MSc Dissertation

The Effect of Windblow on Timber Quality in Sitka spruce

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Abstract

The prevalence of windblow in Sitka spruce plantations throughout the UK has raised concerns about the differences in wood quality of blown trees compared to standing crops. This has led to an investigation of the influence of windblow on batten performance and associated properties. This study has examined timber from 3 sites containing windblown trees of Sitka spruce, which were blown over at different times in the past and were still alive. The three time intervals between the damaging storms and the study were 6 months, 18 months and 36 months.

The three sites were located in North England, Mid Scotland, and North Scotland and a total of 45 trees were sampled from three different ages of windblow. After the field characterisation of the trees and surrounding crop, logs and discs were removed from the sample trees and analysed for batten performance using a stress-grading machine. Batten performance is a direct measure of timber quality in terms of strength, whereas concentrating on density of battens is only an indicator. Discs were cut from the end of each log before they entered the sawmill. The data collected from these discs will allow for growth response of the chosen tree populations to be assessed in terms of batten performance, compression wood, wood density or stem shape.

In conjunction with batten performance, the study also examined the percentage of compression wood in each of the logs removed from the three different ages of windblow. Compression wood was measured and analysed from the discs that were cut from the bottom of each log using Optimus™ computer software. The experiment examined the correlation between the effect of leaving trees leaning or blown over different lengths of time on batten performance and the effect of compression wood on each batten to see if compression wood was a major contributing factor affecting performance.

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Paper 1

A review Paper

Summary

The overall aim of the windblow degradation study is to change the way our management policies deal with areas of windblow and how we can deal with windblow in order to maximize green log outturn. The investigations linked tree characteristics in the forest, conversion at the sawmill and quality assessment of the resulting battens in order to follow the complete chain from the forest to the product. This method allowed for a better understanding of the effect of windthrow on timber quality, with respect to the potential for high quality utilization.

The methodology considered three different levels of assessment: tree, sawlog, and batten. 45 trees, (15 each from different ages of windblow), were selected and characterised by their size, shape and their mechanical properties. 149 logs (butt, mid and top) were cross cut from these trees and assessed by their outer form in relation to the way they were lying and the position of potential compression wood. All the logs were converted into construction size battens based on their length and diameter (see appendix 2). Stress grading and visual assessment of distortion or degrade and wood structure were undertaken on the battens. The marking and separation of battens from different stem positions within each log allowed a more accurate assessment of the effect of degrade within the main utilizable area of the stem.

A system of assessment is described which will allow managers to make decisions and select appropriate stands affected by windblow to be incorporated into the felling plans for future work.

The nature of the study tries to show the need for detailed information relating to the large areas of windblow within British forests and how harvesting within 18 months of windblow can ensure maximum production of timber in terms of passing stress grading.

Introduction

Twenty eight percent (500,000 ha) of UK forest area consists of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) (Moorhouse *et al*. 1998). It is climatically suited to the oceanic climate of the UK and is very resistant to exposure. It can be planted in sites otherwise unsuitable for forestry and is easy to establish to eventually gain high yields. This makes Sitka spruce the most important commercial species in this country at the present time. The reason for the high productivity of Sitka is at least partly explained by the absence of specialized grazing or defoliating insects and leaf diseases, enabling more complete and therefore more efficient canopies to be maintained (Savill *et al.* 1997). Sitka spruce can produce a high volume of timber if managed well. Mature Sitka from N.W. America is a first class construction batten when it meets the specification of the industry. It is readily accepted for pulpwood, chipboard and general construction use if the stem form is good.

Sitka spruce is predominately planted in upland sites at spacings normally no greater than 2m and then thinned where conditions are favorable in order to maximize the yield of sawlog timber. However, Sitka spruce is also planted on sites where exposure levels are high and soils shallow. Conventional thinning is severely restricted or a ‘no-thin’ policy is used. Thinning causes gaps in the canopy, increasing wind turbulence within the stand, rendering such unstable stands liable to much greater risk of windthrow (Quine, *et al*.1995)(see plate 1,2).

However, British Sitka spruce has a relatively bad reputation amongst users. It tends to twist and bow when dried which gives difficulties when sawing and seasoning. When compared to other British grown conifers such as Lodgepole pine (*Pinus contorta* Loud.), Scots pine (*Pinus sylvestris* Linn.) and Douglas fir (*Psuedotsuga menziesii* (Mirb.)Franco.), Sitka has considerably lower values for moduli of rupture and elasticity (see Table 1).

Table 1 MoR, MoE, shear strength, specific gravity and density are averages for the species (Cahalan 1987).

Species	Modulus of Rupture (N.mm^{-2})	Modulus of elasticity (N.mm^{-2})	Shear Strength (N.mm^{-2})	Normal Specific Gravity (@12%m.c.)	Density (@12%m.c.) (kg .m^{-3})
Sitka spruce	67	8100	8.7	0.34	400
Lodgepole Pine	79	8100	12.1	0.42	470
Scots pine	89	10000	12.7	0.46	510
Douglas fir	91	10500	11.6	0.44	530

The main reason is probably the high percentage of juvenile core in the logs we produce, which has lower density and hence reduced strength. Other problems such as high grain angle can lead to drying distortion within each batten. Due to these figures in homegrown Sitka, it has been suggested that this timber is only useful for carcassing and cladding material as well as pulp (Cahalan 1987). Wood properties are inherent features of a species, but silvicultural practices and tree breeding can modify them (Macdonald and Hubert 2002). Density could be increased by closer spacing or thinning at canopy closure, and since genetics also contribute towards determining wood density, tree breeding can also be used, although the cost of breeding programs may be prohibitive. There is now genetically improved material commercially available which provides high growth rates without a loss in wood density (Lee, 1998).

Plate 1: Windblow at Kielder forest

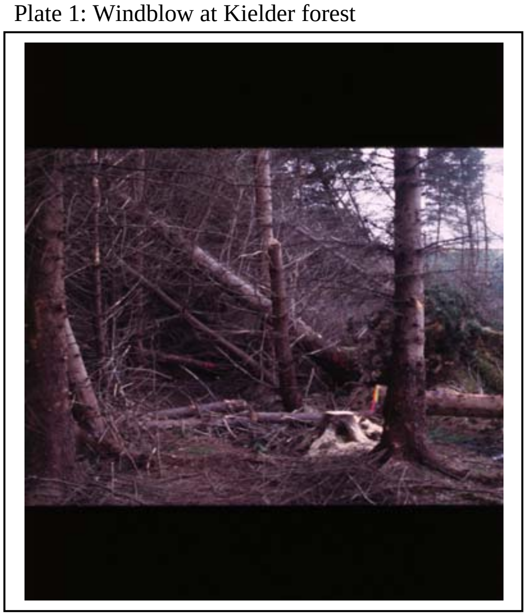


Plate 2: Windblow at Garve forest, Inverness shire

The trees illustrated in plates 1 and 2 are typical of upland windblow sites where the tree diameter is slightly smaller than trees found on lowland sites. The stem form varies from site to site.

Literature review

In many parts of the world wind is responsible for much recurrent damage to forests and gives rise to economic losses and problems of management (Savill and Sandels 1983). The UK's climate, topography and soils, provide almost ideal conditions for tree growth. However in recent years UK forestry has encroached into upland sites, which have caused problems with stability and shallow rooting (O'Carroll 1984). Damage is normally confined to sites that are inherently unstable due to soil type or topography, and usually effects stands once they have grown to a particular top height. Endemic windblow comprises either single trees or groups of trees, and it can spread progressively over several years resulting in significant threat to forestry (Quine and Bell 1998). The amount of damage is influenced more by wind speed, wind direction and local topographic features than by soil conditions or silvicultural treatment (Miller 1986). Very little can be done to prevent losses, for if trees are not uprooted, stems are snapped (Savill and Sandels 1983). While most of the timber in windblown trees can be recovered, significant economical losses are brought about because of storm damage (O'Connor 1999). The direct losses consist of reduced volume and value recovery due to breakage, and increased harvesting and reforestation costs (Bilek and Bown 1997). A 1974 storm in Ireland resulted in breakage of 15% of the stems, reducing the total useable wood content to 20% (Gallagher 1974). Along with volume losses, the revenue per cubic metre may be reduced because of additional harvesting, extraction and haulage costs, smaller log sizes, depressed market prices and higher management costs resulting from the necessary re-organisation of harvesting and marketing plans (Busby 1965).

Wind can lead to a change in wood properties within the tree. The formation of reaction wood within trees is attributed to the displacement of the stem from its natural vertical position (Haygreen and Bowyer, 1996). If displaced for a time known as the presentation time, a gravitropic response is stimulated which leads to the displacement of reaction wood (Westing, 1965). In conifers, the reaction wood that forms is known as compression wood, and it develops on the lower side of leaning or blown trees.

The most important factor in wood structure linked to increased wind exposure is compression wood (Seeling, 1999). It is known to reduce timber quality due to its cell wall chemistry and cell wall structure. Compression wood appears dark to the eye because it absorbs light to a greater degree and scatters light to a lesser degree than normal earlywood. The former characteristic is a consequence of its high lignin content and the latter is caused by the thick wall of its fibres. The high lignin content and low microfibril angle are responsible for a decrease in mechanical strength and a disposition to warp. Compression wood has a higher specific gravity, a lower fibre saturation point, reduced permeability, lower radial and tangential shrinkage but substantially larger longitudinal shrinkage. It also has higher compressive strength but lower tensile strength, a lower modulus of elasticity and it is more brittle in terms of fracture than normal wood.

Wood is characteristically a highly variable material that exhibits differences in anatomical and physical properties between wood cells, tree rings, individual trees, sites and geographic regions. Variation in basic wood density is of particular interest to the forest industry as this property is related to a number of solid wood utilisation characteristics such as timber strength and stiffness and manufacture and performance of reconstituted products. Over the past few decades the world wood supply from old-growth resource has been declining rapidly. Some regions such as Canada are in transition from old-growth resource to managed second growth resource while other areas such as New Zealand have become heavily dependent on plantations for wood supply (Zhang 1995).

These fast growing plantations have steadily increased over the decades and the proportion of plantations of both softwoods and hardwoods will continue to increase until plantation grown timber will dominate the world supply in the next twenty five years or so (Zobel 1980; Bingham 1983). This changing resource will mean a change in wood quality globally. A better understanding of the changing quality of wood from these fast grown plantations is beneficial for the efficient processing and utilisation of the wood.

Traditionally, density has been considered to be the simplest single indicator of wood quality, whether the wood is to be used as solid construction battens or reconstituted into panels, paper or board products. However, a relatively small change in wood density can be accompanied by a considerably larger change in mechanical properties, with the result that estimates of structural performance based solely on evaluation of wood density may not be reliable (Zhang, 1997).

There are established relationships between density and clearwood properties in the USDA wood handbook (USDA 1987). For example the relationships for density with stiffness (Modulus of Elasticity) and bending strength (Modulus of Rupture) are given by the following equations for Sitka spruce.

$$\text{MoE (MPa)} = 3.13\times10^{6}D^{0.9}$$

$$\text{MoR (MPa)} = 2.56\times10^{3}D^{1.05}$$

Where D is density (kg/m^3). These equations suggest that MoR and MoE of clearwood increase almost linearly with density. Therefore a 10% increase in density increases stiffness and strength by approximately 10%.

A study by Tsehaye *et al*. (1995) somewhat disproved this idea, finding that selection on the basis of stiffness and not density alone has the potential for much greater increases in wood quality. The conclusions from this study were:

1. The general trend of increasing density from the pith to the cambium correlates with the changes in stiffness and tensile strength.
2. There was a significant difference in the mean density between the butt log and the middle log and the butt log and top log.
3. There was a decrease in tensile strength from the butt log to the middle log to the top log, but no significant change in the stiffness up the stem.
4. Ranking of trees according to density showed that density did not give a good prediction of machine stress grading. This conclusion was not unexpected, in that the grading criterion is for stiffness.

5. Ranking of trees according to stiffness gave a higher output grade. If machine stress grading is to be used (as in structural engineering), then trees should be bred for stiffness and not density.

However, density is still viewed by many as the best single index of intrinsic wood quality and hence there have been many studies examining determination of density by new methods such as x-ray densitometry (Polge, 1963; Parker and Meliskie, 1970; Echols, 1970), computer tomography (Cormack, 1963), microwaves (Peyskens, 1984) and computer modelling simulations (Hounsfield, 1973). These represent significant advances from the 'classical' oven dried weight method that gives unequivocal answers but involves destructive testing.

The success of UK home grown Sitka spruce for use in the construction industry depends on many factors relating to the timber properties.

i. The timber must have the necessary strength to meet the current BSEN standards.
ii. The quality of the final product must be well prepared and free from any degrade.
iii. The timber must also be kiln dried to the specifications laid out within BSEN standards and comply with moisture content and stress grading standards.
iv. It must be available at a price competitive on the open market.

How is batten performance measured?

Stress grading assesses strength and the existing method used to assess strength is through modules of elasticity (MoE) or stiffness of a batten at its weakest point. The stiffness of wood can be affected by growth characteristics that can be influenced by forest management. The grower's objective is to grow timber that maximizes yields of the correct quality for the markets that are available. These markets tend to be the construction industry, which demands a better quality of batten covering a multitude of uses. Plates 9 and 10 give a indication as to the type of machine used to assess batten performance.

Paper 2

Methods and Materials

& Results

Methodology

Hypothesis

Leaving windblow Sitka spruce for increasing lengths of time, changes the properties of the wood resulting in the reduction of batten performance.

Aim

To examine batten performance through stress and visual grading and density measurements and investigate a possible link with the length of time a tree has been blown over. To sample forty-five trees over three different known ages of windblow on three different sites with similar stand characteristics and growing patterns. This project suggests a method for assessing the time scale for optimizing the felling of windblow Sitka spruce to maximize the green log out turn before degradation.

Materials & Methods

Stand/sample selection

Three stands of approximately the same initial plant spacing and age were selected to represent those typically found in a windblow forest situation. Each stand was selected to represent a distinct age of blow, essentially based upon local knowledge and past data from weather forecasts.

The three stands from which sample trees were taken were as follows:

1. Tay Forest District, Kindrogan forest block compartment 5705, 1.7 × 2.0m spacing This stand was chosen to represent windblow at 6 months old. This stand will be defined as '**Tay**'.
2. Kielder Forest District, Kershope forest, compartment 5132, 1.5 × 2.0m spacing. This stand was chosen to represent windblow at 18 months old. This stand will be defined as '**Kielder**'.
3. Inverness Forest District, Garbat forest block, near Garve. Compartment 2098, 1.8 × 2.0m spacing. This stand was chosen to represent windblow at 36 months old. This stand will be defined as '**Inverness**'

The maps below give an indication of the stand location.

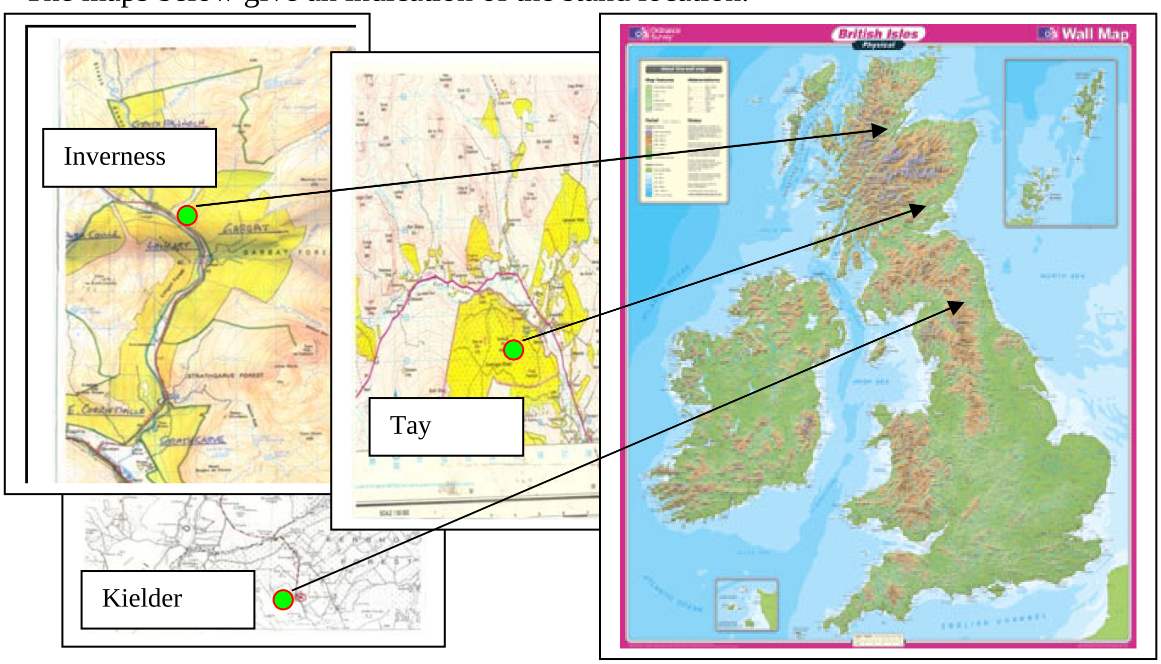


Table 2 Ages of Windblow

	Approx. Date Blown	Date Sampled	Approx. Age of Blow
Tay	Dec-00	Jun-01	6 months
Kielder	Dec-99	Jun-01	18 months
Inverness	Jul-98	Jun-01	36 months

Table 2 gives brief details of when the actual areas were blown down. Tay and Kielder were the result of storms, where as Inverness was the result of a harvesting operation and weakening of the edge anchor trees.

Measurement of stand parameters

To establish the criteria for selecting the trees to be felled for the investigation of wood properties, mensuration data were collected from all three stands. The mean dbh of the stand was obtained by randomly placing five 0.01ha circular sample plots (5.6m radius) in the remaining standing crop, following the procedure laid out by (Hamilton, 1975) for areas less than 1ha. All plots were marked on the survey map before entering the forest. Some of the plots had to be moved on the ground, slightly off the original location due to the severity of the windblow and the dangerous working conditions that were on site. Edge trees were not included in either plots or as individual sample trees as these exhibit abnormal features, such as asymmetric crowns leading to compression wood (Brazier, 1977). The selection from which sample trees were taken was completely randomised by locating the closest DBH to the mean of each sample stand. Standing, leaning, and blown trees with a dbh equal to the mean dbh (rounded to the nearest cm) were selected. These trees were then numbered according to their classification of standing, leaning, and blown. Five trees were selected from each category.

The Tay forest block was located at the end of a forest track with an area of approximately 3 hectares of windblow. This site was recorded as blown on boxing day of 2000. The site was shallow ploughed and planted in 1965. Kielder a typical upland Sitka spruce site with peat soil and recorded as blown over 18 months prior to felling. The site was located close to a minor road where neighboring plantations had also suffered the effects of windblow. The Inverness site was located close to the Highland village of Garve. The site is adjacent to a clearfell, on a gradual slope consisting of mainly peat soil. The stand was recorded to have blown down 36 months before the research work started. Table 3 shows the background information for each of the three sites.

Numbering the trees was kept as simple as possible. Each category of trees were numbered using the prefix of their locations and a numerical value from 1-5.

e.g. Standing = S, Leaning = L, Blown = B. Tree Number 1-5 (Appendix 3).

Having assigned a number to each selected tree in the stand, a North line and direction of fall or lean was marked on each stem using marking paint.

Selection of sample trees

The smallest (non-suppressed) and largest dbh measurements taken in each stand were converted to equivalent basal areas. The range of basal areas was then divided into 3 equal-sized classes; the resulting basal area classes were then converted back to dbh ranges. 15 sample trees were selected per site - 5 from each class (standing, leaning, blown). It should be noted that the sample trees are representative of all of the (non-suppressed) trees in the sampled areas of each stand. The sampled trees included both final crop trees and stems, which may be removed prior to final felling. This should be borne in mind when interpreting the results of the investigation.

Prior to felling the dbh was measured to the nearest 0.1cm. The "stem straightness" of all sample trees was measured according to the FC Mensuration branch method (Macdonald *et al.* 2001). This method involves assigning a 'straightness' score to the lowest 6m of the standing stem (butt length). The scoring system is outlined in Table 5.

Table 3 Topographical data.

Location	Grid Ref	Elevation (m)	DAMS	Soil	Lithology	Annual Precipitation[+]
Tay	NN055625	292	14.49	Peat	Quartz, mica schist Dalradian	947.8mm[1]
Kielder	NY509811	170	13.42	Peat	Carboniferous Limestone	749.3mm[1]
Inverness	NH415673	181	11.41	Peat	Quartz-feldspar Moine	420.0mm[1]

[1]Source of information from individual forest districts.
[+] 30 year average date 1970-2001.

Sampling strategy

There were a total of 45 trees selected for the experiment.

- 15 trees from each age of windblow area which consisted of 5 trees standing, 5 trees leaning, and 5 trees blown (definition in appendix 3).
- A simple tariff plot was used to calculate the mean diameters and top heights of the crop (taken from Forest mensuration handbook).
- After the characterisation of the standing crop by their diameter class and size and the mechanical characterisation, the sample trees were selected at random using the trees closest to the upper, mean, and lower quartiles of the dbh range.
- Before the trees were felled dbh, tree height, straightness score, spacing, angle of lean, slope angle and orientation (azimuth) were recorded.

The data recorded included:

- Top height of the stand using the standard method (as laid out in the FC field book 2- Thinning Control). Height of the tree of largest dbh in each plot - Measured to the nearest 0.5m using a Vertex Hypsometer. Estimate top height (h^{dom}) for each stand.
- The compass bearing of each tree, measured using a suunto compass (degrees^{0}), in relation to the felling direction or the leaning /blown direction.
- Tree height measured to the nearest 0.5m using a Vertex Hypsometer and then measured by tape on the ground once felled.
- Planting year was recorded for each stand.
- Diameter @ breast height (dbh) / to the nearest 0.1cm - measured on all of the trees in each plot.
- The straightness score for each tree was assessed. (Macdonald *et al. 2001*)
- The distance between the centers of 6 trees grown in a row and between row was measured. Any point with evidence of a tree was counted, i.e., live trees, dead trees and stumps. Gaps were ignored. Dividing this figure by 5 gave the mean "establishment spacing" per plot that was used to calculate initial stocking density.
- Pilodyne density was measured at 1.3m above ground level on the stem.
- Root plate angle at the base of the root plate using a clinometer to determine if the tree was classified as leaning or blown.

- Angle of slope for each individual tree again using the clinometer.
- Tree fell angle in relation to North was recorded.
- Angle of lean for trees other than the standing/control trees.
- Diameter at 1m intervals (North/South and East/West)
- Zoning of compression wood in logs before stems are cut.
- Log size was recorded for each log cut on each stem to enable me to piece together each batten with each log.
- Number of logs from each tree.
- The logs were then transported to Gordon’s sawmill at Carrbridge for preparation for further work.

A summary of the crop characteristics for each stand/spacing treatment is given in Table 4.

Table 4 - Some Crop Characteristics of the stands utilized in the investigation.

Forest District **Initial Spacing** **Planting year**	**Tay FD** **2.1 × 2.3 m** **P65**	**Kielder FD** **1.9 × 1.9 m** **P67**	**Inverness FD** **2.0 × 1.9 m** **P68**
Top Height (h^{dom}) (m)	27.0	23.3	23.7
Timber Height (m)	11.70	10.05	10.23
Basal Area - (m^2) ha^{-1}	160.42	135.73	226.26
Volume (m^3) ha^{-1}	366.4	347.2	441.7
Sitka Spruce Stems per (ha)	2070	2770	2631
General Yield Class (m^3 ha^{-1} yr^{-1})	24	22	22
Mean Tree Volume (m^3) OB	1.01	0.50	0.79
Mean dbh (cm)	33	25	31.5

Yield Class estimated by comparing h^{dom} and age at felling in years against Curves given in FC Booklet 48 Vol.1 (1973).

Tree Characterisation

Each selected sample tree was characterised by

- The external dimension and shape of each tree stem: dbh, tree height, timber height, stem taper, stem straightness.
- The position of the tree in relation to the surrounding trees taken as a distance and a bearing.
- The ability to actually remove the trees without endangering members of the experiment team.

Dbh is defined as stem diameter at 1.3m stem height, measured in two perpendicular directions,

Tree height is defined as total length of the stem.

Timber height is defined as stem height with 7cm radius over bark.

Stem taper is defined as reduction of diameter in centimeter per meter stem length.

Stem straightness: the butt 6m stem length has been assessed using a scoring system 1-7 classifying the length and the number of straight logs according to the following system developed by(Macdonald *et al* 2001), which is illustrated in Table 5.

Table 5. Straightness score index

	No. of straight logs counted in butt 6m			
SCORE	**≥ 5 m**	**≥ 4 m < 5 m**	**≥ 3 m < 4 m**	**≥ 2 m < 3 m**
1	-	-	-	-
2	-	-	-	1
3	-	-	-	2
4	-	-	1	-
5	-	-	1	1
6	-	1	-	-
7	1	-	-	-

A detailed system of recording each log from each location was introduced to enable easy identification. The photographs shown in Plates 3-7 show some of the work that was undertaken to gather the information necessary to complete the project.

Plate 3

Plate 3 shows the numbering system used to keep track of where each log was originally cut from.

I:S:3:1 indicates that this log is from Inverness, was a standing tree and is the third tree from five. The last number indicates that this is the first log.

Plate 4

The extraction of the felled timber after tree and stem characterisation was completed proved difficult at times. Due to the time element of this project forwarders were contracted in to extract all material from the site. In some cases a chainsaw winch was used to assist in the extraction process.

Plate 5

Plate 5 gives a clear insight to the marking system that was used for recording the location of compression wood on each log. The coloured quarters are marked on each of the butt ends of the logs in the same direction relating to the direction of lean or blow. In the case of standing trees the logs were marked in the direction they were felled.

Plate 6

Plate 6 illustrates the size of discs that were removed for further analysis. The discs were taken from the base of each log. Each disc was recorded using the same code used for the logs. These discs were later scanned into a computer to study the area of compression wood with each disc.

Plate 7

Plate 7 illustrates the marking system at ground level. The plate gives an example of the way the logs were marked. A paint line can be seen up the stem of the logs to indicated the direction of lean or blow for each specific tree. The log ends are clearly marked allowing for easy assessment of the way in which the trees need to be cut at the sawmill.

Sawlog and Discs

Sawlogs and stem discs were sampled in a way to allow both an analysis of the internal structure for the entire tree and an analysis of sawn timber in construction dimensions. The sampling strategy is illustrated in Figure 1.

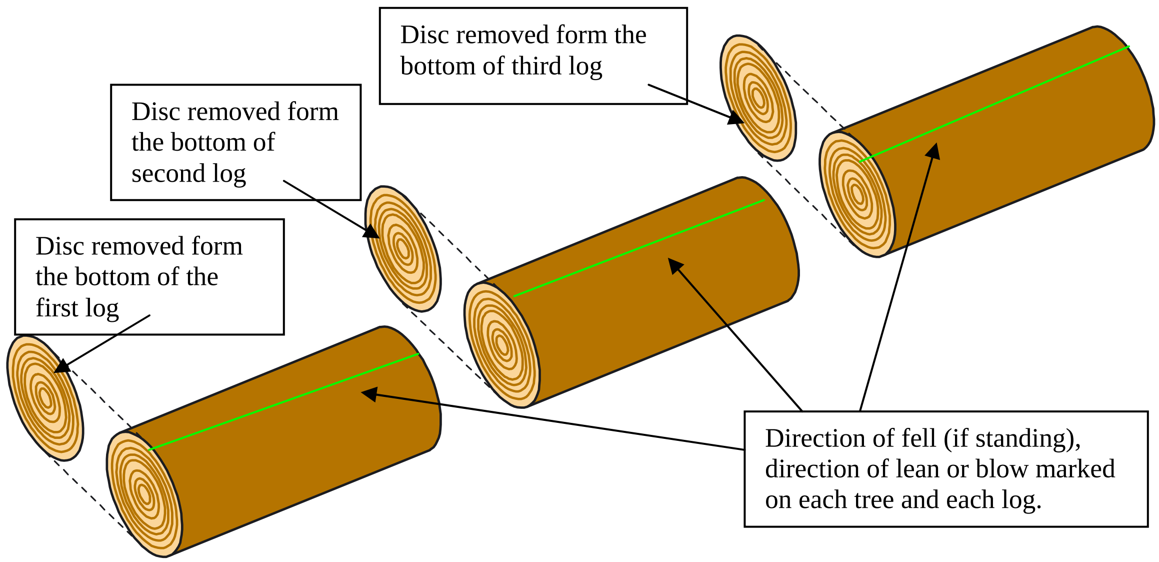


Figure 1: Sample pattern of sawlogs and stem discs.

The logs were selected to represent the maximum sawlog outturn, from each of the trees from a commercial perspective.

Log / Batten

The logs taken from each tree were cut longitudinally, parallel to the pith, into battens with a nominal thickness of ≈ 47mm (see Plate 8). The battens from each site were stacked with the ends overlapping in an outside storage area, before going into the kiln. The battens were restacked top to bottom during drying to equalize any differences in rate of drying within the stack. The moisture content of each slab was measured at the time of stress grading, using an electrical resistance moisture meter. The average moisture content of the battens was 14% (dry-basis) after kiln drying.

Plate 8 The final battens illustrating the markings which allow identification of their origin.

After the cutting process was complete the painted ends of each batten were still visible as shown in Plate 8. This allowed for further investigations into which battens were recorded as having been in tension or compression before harvesting and from which side of the log they came. The batten ends were recorded has having two colours of paint on the ends. This clearly showed which location of the log was under compression and tension wood. The direction of fell or lean and blown was always between the yellow on the left and the orange on the right. Table 6 below shows how these figures were recorded relating to each batten and location.

Table 6 Log and batten recordings

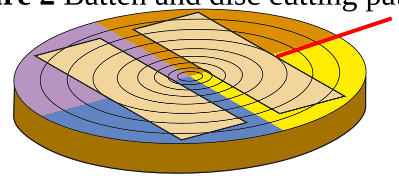
BATTEN NO.	COLOUR CODE	SITE	STANDING/ LEANING/ BLOWN	TREE NUMBER	LOG NUMBER
69	OY	**K**	**B**	**1**	**1**
70	OYBC	**K**	**B**	**1**	**1**
72	BC	**K**	**B**	**1**	**1**
83	CB	**K**	**B**	**1**	**1**
354	Y	**K**	**B**	**1**	**2**
358	OBY	**K**	**B**	**1**	**2**
362	BCO	**K**	**B**	**1**	**2**

Orange and yellow were the top left and right quadrants of each log. These were recorded as OY. There were four colours as shown in appendix 3, orange, yellow, blue and cerise; each indicating which part of the log was recorded to have compression wood.

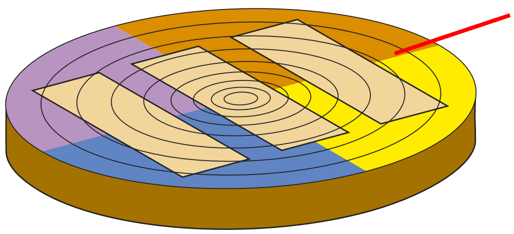
End product

The final product cut were battens of construction timber in four dimensions : 100×47, 150×47, 200×47, and 225×47mm. The cutting scheme for the different log dimensions is shown in Figure 2. The cutting model took into account the orientation of the north mark to investigate the position of the batten in the cross section of the stem.

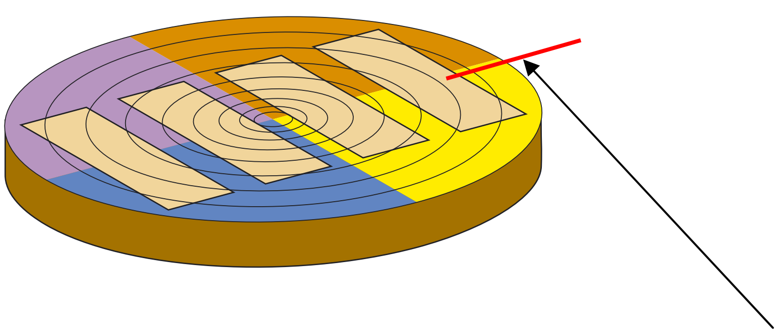
Figure 2 Batten and disc cutting patterns.



A log diameter with 150mm top diameter underbark (TD UB) produced a minimum of two suitable construction battens. These battens were cut as illustrated depending on their size.



The battens were all cut with the direction of lean or fell vertical to the saw bench in other words with the orange and yellow quadrants of the log located to the top of the log. Up to 200mm diameter logs produced a minimum of three construction grade battens.



The direction of lean or felling for each tree was clearly marked on all of the logs before harvesting. The larger diameter logs with 300mm or more TD UB produced a minimum of four battens.

Kiln Drying

The battens were dried in a conventional high temperature kiln. The drying schedule is given in Table 7.

The battens were stacked using spacers to allow the air to move more freely between each bundle. This allowed the battens to dry without any constraints allowing maximum distortion. The drying process was completed within four days.

Table 7: Drying schedule for kiln drying test battens.

Phases	Heat Up	Drying	Conditioning	Cooling	Total
Variables	1	2	3	-	
T Dry Bulb (^{0}C)	20-55	60	65	65-20	
T Wet Bulb (^{0}C)	20-54	55	64	64-20	
RH (%)	97	77	98		
EMC (%)	21	13	21		
M/C Initial (%)	c 110				
M/C Final (%)				15	
Time (Hours)	22	96	12	12	142

Plate 9

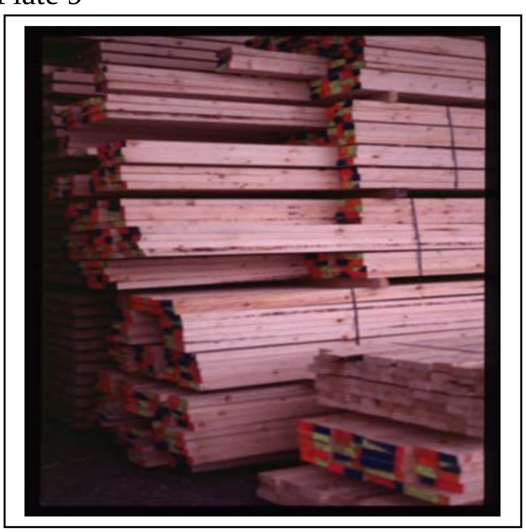


Plate 10

Plates 9 and 10 show the battens drying in the kiln at Gordon's sawmill in Nairn.

Machine stress grading

The mechanical behavior of the battens was tested under normal commercial conditions using a stress-grading machine at Gordon's sawmill, Nairn. The battens were bent by 3-point bending to 5.4mm deflection and the required force was recorded in 100mm intervals. Testing speed was 60m/min. Each batten was tested twice to C16 and C24. The average deflection of both measurements was used to calculate the MOE automatically. Both C16 and C24 grades were recorded separately in order to analyse which battens were suitable for C24 construction timber. The minimum MOE was derived over the length of the batten and used for the strength classification. Plates 11 and 12 show the stress-grading machine at the sawmill.

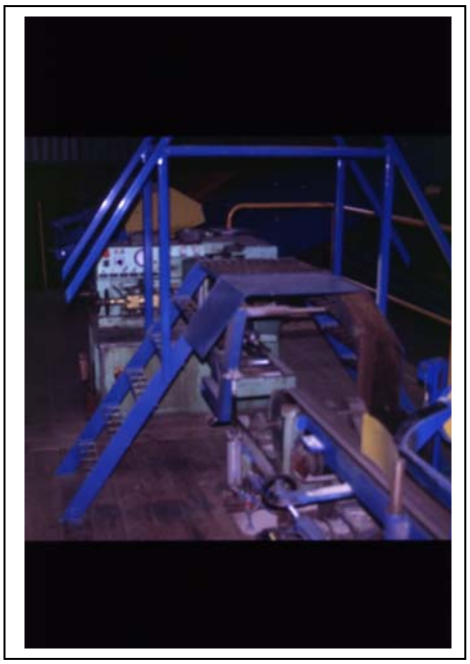


Plate 11 Machine stress grader

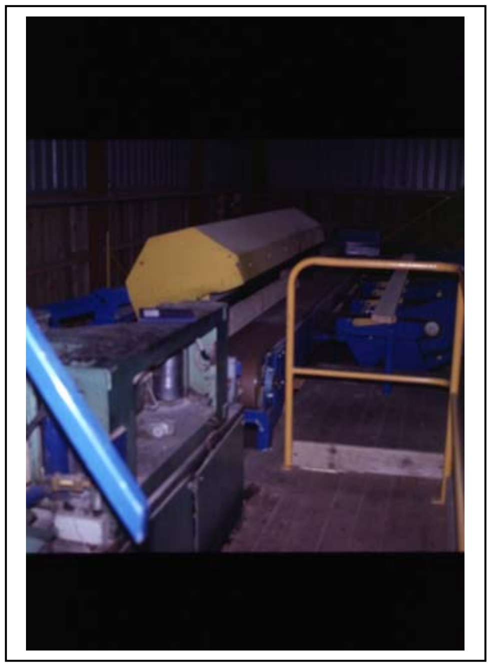


Plate 12 Machine stress grader

Compression Wood Analysis

To fully understand how batten performance was related to the levels of compression wood, a small study was taken to look at the percentage of compression wood within each log by analysing discs cut from the bottom of each log. These cut discs were planned and scanned using an A3 scanner and the percentage of compression wood was measured by colour analysis using Optimus™ software. Figure 3 gives a clear indication of compression wood within a cut disc.

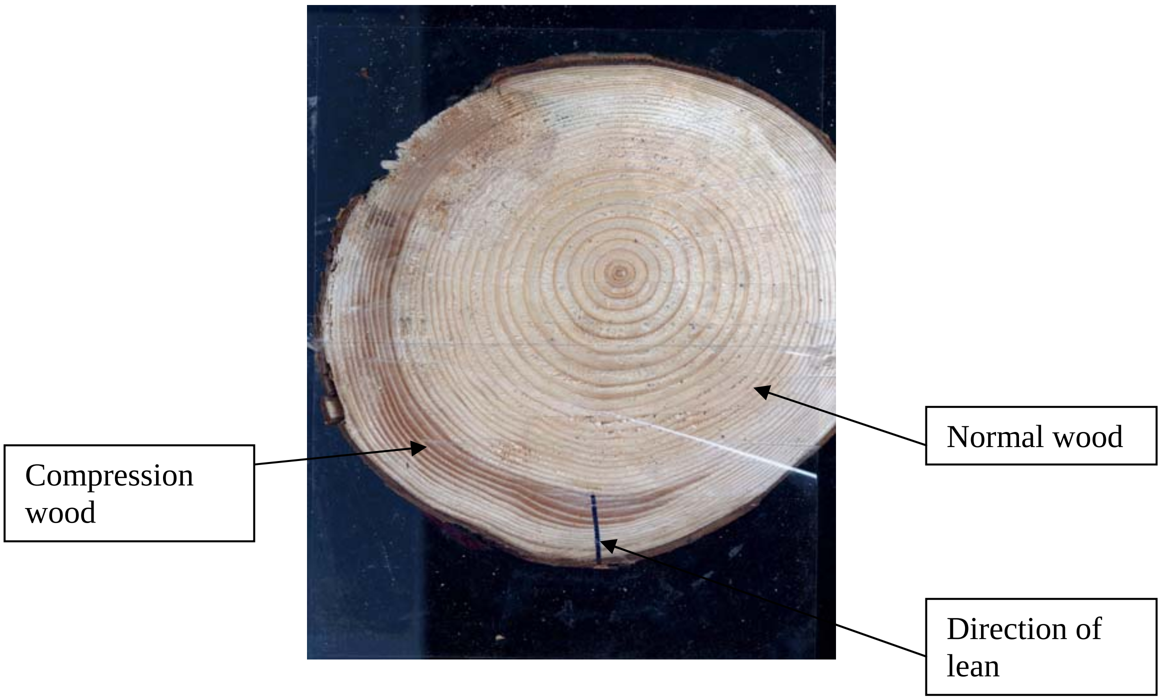


Figure 3 - Close-up of log end disc

The darker wood signifies compression wood where the tree has been bent or stressed to such a degree that compression wood has formed. The direction of lean is also indicated showing that the majority of the stressed area in this sample was to the left of the direction of lean. The discs taken from the logs were used to measure the percentage of compression wood. The figure also shows that most of the compression wood formed before windblow.

Analysis of the Compression Wood content of discs using Optimas^{TM} 6.5

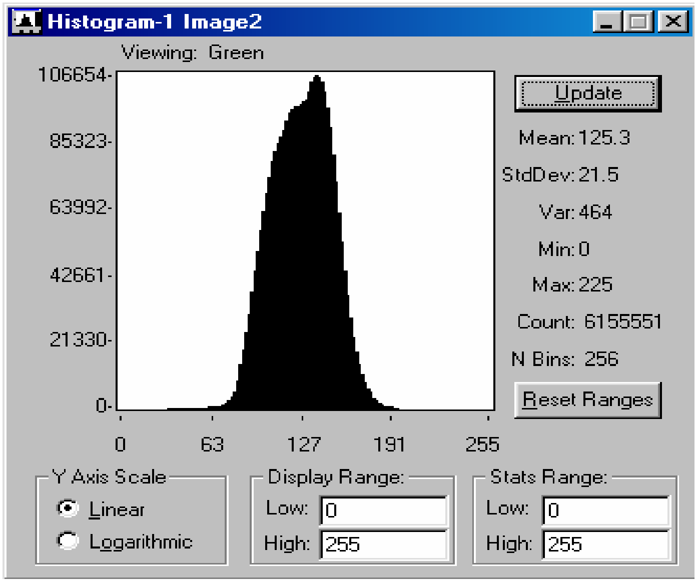
Optimas 6.5 is image analysis software. Colour is used to differentiate between two or more classes that are defined by the user. The discs are first scanned and saved as 'tif' images so that they are in a usable format and contain sufficient detail to facilitate accurate analysis.

Once the image was opened in Optimas, the first step was to define a 'Region of Interest' (ROI). This is a manually defined area that selects the area on which the analysis is to be performed. The area selected includes all the wood of the disc but excludes the bark. The colour of the disc is represented by the intensity of three colour bands, red, blue and green.

After investigation and review of previous research it was decided to use only the green colour band to view the image and analyse the disc as this gave the most accurate separation between normal wood and compression wood.

To analyse any image using the Green colour band, thresholds were decided upon. Thresholds define sets of information, for example normal and compression wood, based on a set of light intensities. These thresholds can be defined by the user for each image or they can be defined as a set of intensities from the colour histogram of the image. See Figure 4 below. When viewed only in the green colour band the image appears as a black and white image each pixel represented as a grey scale from 0-255 depending on the intensity of the green part of the image at that point. Predefined thresholds were decided on, to provide an objective separation between normal wood (101-255) and compression wood (0-100).

Figure 4 – Histogram for an image in Optimas



X-axis – light intensity scale
Y-axis – No. of pixels found for each grey value in the range

User defined thresholds were not suitable for this analysis as it was too subjective. Discs vary greatly in colour so that in a light coloured disc the user may define wood as compression wood which in a darker image would be classified as normal wood.

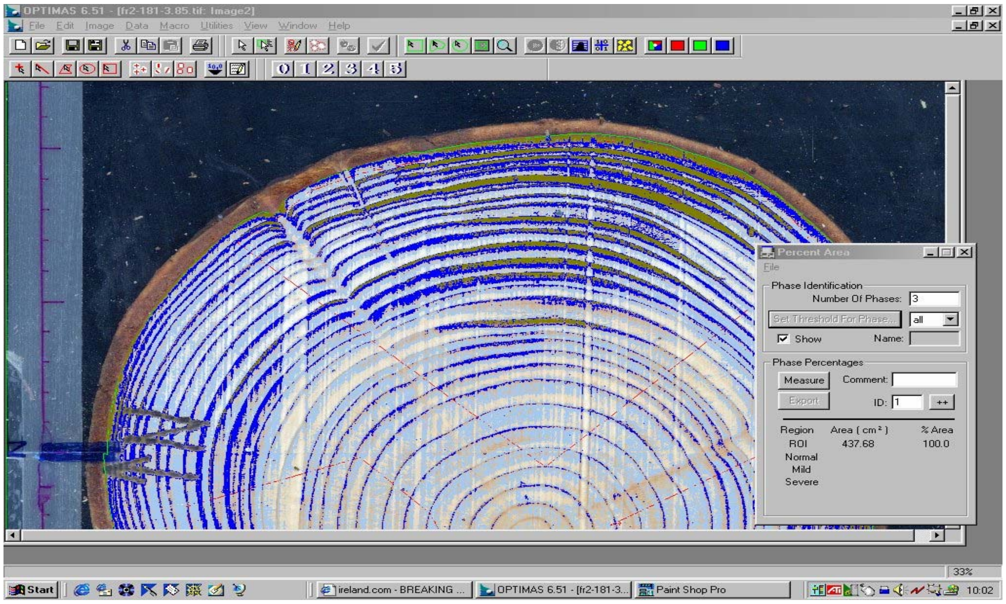
The thresholds used for this analysis were:

- Normal wood – 101-255
- Compression wood – 0-100

These values are from the x-axis of the histogram. The thresholds were tested by examining thin slices.

When these thresholds are applied to an image the percentage area of the ROI that each class accounts for can be calculated through Optimas and exported to an Excel file. Compression wood falls into the lower part of the histogram as it is darker in colour and absorbs more light. It is necessary to set a strict upper limit for compression wood as if the upper limit is set too high, latewood will show as compression wood. The blue areas of the image in Figure 5 show the areas of compression wood.

Figure 5 – Optimus™ digital image of a disc showing compression wood**.**



Compression wood disc analysis

A 20% stratified, random sub-sample of planed discs from each site was analysed using the Optimus™ software, shown in Figure 5 to determine the percentage of compression wood from each disc. A sample of the data from Inverness is shown in Figure 6.

Figure 6 Excel data for compression wood.

Standing Inverness % area	**Leaning Inverness % area**	**Blown Inverness % area**
1.27	2.56	1.07
4.04	4.26	1.53
0.79	1.07	1.08
0.36	2.05	1.56
0.64	6.23	1.62
0.53	2.45	5.99
0.27	4.04	4.4
1.22	1.92	2.13
0.52	6.31	1.98
2.41	2.97	3.59
1.39	3.08	1.95
1.22		2.45

The variation in the percentage area of compression wood between all the sites fluctuated. This may be accounted for by the time factor the trees were left on the ground. The majority of the control trees appear to have a generally low percentage area compared to the leaning and blown trees. The figures in red at the bottom of the table are the mean percentages for each of the site types.

Results

Analysis of C16 and C24 batten pass rates in windblown timber

The purpose of this analysis was to relate the C16 and C24 pass rate, per tree, to the site and tree type information

The significance of the effects of site, tree type and a site by tree type interaction were assessed using a linear logistic model. In this model the pass rate (P) for each tree is transformed to log (P/(1-P)), terms were added and their significance quantified by an analysis of deviance (which compares the increase in information for a term to that which would have arisen by chance). A binomial distribution is a very discrete statistical probability distribution to give a total random variable.

For example : Take n=8 logs and do a C16 grade test. Assume the outcome for each log is independent and that Probability (pass)=p and Probability (fail)=1-p. Then Y ~ Binomial (8,p). Notice here we write p because we do not have a prior value and we estimate it from the data.

From the main area of the results, batten performance was the main objective for investigation.. The results from the batten performance gave a good indication to the quality of wood from the three ages of windblow.

Batten Performance

The batten performance was analysed as a function of the variables using binomial modelling. Observations made from Figures 7 and 8 would suggest that there is a decrease in the number of battens passing with age of windblow.

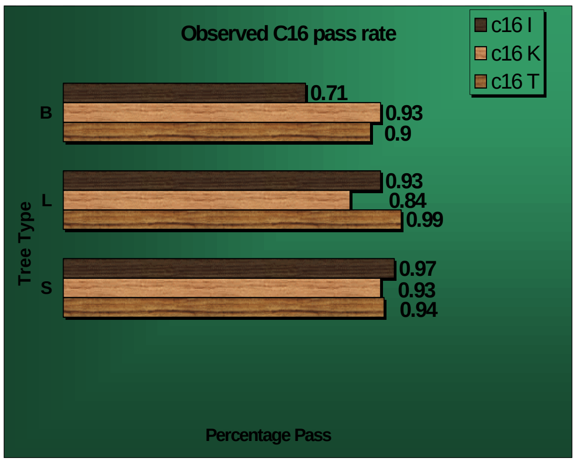


Figure 7 Observed C16 pass rates

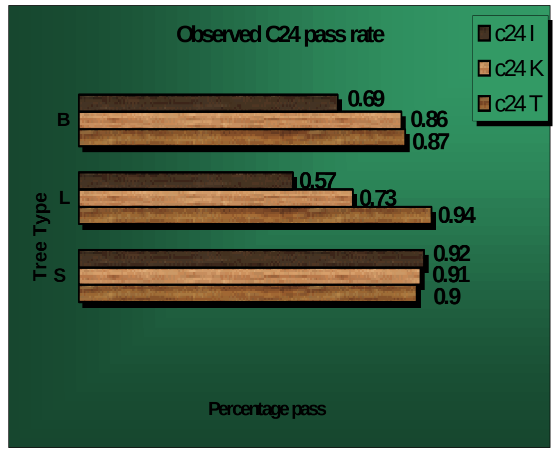


Figure 8 Observed C24 pass rates

The evidence presented here shows that the batten performance taken from windblown trees, and compared with leaning and standing trees, gives initial evidence that battens are weakened by a combination of compression wood and lower density.

The data for each tree are listed in Table 8. From the 45 trees a total of 438 battens (between 3 and 18 battens per tree) were selected. The average C16 and C24 pass rates were 89% (390/438) and 84% (367/438), respectively. Both C16 and C24 pass rates per tree varied from 29% to 100% (with 20 trees at 100% for C16 and 14 such trees for C24). The observed pass rates for C16 and C24 are given in Table 9 and 10, respectively. The notable feature of Tables 9 and 10 is the lower C16 pass rate for leaning and blown trees (type L or B) at Inverness (site I). For C24 the pass rate is lower for leaning and blown trees at both Kielder and Inverness.

The analyses of deviance for C16 and C24 are given in Table 11. The deviance for both the C16 and C24 interaction models significantly exceeded their degrees of freedom, whereas for binomial data they should be equivalent. For example, the C16 interaction model was 55.06 on 36 d.f. (whereas the probability of a chi-squared random variable with 36 d.f. exceeding 51.00 is 0.05 and of it exceeding 54.44 is just 0.025). Such data are termed “overdispersed”. The procedure of Williams (1982) was used to account for this overdispersion, as outlined in Collett (1990). From the Williams procedure deviance’s in Table 11 there is, for C16, a significant site x type (type = standing, leaning or blown) interaction. For C24 there were significant site and type effects but no site x type interaction; the change in deviance when adding site x type is 6.11 (47.67-41.56) on 4 d.f. (40-36) and this is not significant at 5% (the 5% point of a chi-squared random variable with 4 d.f. is 9.488).

The fitted models for C16 and C24 contain terms, e.g. constant, site, type and site x type interaction, each of which have associated coefficients. The predicted pass rates for C16 and C24 Tables 12 and 13 are derived from the coefficients. Consider Table 12 and the predicted C16 pass rate for type S (standing trees) at site T (Tay). The addition of the coefficients in the C16 model, i.e., for the constant, type S, site T and for the interaction between type S and site T, gives a predicted value of log(P/1-P)) (here 2.75). This predicted value is back-transformed (exponentiated) to give a predicted value of P (here – P=exp(2.75)/(1+exp(2.75))=15.67/16.67=0.94. The standard error is derived in a similar manner.

The predicted C16 pass rates, with associated standard errors, are given in Table 12. The predicted C24 pass rates and standard errors for type are given in Table 13 and for site in Table 14. In Table 12 the C16 pass rate is generally predicted at or above 85% (except, as noted before, for the leaning and blown trees in Inverness). In Table 13 the C24 pass rate is markedly different between types standing (S) and leaning (L) and in Table 14 the largest site difference is between Tay (T) and Inverness (I). The predicted C24 pass rate falls below 80% for leaning tree type and for the Inverness site.

Table 8 Data listing

idx	site	tree	tree type	C16 pass	C16 fail	C16 total	C16 pass rate	C24 pass	C24 fail	C24 total	C24 pass rate
1	T	1	S	12	2	14	0.86	11	3	14	0.79
2	T	2	S	17	0	17	1.00	16	1	17	0.94
3	T	3	S	12	1	13	0.92	12	1	13	0.92
4	T	4	S	13	0	13	1.00	12	1	13	0.92
5	T	5	S	11	1	12	0.92	11	1	12	0.92
6	T	6	L	16	0	16	1.00	16	0	16	1.00
7	T	7	L	16	0	16	1.00	15	1	16	0.94
8	T	8	L	7	0	7	1.00	7	0	7	1.00
9	T	9	L	17	0	17	1.00	15	2	17	0.88
10	T	10	L	17	1	18	0.94	16	2	18	0.89
11	T	11	B	13	0	13	1.00	11	2	13	0.85
12	T	12	B	15	1	16	0.94	15	1	16	0.94
13	T	13	B	11	0	11	1.00	11	0	11	1.00
14	T	14	B	9	0	9	1.00	9	0	9	1.00
15	T	15	B	5	4	9	0.56	5	4	9	0.56
16	K	1	S	8	1	9	0.89	7	2	9	0.78
17	K	2	S	8	0	8	1.00	8	0	8	1.00
18	K	3	S	7	1	8	0.88	7	1	8	0.88
19	K	4	S	7	1	8	0.88	7	1	8	0.88
20	K	5	S	5	0	5	1.00	5	0	5	1.00
21	K	6	L	6	3	9	0.67	4	5	9	0.44
22	K	7	L	2	1	3	0.67	1	2	3	0.33
23	K	8	L	6	1	7	0.86	6	1	7	0.86
24	K	9	L	8	0	8	1.00	8	0	8	1.00
25	K	10	L	7	0	7	1.00	7	0	7	1.00
26	K	11	B	9	1	10	0.90	8	2	10	0.80
27	K	12	B	8	1	9	0.89	7	2	9	0.78
28	K	13	B	6	1	7	0.86	5	2	7	0.71
29	K	14	B	9	0	9	1.00	9	0	9	1.00
30	K	15	B	10	0	10	1.00	10	0	10	1.00
31	I	1	S	12	0	12	1.00	9	3	12	0.75
32	I	2	S	6	0	6	1.00	6	0	6	1.00
33	I	3	S	6	1	7	0.86	6	1	7	0.86
34	I	4	S	11	0	11	1.00	11	0	11	1.00
35	I	5	S	6	0	6	1.00	6	0	6	1.00
36	I	6	L	9	1	10	0.90	6	4	10	0.60
37	I	7	L	5	3	8	0.63	5	3	8	0.63
38	I	8	L	6	6	12	0.50	6	6	12	0.50
39	I	9	L	5	3	8	0.63	5	3	8	0.63
40	I	10	L	3	3	6	0.50	3	3	6	0.50
41	I	11	B	5	2	7	0.71	5	2	7	0.71
42	I	12	B	4	2	6	0.67	4	2	6	0.67
43	I	13	B	2	5	7	0.29	2	5	7	0.29
44	I	14	B	5	0	5	1.00	5	0	5	1.00
45	I	15	B	8	1	9	0.89	7	2	9	0.78

Table 9 Observed C16 pass rate

site type	T	K	I	Mean
S	0.94	0.93	0.97	0.95
L	0.99	0.84	0.63	0.82
B	0.90	0.93	0.71	0.85
Mean	0.94	0.90	0.77	0.87

Table 10 Observed C24 pass rate

site type	T	K	I	Mean
S	0.90	0.91	0.92	0.91
L	0.94	0.73	0.57	0.75
B	0.87	0.86	0.69	0.81
Mean	0.90	0.83	0.73	0.82

Table 11 Deviance table for C16 and C24 analyses (including Williams procedure)

			Williams	procedure	
	C16	C24	C16	C24	
Term fitted in the model	Deviance	Deviance	Deviance	Deviance	DF
Constant	102.89	97.50	68.57	64.99	44
Constant + Site	80.51	78.62	54.55	53.77	42
Constant + Type	94.74	90.22	62.23	59.09	42
Constant + Site + Type	71.72	70.88	47.89	47.67	40
Constant + Site + Type + Site x Type	55.06	61.35	37.40	41.56	36

Table 12 Predicted C16 pass rate (with standard error) for type x site

site type	T		K		I	
S	0.94	*0.038*	0.92	*0.051*	0.97	*0.030*
L	0.99	*0.018*	0.85	*0.071*	0.64	*0.088*
B	0.91	*0.049*	0.93	*0.045*	0.71	*0.091*

Table 13 Predicted C24 pass rate (with standard error) for type

type		
S	0.90	*0.030*
L	0.78	*0.042*
B	0.81	*0.040*

Table 14 Predicted C24 pass rate (with standard error) for site

site		
T	0.90	*0.028*
K	0.84	*0.040*
I	0.72	*0.049*

Compression Wood

The analysis of the presence and proportion of compression wood focussed on material taken from end log discs from the different exposure situations on all three sites.

The variation of mean compression wood ratio on the disc surface is illustrated in Figure 9. The means varied between 0.88% and 3.07% for the different batten positions in the stem with the highest values recorded from the discs from trees exposed more than 36 months. The overall mean of compression wood found windblow of 36 months was significantly higher than the amount of compression wood found at 6 months.

Figure 9- Mean percentage of compression wood as function of time since wind damage.

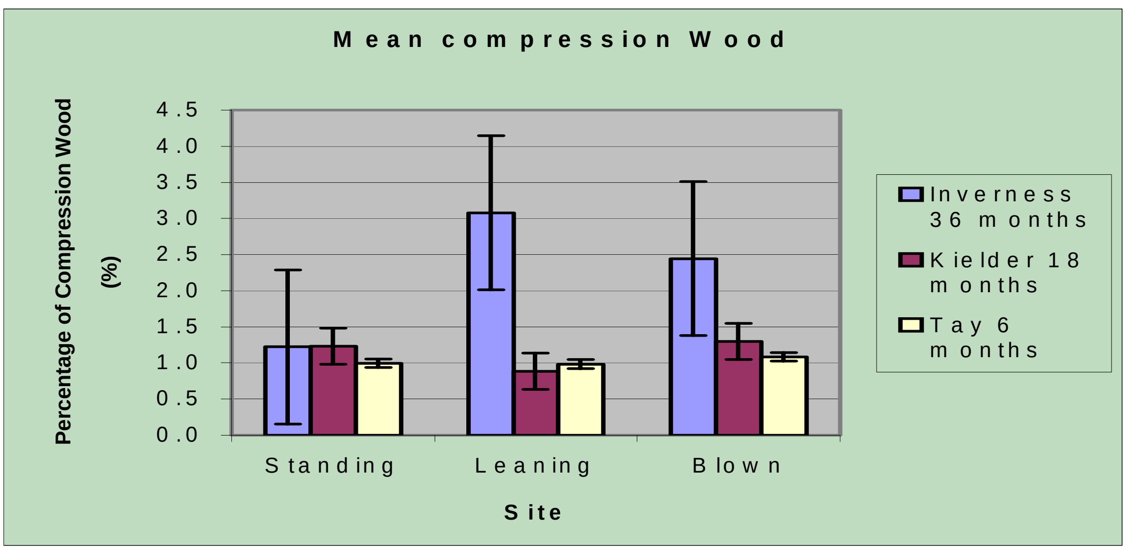


Figure 9 shows the variation within the locations of each age group. The 95% confidence limits show that there is no difference between the percentage of compression wood for the standing trees on the three sites. The blown trees show a greater variation between the mean percentage of compression wood, indicating that with time there is a higher percentage of compression wood or degrade of timber. The leaning stems show a significant variation between the observed means giving us a greater percentage of stems that have a higher percentage of compression wood than both standing and blown. These observed variations are likely to be due to the effects of windblow but could also be influenced by site factors such as spacing, soil and exposure, which have not been taken into consideration.

However, statistical analysis showed a large variation of compression wood proportion within each age group, Figures 10, 11 and 12. Thus the proportion of compression wood from the 36-month stand is not significantly higher than 6 months as one would expect.

Analysis of variance of all battens found the batten position in the log relative to the direction of blown timber. This had a significant effect on the variation of compression wood. Figures 10-12 also suggests that there might be a stronger site factor than age of windblow factor since the site at Inverness (leaning) has the highest percentage of compression wood.

Figure 10 6months

Figure 11 18 months

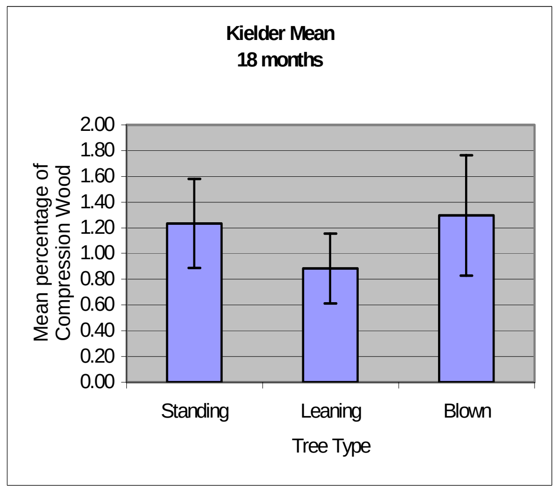
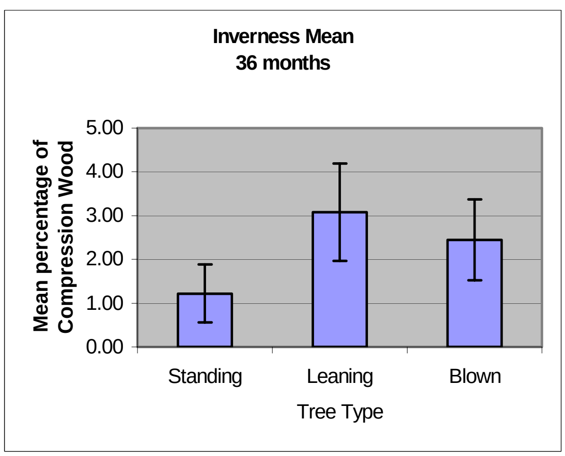


Figure 12 36 months (Error bars represent 95% confidence limits).



The results have given sufficient evidence to suggest that within a timescale of up to 18 months a high proportion of battens cut from windblown trees can be utilised for the construction industry. However, after this time period the message is very clear cut. By 36 months there is a significant reduction in percentage battens passing stress grading at C16 and C24 (Tables 9 and 10).

The blown and leaning battens were no different in relation to the pass rate at 6 months but greater at 18 months. The difference in compression wood taken from samples of the log discs were compared over the three timescales. Figures 10,11, and 12 indicate that there is an increased area of compression wood the longer the trees are left. During the formation of compression wood, the area of compression wood shrinks less than normal wood during maturation and so the stem will tend to bend upwards. For example, compression wood will exhibit much greater longitudinal shrinkage than normal wood and is also less stiff (Desch and Dinwoodie, 1983).

This type of formation has occurred significantly over the 36-month battens that have been subjected to longitudinal shrinkage over a longer period of time.

Grain Angle

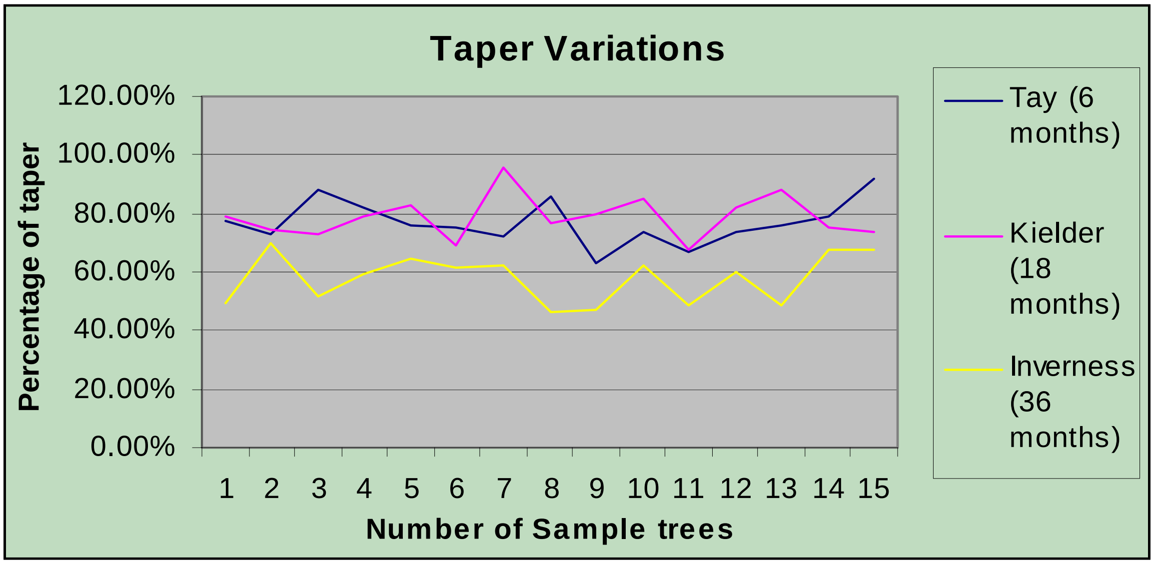
In combination with juvenile wood and compression wood, the grain angle is also known to cause severe distortion in battens by twist during the drying process. As noted in Ormarsson *et al.* (1998), the spiral grain angle is defined as the angle between the pith and the fibre direction in the plane. This angle often shows a radial variation within the timber log, see e.g. Harris (1989). The spiral grain angle is an important parameter that has a considerable influence on drying deformations as twist and bow. Radial variation in the spiral grain angle likewise has an influence on the development of deformation.

Time did not allow for a suitable study to be done on the respective battens in relation to grain angle.

Log Taper

The log taper (the reduction in diameter per unit tree length) varied in a wide range between 46% and 95%. Figure 13 shows the variation of the individual tree mean taper with respect to the three sites.

Figure 13 Taper variations



The standard measure of taper is classed as a percentage of the diameter to height ratio. When the percentage of taper exceeds 80%, this generally indicates that the tree is too thin for good stability for its height. From the data provided, Tay appears to show signs of normal growth with only minor fluctuations in the growth response over the six-month period since it was blown down. However, Kielder has slightly higher percentages, which may indicate that the trees were suppressed or are competing for light due to closely planted stems. Inverness is characteristically showing the signs of response to change over the time period in which the stems where exposed after the initial blow. The stem top will stop growing and the lateral shoots or epicormic growth will take over and form the actual crown therefore decreasing the stem height and increasing the stem girth.

Paper 3

Discussion Paper

Discussion

An ideal study would have compared the three ages of windblow from the same site and then replicated that on other sites. The study alone was difficult enough to try and locate sites that had been recorded as windblown with exact dates. Within Scotland I came across only one forest district that meticulously recorded sites of windblow. However some forest rangers show a willingness to record for their own records what is happening within their own areas. The study could have been more in-depth covering many aspects of windblow such as closer ages of windblow to try and pin point the exact point at which failure rates increase in battens. Cost was another parameter that had to be considered when undertaking the experiment. The limited funding ment that the results of the experiment are only a snapshot of what was available to study. A more detailed validation study may produce more accurate results.

Batten Performance

The sites were not replicated but there were control trees within each age of windblow in the form of the standing trees. Consideration of climate and soil type was taken into account when locating each of the three sites as can be explained in the DAMS and topographical Table 2. However exposure and fertility were not considering factors which may have been an influencing factor through increased compression wood, eccentricity of the pith and increased taper. Wind exposure could increase the stresses on the tree leading to an increased area of compression wood. Wind exposure or mechanical loading by snow can also damage the wood of both the remaining standing trees as well as the blown ones. Delorme and Verhoff (1976) have described cell wall deformations of Norway spruce in living wood caused by mechanical stress when trunks are bent by wind, snow or ice.

This experiment has shown that there appears to be a general trend of degradation within batten performance for Sitka spruce the longer the live trees are left on the ground (Tables 9,10). This trend is indicated by the increase in the number of failures when the battens are passed through a stress grader at C16 (SC3) and C24 (SC4). This suggests a general decline in the strength properties for construction timber.

Compression wood appears to develop under abnormal conditions in which wood fibres are exposed to compressive stresses during the growing period. In conifers, compression wood often develops on the lower side both of leaning and blown stems (Ormarsson S. and Peterson H. 2000). The longer live trees are left blown or leaning the more compression wood that forms. The internal forces created within the stem are released when the battens are cut which leads to bending and twisting. Because of its large microfibril angle and reduced cellulose content, compression wood has much less stiffness and strength along the grain than normal wood. In addition the longitudinal shrinkage is much higher which makes the material distort as it dries, furthermore compression wood suffers from brash fracture which makes it unsuitable for use in construction. However, generally compression wood is stiffer than normal wood, since stress grading measures the force required to bend the batten by a certain amount, compression wood will appear stronger than it really is. The reason for less passing may be the wood has dried out while leaning or bent. The increase in compression wood is possibly a separate but additional problem.

Compression Wood

The distribution of compression wood showed a more heterogeneous orientation in the exposed trees, in particular in the inner log parts. This is probably due to larger stem deflections in all directions at the stand edge. However, all trees showed a relatively high proportion of compression wood in comparison to normal wood at the three sites, indicating that overall, the study sites were very wind exposed.

For the tested material, the presence of compression wood did not alter the performance of the battens in a significant way. The absolute difference in windblown material, which effected the tree growth, was not large enough to cause a general difference in wood properties integrated over the stem. However, the tested material showed generally the features of strong exposure such as the presence of compression wood in almost all battens. To separate out the effects of wind exposure completely, it would be necessary to investigate other material on the same site at different ages.

However, work by Macdonald and Hubert (2002) has suggested that exposed stands that are likely to be unstable should only be considered for ‘fibre type’ (i.e. pulp or panel).

This disagrees with these present findings, suggesting that unstable and windblown timber of suitable grade can be used for the more lucrative market of high-grade sawlog material.

The experiment showed blown or leaning trees left for 36 months will reduce the outturn of battens passing stress grading and therefore useable for construction. The findings found that battens at C16 grade were passing the stress grading tests at c95% for all ages. This suggests that the performance of each age of blown batten is not being affected by the changes in the wood properties. However, a significant drop in batten performance even at C16 after blown and leaning was observed at Inverness. The observed differences in C16 pass rates may be a direct result of the sampling technique. The batten performance at C24 gave a dramatic difference compared to the C16 pass rate. Between 60-70% of all battens tested under C24 passed the stress grading. This significant drop could cost the grower substantially more in lost revenue from timber sales of higher grade timber.

In the present experiment, battens cut from trees that have been leaning or blown for between 6-18 months were found to be suitable for construction use, relating to the performance of stress grading. Although they were found to have a proportion of compression wood, the strength and visual tests did not show that this would have a detrimental effect of their performance.

If this statistical model was run on a completely new stand, the results would be encouragingly high. For example, when working on trees that have been blown down for less than six months and compared to trees that have been blown for more than 36 months the accuracy of the model is high, giving accurate predictions. The above results suggest that this should be the case Figures 9 and 10. It remains to be seen whether the full set of 45 trees is a representative sample of Sitka spruce logs.

Taper

There was a significant difference between the Sitka spruce treatments in log taper (height/dbh) indicating that blown trees were more tapered than standing trees. This may account for some of the variance between blown and standing trees in relation to batten performance. However no significant difference between tree height and diameter ratio between leaning and standing trees was found, which may indicate that taper does not have an influence on batten performance.

Shorter more tapered stems at a stand edge are better adapted to wind and these trees will sway less (Telewski, 1995), which might help to prevent the root system being weakened. However, it is quantitatively not known at the moment how much the movement of the root plate influences the development of tree form, but adaptive root development as a result of different loading on both sides of a trunk has been reported by Nicoll & Ray (1996) and Watson (2000). The key is that in a wind damaged stand the standing trees will not put on any height because they are now subjected to greater wind loading (Urban *et al*.1994). The blown and leaning trees will tend to stop putting on height because the side branches will start to compete for opical dominance. The effect appears to be most prominent after 3 years.

Density

Wood density is probably the most extensively studied and widely used indicator of timber quality (Dickson and Walker, 1997; Zhang, 1997). Density affects the performance of sawn timber and has been shown to be positively correlated with the strength and stiffness of small clear samples of wood (Panshin *et al*., 1964; Desch and Dinwoodie, 1996). Consequently, higher density timber is generally associated with superior mechanical performance. However the presence of other strength reducing factors mean that density alone is not always a good predictor of mechanical properties.

The results from the experiment show that there is no significant differences in log density between the sites or blown, leaning and standing trees. The variability in the density measurements is too high to form any firm conclusions. The between tree/ site variability was also too great to draw any firm conclusions from the data analysed indicating that there was no clear picture in relation to growth rate.

Conclusion

The study has shown that windblown trees can be left for up to 18 months without reducing the percentage of battens that will pass stress grading. There were also a larger number of battens passing at C24 from all ages of windblow that would initially have been expected. After 18 months a smaller percentage of battens pass stress grading. The battens have more compression wood and increased taper, which is likely to lead to slightly increased conversion losses. There is sufficient evidence to provide the forest industry with guidelines on how long to leave windblown timber without the wood properties being altered to a degree where they cannot be used for construction timber. Design plans and harvesting rotations may have to be changed in order to incorporate the idea that harvesting of windblow could increase revenue, due to the higher prices paid for construction timber, for forest managers within the set time period.

Recommendations

The forest manager has to balance

1. the potential value of blown timber without degrade, with
2. the potential value after degrade, against
3. additional cost of moving machines etc. and altering harvesting schedules.

This will depend on the quality of blown timber and the scale of each operation.

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Appendix 1

Measurement of density

Before destructive strength testing was carried out, the density of a small, clear specimen cut from each end of every batten was determined. A nominal length of ≈ 60 mm was cut from one end of each 30 cm long strength sample. The 'current' weight (after storage for at least 2-3 weeks in a heated laboratory) of each new 60mm sample was measured on an electronic balance and recorded. The volume of each sample was estimated by measurement of the width, depth and length using a pair of digital vernier callipers to the nearest 0.1 mm. Width and depth were measured close to both ends of the sample. Length was measured from the middle of each end (transverse) surface. A diagram of the points of measurement is shown in Fig. 3.3.

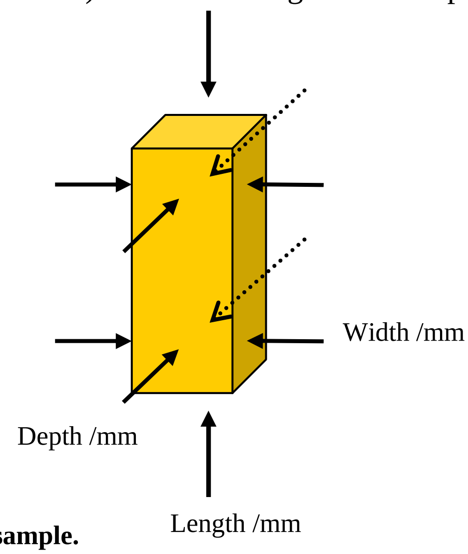


Fig 3.3 - Diagram of points of measurement of density sample.

Volume was estimated geometrically for each sample using the formula:

$$V = w \times d \times l$$

Where: V = Volume /mm³

w = Average width /mm

d = Average depth /mm

l = Length /mm

The weight was converted to kilograms and divided by the derived volume converted to cubic meters. This gave the density at current MC, which was measured using an electrical resistance moisture meter for each sample, an equilibrium MC of approximately 9%.

Estimation of Wet or Green Volume

1. The increase in volume (swelling) from oven dry to Fibre Saturation Point (F.S.P.) - The point at which the hydroxyl groups in the cell wall are unable to take up any more water (≈ 30%, though it varies with species [Tsoumis, 1991; Panshin & de Zeeuw, 1970]), was calculated for each specimen in the sample, and converted into a percentage of the oven dry volume. The resulting values were then averaged within each type (Juvenile/Mature) and site (Tay, Inverness and Kielder) to give a mean percent increase in volume (volumetric swelling) from oven dry to FSP.
2. The average increase in volume from oven dry to the MC at which the specimens in the sub-sample were originally measured, along with the rest of the 60 mm density samples; typically ≈ 9%, was calculated and converted into a percentage of the oven dry volume. The resulting values were then averaged within each type (Juvenile/Mature) and site to give a mean percent increase in volume (Volumetric change) from Oven dry to "Current" (≡ Ambient).
3. The percentage increases in volume from oven-dry to current for each specimen were subtracted from the percentage increases in volume from oven dry to FSP. The resulting percentages being the mean increase in volume from current to FSP.

For example the average increase in volume (current [ambient] → FSP) for the Juvenile sub-sample of site 'Kielder' was 8.488% (to 3.d.p.) Therefore the current volumes of each of the Kielder juvenile density samples were multiplied by 1.08488 to give an estimate of volume at FSP (wet/green). The wet volume was estimated in this way because direct extrapolation of the volumetric change per % MC, based on the change between oven-dry and ≈ 9% by multiplication by 30 (i.e. assuming FSP @ 30% MC [Wood Handbook, 1999]) gave very inaccurate results when compared to the measured wet volume of the sub-sample specimens. This suggests that the average FSP for the samples occurs at a moisture content considerably higher than 30%. The Wood Handbook (1999) suggests that if the FSP is known to differ from 30% MC, the appropriate MC should be used, if known.

Estimation of oven dry weight

1. The mean weight change values per percent MC were then used in a formula, of the form shown below, to estimate the oven dry weights of all of the density samples from the measured 'ambient' values for each site/type combination.

$$W_{OD} = W_A - (MC_A \times \Delta W_{/MC})$$

Where: W_{OD} = Oven Dry Weight (kg)
W_A = Weight at ambient MC (kg)
MC_A = Moisture content at ambient (typically 9%)
$\Delta W_{/MC}$ = Mean change (reduction) in weight / percent MC

2. Both wet and green volume and oven dry weight were estimated for the sub-sample specimens and compared to the measured values for each respective characteristic to estimate precision. Estimated wet/green volumes differed, within the sub-sample, from measured values by ± <1.86%. Derived oven dry weights differed from measured values by ± <3.6%.

Estimation of density at strength testing conditions

To relate the values for MoR and MoE attained from strength testing to the density corresponding to the MC at which the strength samples (from which the density samples were cut) were tested, both weight and volume were extrapolated from oven-dry to those of the equilibrium MC measured post strength testing. The weight of each of the density samples was increased from the estimated oven dry weight by multiplying the mean change (increase) in weight per percent MC for each site/type, by the measured MC of the corresponding strength sample at test - essentially using a formula similar to 3. above.

$$W_T = W_{OD} + (\Delta W_{/MC} \times MC_T) \qquad 4.$$

Where: W_T = Weight at (strength) Test (kg)
W_{OD} = Oven Dry Weight (kg)
$\Delta W_{/MC}$ = Change (increase) in Weight / percent MC
MC_T = Moisture Content at Test

Volume at point of strength testing was estimated in a similar way to weight. The difference between volume as measured at ambient (≈ 9% MC) and oven dry (measured in the sub-sample) was divided by the measured equilibrium MC of each specimen at 'ambient' conditions to give an average change in volume per percent change in MC. The mean volume change per %MC was calculated for each 'site and type' group of density sub-samples. The volume under the conditions of the strength test was then calculated for each density sample by multiplying the average change per percent MC by the difference in MC between measured 'ambient' density sample (average = 8.97%) and the corresponding strength sample at test (average = 12.3%). The resulting value was then added to the volume at ambient, as measured for each sample.

$V_T = V_A + (\Delta V_{/MC} \times \Delta MC)$

Where: V_T = Volume at (strength) Test
V_A = Measured Volume of Density Sample
$\Delta V_{/MC}$ = Change in Volume / percent Moisture Content
ΔMC = Change in Moisture Content between Strength and Density Tests

This is an extrapolation beyond the measured range of MC (0 - 9%) and should be treated with caution. All of the above calculations assume a linear relationship, within the range 0-<13% MC, between volume and moisture content (Tsoumis,1991 p.152).

Appendix 2

Protocol Windblow Experiment.

The Effects of Windblow on Timber Quality

Summary

The original proposal was altered once the reality of the work had been established. Certain aspects of the work were not covered and more work was undertaken than first envisaged. This original protocol has not been adjusted to take into account the changes that have been made in the experiment.

Introduction.

Information on the quality of windblown timber is an important factor to consider when harvesting.

a) Locate areas of windblown timber where the date of windblow is known.

b) Assess area for all the major dangers relating to felling and extracting

c) Select trees with average dbh or greater. Top diameter must be 16cm OB.

1. Material:

a) 3 stands of differing age of windblow. 6 months: 18 months: 36 months

b) Same age structure for each stand. Approximately to be planted around P60

c) Within each stand 15 trees to be assessed – 5*Control, 5*leaning and 5*blown. Total of 45 trees.

2. Work Program

Standing Trees

a) Measure tree-height, dbh, straightness score, spacing, slope angle and azimuth.

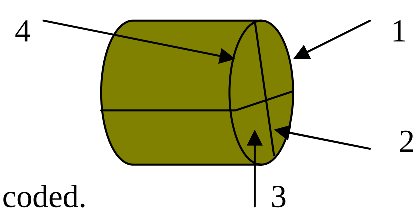
b) Standing, leaning or blown trees: 5 trees from the 3 categories within each of the three areas.

c) Pilodyne measurements will also be taken to measure wood density.

d) Measure the root plate angle in relation to the ground along direction of fall.

e) Mark the topside of the leaning tree (direction of fall). Note if the tree is leaning into another tree or free standing.

f) Mark the length of the logs with paint. On each quarter of each log, spot paint a colour to represent compression and tension wood. Once the logs have been cut spray the end of the logs in quarters indicating compression and tension.



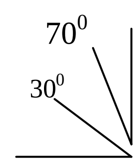
Each sector is colour coded.

Definition of Standing – 90^0 - 70^0

Leaning - 69^0 - 30^0

Blown - 29^0 - 0^0

From Horizontal to Vertical



3. Felled Trees

a) Crown characteristics: exact crown length, first dead whorl, and first green branch, first live whorl (3/4 live) and crow width.

   Other measurements: Angle of lean, direction of blow, straightness score, DBH.

b) Tree age at stump, exact stem height from stump, stem taper by measurement of two diameters perpendicular to each other at meter intervals along the stem.

c) The tree must be marked with paint to indicate the direction of fall.

d) Four (4) logs will be removed from each stem. Only 'green' logs will be removed. Discs form either end of the logs will be removed and marked by

   Location

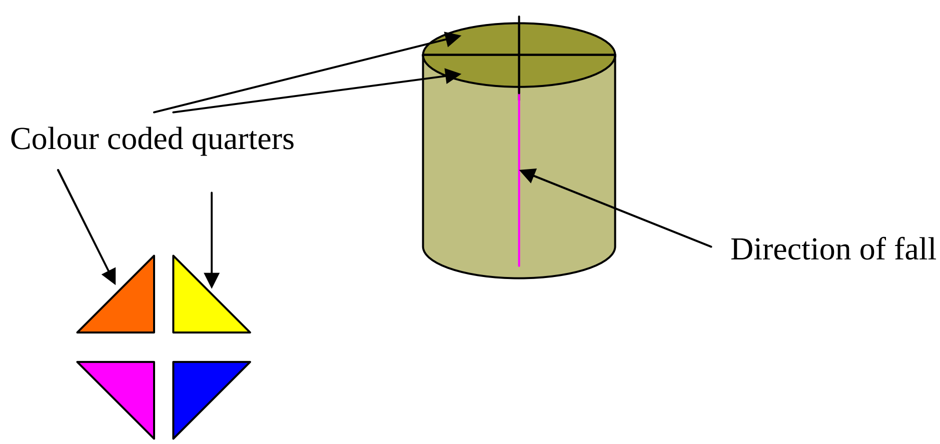
   Tree number

   Control/leaning/blow

e) Cutting logs, see logs and battens. 4 main logs to cut.

4. Marking the logs

The butt end of the logs will be marked **after 2"discs have been removed**. The butt end of the logs should be marked using four different coloured spray paints to ensure each section can be identified in relation to the direction of fall.



5. Logs and Battens

The logs are removed and transported to a Carrbridge sawmill where they will be cut into various sized battens.

Total maximum number of logs 135

Length of logs to be cut: Four main lengths - 3.0m with tolerance = 3.2m

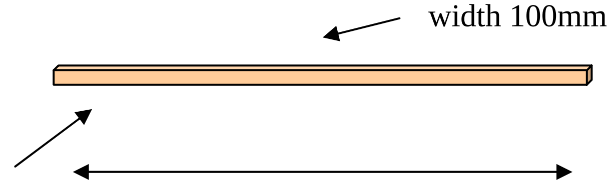
3.6m with tolerance = 3.75m

4.2m with tolerance = 4.35m

4.8m with tolerance = 4.95m

Log diameters: 150mm TD UB = 2 battens
200mm TD UB = 3 battens
300mm TD UB = 4 battens
per log

Batten sizes: width 100mm to 225mm



Thickness 47mm Length from 3.0m – 4.8m

Standard log lengths for different diameter classes OB:

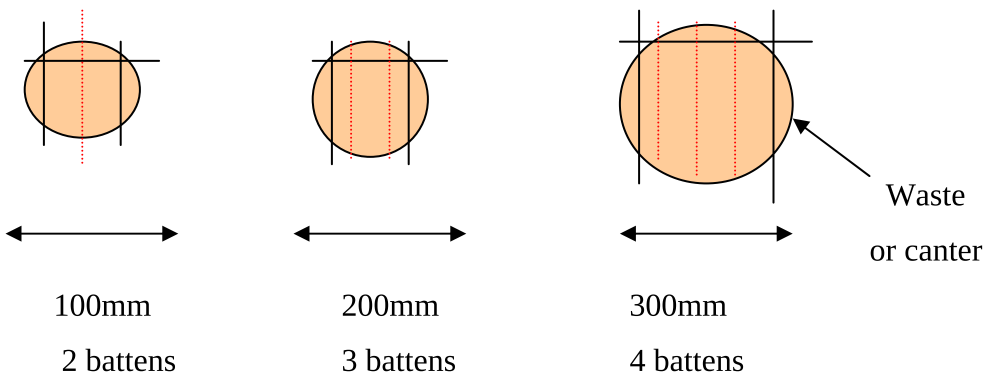
20cm length of logs – 7.5m log = 47% logs within tree

30cm length of logs – 3.65m + 4.85m logs = 75% logs within tree

35cm length of logs – 3.0m + 4.85m + 4.85m logs = 82% logs within tree

6. Cutting patterns

Depending on the diameter size class there will be 2, 3 or 4 battens cut from each log.



The sawmiller will assess each log, in order to cut construction battens to fit the market rather than to fit the yield. (This is a standard practice with all sawmills).
Each forest area will be cut at one time. Each batten will be marked in relation to the

- location, (Kielder, Tay, or Inverness)
- the tree (standing, leaning, blown)
- log number (1,2,3).
- Batten no. (1,2,3,4)

Example: The coding will be K:S:1:2. (Kielder, standing tree, log 1, batten 2) or
T: B:3:3 (Tay, blown tree, log 3, batten 3).

Once the battens have been cut they will be stacked by location. Stacking will be without spacers between each batten. The battens will then be transported to the sawmill at Nairn for stress grading wet before being dried in the kiln for the specified time to reach C16.

The moisture content will be taken before and after the drying process and before and after stress grading. Each batten will be given a grading relating to stress and moisture.

The timber can then be used by the sawmill at its own discretion.

7. Equipment

3 chainsaws	Clinometer/ Vertex - Hypsometer
4 colours of paint (yellow, blue, cerise, and orange)	Compass
Chainsaw fuel	Pilodyne
Chainsaw oil	Pins for pilodyne
Two stroke oil	Girth tapes
Timber rule	First Aid kit
Turning Strops	Bags for discs
Callipers	Winches – chainsaw
Risk Assessment	Turfor
Measuring tapes	