mid 50% of the tree's height, an "even prune" which involved removing every third branch starting from the top, and a "bottom prune" which removed the branches from the lowest third of the stem (Barton 1995). This trial found no effect of sail pruning on height increment. Toppling was identified only in the *C. lusitanica* control and "even prune" trees (Barton 1995). No results are yet available from the trials installed by Turner and Tombleson (1997). A lower incidence of toppling has been identified in physiologically aged *Pinus radiata* cuttings when compared with seedlings (Holden *et al.* 1995). The lighter, more permeable crowns of aged cuttings compared with seedlings (Menzies and Klomp 1988; Holden *et al.* 1995) has been linked to their lower susceptibility to toppling (NZ Forest Research Institute 1991).

Purpose of Trial

A trial to evaluate the effectiveness of a crown lightening technique termed 'windproofing' to reduce topple in 2-year-old radiata pine was established in June 1996. The trial also assessed the impact of crown lightening on the growth and form of young radiata pine. The Tree People Ltd (TTP) have been using windproofing for a number of years. Windproofing involves shortening branches in the top half of rising 2-year-old trees. TTP's theory was that windproofing reduces the sail area at the point of greatest moment during the period of critical susceptibility through the second winter. Wind acting on the upper portion of the crown will provide greater leverage, and hence, the largest applied overturning force at the base of the tree. This is because wind speed increases with height above ground level, and the length of the lever arm between the base of the tree and this part of the crown is greater. Shortening, rather than removing, branches attempted to minimise reduction of photosynthetic material. The shortened branches continue to grow and also shade the stem with the intention of minimising epicormic growth. Application of windproofing in plantations indicated that windproofing helped lower the incidence of topple, but the effect of the windproofing technique on growth and form was unknown.

Site

The trial is situated at Tangiteroria, 30 km west of Whangarei, New Zealand, on a fertile farm site, owned by Paerata Forest Farm Ltd. The soil is Waiotira clay loam. The area is in good quality pasture with some scattered patches of blackberry. GF17 bare-rooted seedlings were established in August 1994 at 800 stems/ha using a 2-cut planting method. Trees were spray released with Gallant and Gardoprim in September 1994. The trial was installed on June 20 1996, in the rising two-year-old trees.

The site aspect is north and north-east. The windiness of the trial site was scored using the *Detailed Aspect Method of Scoring* (Quine and White 1993). This score (TOPEX) defines the windiness of a site as a function of wind zonation, elevation, and topographic exposure. The TOPEX for the trial site of 1.69, is not considered particularly exposed.

Climate

The wind and rain climate is an important influence on the incidence and degree of topple likely to occur at a site. Toppling is considered to be a wind-related phenomenon (Mason 1985). Chevasse (1978) identifies excessive windspeed as being the most important factor influencing susceptibility to windthrow. Soil moisture as influenced by soil type and site rainfall is also suspected to influence tree stability, although direct evidence is limited (Burdett *et al.* 1986). Wendelken (1966), Chandler (1968), and Irvine (1970) all associated susceptibility to windthrow with wet soils. Coutts (1983) mentions that windthrow tends to occur during winter gales when the soil is wet.

Windspeed information for the site was based on meteorological observations made at Whangarei (24 km east of the trial site) and Dargaville (29 km south-west of the trial site) airports over 37 years. Two meteorological stations were used to provide data to describe the trial wind climate because no station existed in close proximity to the trial, and neither station is certain to be representative of the trial site. The average 8 am wind speed (from meteorological observations made at Whangarei and Dargaville airports over 37 years) at the trial site is approximately 3.2 m/s (12 km/h). Predominant winds for the trial area come from the south-west, north-west and easterly directions (Figure 2). The strongest winds experienced at the trial site tend

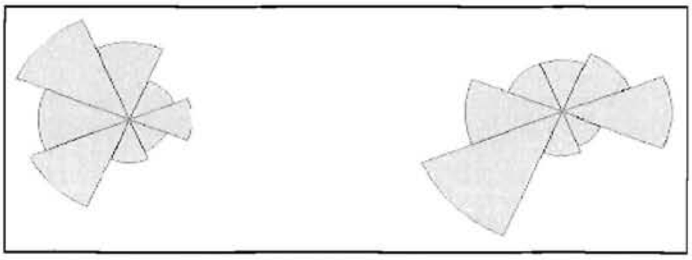

Figure 2: Windrose showing frequency of winds from the eight compass directions for Whangarei Airport (left) and Dargaville Airport (right) Meteorological stations. Observations were made daily at 8 am from 1960 to 1997.

to come from the east, west and south-westerly directions.

Complete rainfall records for the trial site were available only from Whangarei Airport meteorological station. Site mean annual rainfall is 1 300 mm (from 1960 to 1997). Total annual rainfall in the year of planting, 1994, was below average at 846 mm, although the month prior to planting experienced above average rainfall. Annual rainfall in 1995 and 1996 was, 1469 and 1437 mm respectively.

Storm

On 22 June 1996, a storm resulted in significant toppling of some of the control trees in the trial. This provided an opportunity to evaluate the effect of windproofing on preventing topple. Wind and rainfall data from the meteorological station, located at Whangarei Airport, provided details of this storm event. Toppling appears to have been due to easterly winds increasing to a 10 minute mean of 15 m/s (54 km/hr) with a maximum gust of 26 m/s (95 km/h), along with 76 mm of rain over 20 to 22 June.

Methods

Trial Design

The trial is a complete randomised block design using 10 tree plots for each treatment. Each plot has 10 trees planted in a row on the contour. There are five blocks at various heights on the slope with an untreated buffer row between each block. Both control and treatment trees in the trial had a standard form prune to remove double leaders and ramicorns greater than 25 mm. The windproofing treatment involved shortening the branches in whorls above half the tree height (Figure 3). In each whorl to be treated, the branches are cut to half of the mean length of the branches in that whorl. Any branches in the lower half of the trees that extend through an imaginary plane at half tree height are cut where they pass through that plane.

Figure 3: A two year old radiata pine seedling prior to windproofing (left) and following windproofing (right).

Measurement

Root collar diameter (measured at 0.1 m above the ground to the nearest 1 mm) and height (measured to the nearest 0.1 m) were measured on all trees at the time of trial installation.

After the storm event on June 22 the trees were assessed for topple and any toppled trees had the degrees of lean measured. Topple was determined by moving the tree to identify root connection failure (Coutts 1983). Non-toppled trees would not move at ground level, whereas toppled trees could be easily moved. Lean was measured in degrees from the vertical. There was no lean in non-toppled trees, and all toppled trees had lean.

Re-measurement

The trees were remeasured for root collar diameter and for height at age three and four years. Diameter at breast height (dbh) and sweep were also measured for each tree at age four years. Sweep was measured over a 3 m stem section from 0.3 to 3.3 m with a height pole using the centre-to-centre method (Turner and Tombleson 1999). For each tree the maximum stem deviation measured was divided by the 3 m log length to express sweep as mm/m. The height of maximum sweep was measured from ground level using the height pole. Lean was not assessed at re-measurement, therefore it was not possible to determine if the lean of toppled trees changed between measurements.

Analysis

Toppling in the control trees was analysed in terms of the percentage incidence and average degree of lean of toppled trees, and tabulated. The effects of the windproofing treatment on tree diameter and height were first explored by plotting diameter and height against age. The

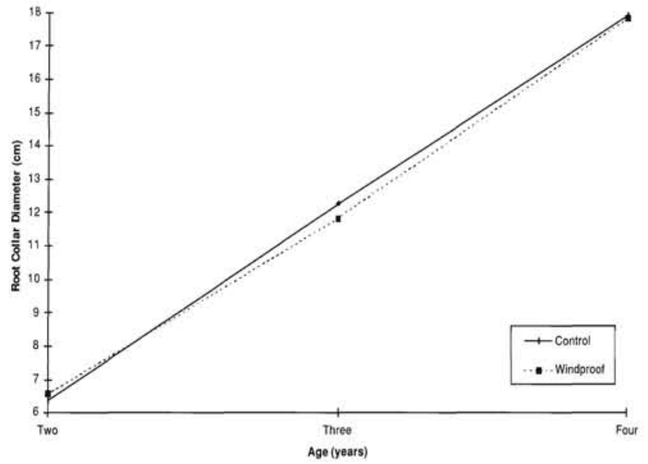

Figure 4: Average root collar diameter (cm) for windproofed and control trees from 1996 (immediately prior to windproofing) to 1998.

difference in tree root collar diameter and height, between the control and windproof treatment, and the difference in diameter increment between toppled and non-toppled control trees, were analysed within a randomised block design. The analysis of variance (ANOVA) was performed in PROC GLM in the SAS system (SAS Institute Inc., 1986). To separate the effect of toppling on height growth from treatment effects, height data was analysed excluding the toppled trees from the control in the dataset. This analysis without toppled trees was made using Type III SS and comparison of least square means in PROC GLM in the SAS System (SAS Institute Inc., 1986). Differences in height increment between toppled and non-toppled control trees were not analysed because results were confounded by stem sinuosity in the toppled trees. Differences in the level of underlying sweep between the windproof treatment and the non-toppled control trees were tested in an ANOVA. All statistical differences were tested at the 1% level (ie. $p \leq 0.01$).

The relationship between initial level of lean and degree of stem sinuosity was analysed using simple linear regression in PROC GLM in SAS (SAS Institute Inc., 1986). In this analysis trees that had not toppled and so had no lean, were included.

Results

Growth

There is no significant difference in root collar diameter between the windproof and control trees at the start of the trial, and at both one year and two years following windproofing (Figure 4). There is no significant difference in diameter at breast height between the treatment and the control. Comparison of toppled and non-toppled control trees for diameter showed a significant difference ($p < 0.05$) in root collar diameter one year following topple but no difference two years following topple.

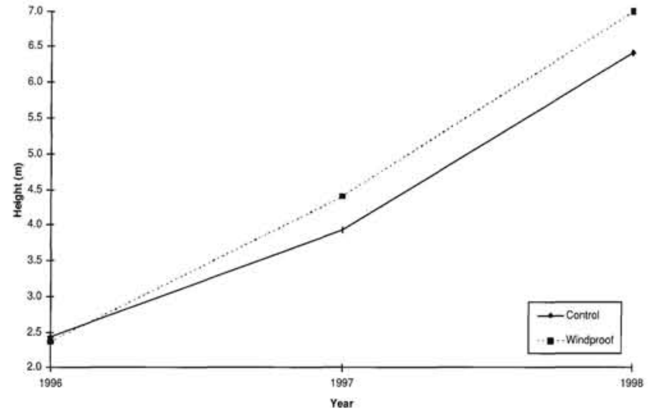

Figure 5: Average height (m) for windproofed and control trees from 1996 (immediately prior to windproofing) to 1998.

Analysis of tree height with toppled trees excluded showed the windproofed trees to be slightly taller than the control trees though there is no significant difference in tree height between the treatment and the control either one or two years following windproofing (Figure 5).

Topple and Lean

The control trees (non-windproofed) suffered 50% toppling with an average lean of 30°, while none of the windproofed trees toppled (Table 1).

Table 1: Percentage incidence by degree of topple.

	Control (%)	Windproofed (%)
No Topple	50	100
Topple > 0° ≤ 15°	16	0
Topple > 15°	34	0

All trees that toppled had lean, and no non-toppled trees had lean.

Sweep

There is a significant difference in the level of underlying sweep between the windproofed and non-toppled control trees (Table 2), with the control trees having a higher level of sweep, 2.4 mm/m compared with 0.9 mm/m. The toppled control trees had significantly more sweep than the non-toppled control trees, 9.5 mm/ m compared with 2.4 mm/m.

There is a weak, though significant, linear relationship (R^2 0.46) between the level of lean at age two resulting from toppling, and the degree

Table 2: Percentage of trees from the control and the windproof treatment in each of three sweep severity classes. The sweep classes are straight < 10 mm/ m, moderate 11-20 mm/ m, and severe > 20 mm/ m (Cown *et al.* 1984).

	Control	Windproof
Straight	80%	100%
Moderate	14%	0%
Severe	6%	0%

of stem sinuosity measured at age four (Figure 6). Figure 6 shows that all trees that toppled had lean and subsequently developed a swept butt log.

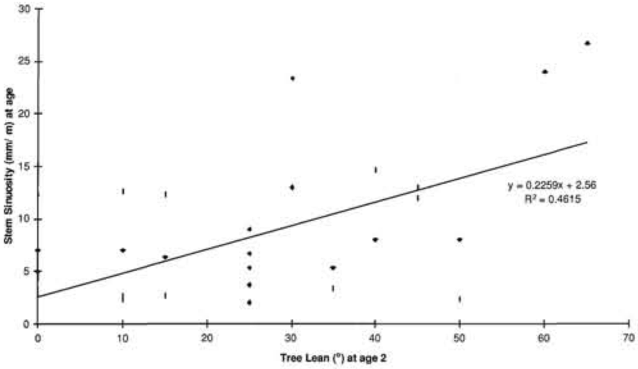

Figure 6: Degree of lean, measured at age two, resulting from toppling, plotted against the level of stem sinuosity for each tree, measured over 3 m, two years following topple, at age four.

Discussion

Growth

It would be anticipated that removal of foliage by windproofing would have resulted in a reduction in root collar diameter (Young and Kramer 1952; Kramer and Kozlowski 1960). Results of this study, however, identified no significant difference in root collar diameter between the windproofed and control trees either at one or two years following treatment. A possible reason for this result is the difference in photosynthesis rates between short and long branches. Based on carbon isotope discrimination work by Waring and Silvester (1994) and Walcroft *et al.* (1996) in *Pinus radiata*, shorter branches are able to maintain photosynthesis rates during the day for a greater period of time than long branches, particularly for days with increasing water deficit. Branch ends therefore, contribute proportionately less to photosynthesis. The extent of branch autonomy, with respect to carbon, also provides a possible reason for there being no difference in root collar diameter. Under normal growing conditions most branches are self-supporting in their production of carbon (Sprugel *et al.* 1991). When a branch's source of photosynthate is reduced by shortening of the branch there is likely to be some import of photosynthate to the branch although the amount imported is usually much smaller than is lost (Sprugel *et al.* 1991).

Topple and Lean

The application of windproofing has resulted in a clear reduction in the incidence of topple compared with the untreated control trees. The static model of tree failure (Figure 1) described in the introduction, suggests that this result may be due to the smaller crown frontal area of the windproofed trees. As a result the overturning moment of the windproofed trees is less than that experienced by the untreated trees for the same windspeed. The threshold windspeed at which topple occurs is, therefore, higher for windproofed trees compared with the control trees.

Sweep

Topple in the control, compared with no topple in the windproof treatment, has resulted in poorer stem straightness in the control, though the relationship between degree of topple induced lean and sweep is poor. An unexpected result was the lower level of underlying stem sinuosity in the windproofed trees compared with the non-toppled control trees. This result suggests that there may be some improvement in stem form associated with application of the windproofing treatment, or that subsequent topple occurred in the trial after June 22 1996.

Implications for Forest Managers

Radiata pine seedlings are most prone to topple during their second winter, although southern South Island grown radiata pine may be more prone in the third winter if growth is slow. Windproofing, therefore, needs to be applied in the autumn prior to the trees' critical period of susceptibility.

Toppling is a random event, dependant on the likelihood of a given site being subjected to a wind storm event and the perceived topple proneness of a site. Although windproofing is a useful method of reducing the incidence of topple, its adoption by growers will depend on the level of risk that growers and investors are willing to accept. The relatively low cost (10 to 20 cents/tree) of windproofing in terms of application and no significant loss of growth in comparison to the potentially high costs of toppling (NZ Forest Research Institute 1987; Mason 1989) suggest that windproofing provides a useful tool for forest managers to increase the likelihood of achieving a high value tree crop at rotation end.

Further Research

Trees in the trial received their first pruning lift in early May 1998. The trial will continue to be assessed for growth and form, with particular emphasis on stem straightness, and stability up until the final pruning lift. Assessment of stem straightness in the final pruned log will provide an indication of the loss of pruned log value arising from varying degrees of topple. The cost of applying the windproofing treatment can then be more readily weighed against the potential loss of value in the pruned log associated with topple. If the root: shoot ratio in radiata pine is fixed, removal of foliage by windproofing could result in restricted root growth as the tree restores theroot: shoot ratio.

Conclusion

The application of the windproofing treatment at age 2 years has had no effect on tree diameter and height at age 3 or 4 years. Windproofing resulted in a zero incidence of topple compared with 50% topple in the control. This difference in topple has resulted in significantly better stem straightness in the windproofed trees. Windproofing therefore leads to reduced incidence of topple with an associated benefit of better stem straightness, without a loss in height or diameter. Further monitoring of the trial is to be carried out to assess changes in stem form, and determine the effect of windproofing on future tree stability due to possible changes in the root: shoot ratio.

Acknowledgments

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The NZIF and the FSC

The Forest Industries Council (FIC) and the New Zealand Foresters Owners Association (NZFOA) have begun a process that will result in a set of standards for the assessment of sustainable plantation management by building on a matrix of existing New Zealand standards. The ultimate aim is to acquire Forest Stewardship Council (FSC) approval of the new standards thereby making it easier for plantation owners to get FSC certification of their management.

The Council of the New Zealand Institute of Forestry resolved that this was a positive step that will improve both our environmental and financial performance; however it would like the standards to apply to all forests in New Zealand, and wishes to ensure that the standards are technically based. The process involves a number of structures to which people are elected. The National Initiative Working Group (NIWG) is the highest level body that gives final approval to standards set by "Technical committees". There are two technical committees in the New Zealand process - one to draft plantation standards and one to draft standards for indigenous forests.

Members of the NIWG and the technical committees are elected in equal proportion from four "chambers". The chambers are supposed to represent different types of stake holders in forestry. In New Zealand the chambers are "Economic", "Environmental", "Social" and "Maori". Three members are elected to each body from each chamber. The environmental chamber has chosen not to appoint anyone to the indigenous technical committee. The New Zealand Institute of Forestry is a member of the social chamber and can exercise one vote within it. We have members in all three elected bodies. John Wardle is in the NIWG, Euan Mason is a member the plantation standards technical committee, and Colin O'Loughlin, Clive Anstey and Tony Newton are on the indigenous standards technical committee.