



Scots pine forest, Deeside, Scotland

Research Note

Developing methods for assessing Scots pine timber quality

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Timber production from Scots pine forests in Great Britain is forecast to increase over the next 15 years. This Research Note presents the results of a project to develop and test methods for assessing the quality of Scots pine timber from measurements on trees and logs. Six stands of Scots pine growing in the north of Scotland were studied to evaluate the potential of different non-destructive assessment methods (stem straightness score, various branch indices, and portable acoustic tools) for predicting log grade out-turn, sawn timber appearance grade and mechanical properties. Stem straightness score and the height of the lowest dead branch were found to be the best predictors of log grade out-turn. The height of the lowest dead branch was also a means of identifying those trees most likely to produce falling boards in the higher quality appearance grade classes. Measurements of stress wave velocity in trees and logs, using portable acoustic tools, were good predictors of the mechanical properties of sawn timber. By removing those logs which had low stress wave velocities it was possible to increase the strength class assigned to the sawn timber from C20 for the entire sample to C22 or even C24. Segregating material based on acoustic measurements taken on standing trees was also possible, but this was less efficient.

Introduction

Scots pine (*Pinus sylvestris* L.) is the most widely distributed conifer species in the world, with a natural range stretching from Spain to Norway and from Scotland to Siberia. It is the only conifer species native to the British Isles that has the potential to produce significant volumes of timber, and as such has a key role to play in the rural economy. In addition to timber production, Scots pine forests are highly valued for the wide range of benefits that they can provide – including biodiversity, landscape enhancement and recreation opportunities.

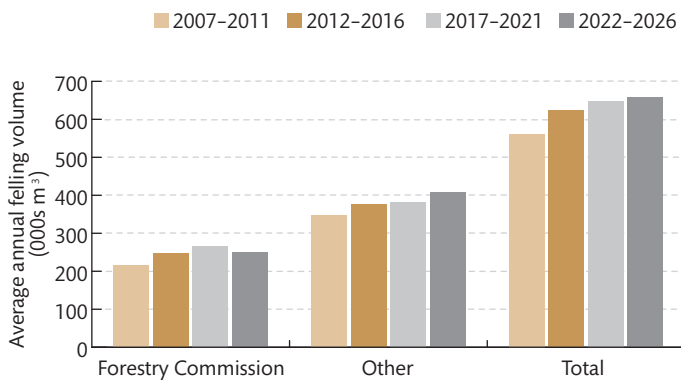
There are approximately 220 000 hectares of Scots pine high forest* in Great Britain, comprising around 16% of conifer high forests and 10% of the total high forest resource (Table 1). Almost two-thirds of the Scots pine forest area lies in Scotland, and the species is of particular importance in northern Scotland (Grampian and Highland Conservancy areas) where it represents about 30% of the conifer high forest area (Forestry Commission, 1997–2003). A recent forecast of the availability of Scots pine timber from forests in northern Scotland predicted that it will increase on average by about 15% per annum over the next 15 years (Figure 1), representing approximately 20% of the softwood timber harvest in these areas. The management, timber marketing and use of Scots pine forests in northern Scotland is therefore of considerable importance to the local economy.

Table 1 Area of Scots pine high forest.

	Great Britain	Scotland	North Scotland
Area of Scots pine high forest (ha)	219 438	135 828	107 797
Scots pine as a % of total conifer high forest	15.9%	15.0%	29.7%

Source: Forestry Commission, 1997–2003.

Figure 1 Softwood availability forecast for Scots pine in Grampian and Highland Conservancy areas (after Halsall, 2006).



*Defined in the Forestry Commission National Inventory of Woodland and Trees as all woodland except stands managed as coppice or coppice-with-standards with, or with the potential to achieve, a tree cover of more than 20%.

Recent studies reviewed the current use of Scots pine timber in northern Scotland, and evaluated potential new markets (Macdonald *et al.*, 2008). Approximately 50% of the Scots pine timber harvested in this area is processed into wood-based panels. A further 40% is used in agricultural and domestic fencing, with only small quantities used in construction or products such as decking and sleepers. Possible areas for market expansion that were identified included garden and landscaping products (with a focus on thermal and chemical wood modification techniques), stress-laminated timber bridges, massive wood construction, external cladding, and playground equipment.

The suitability of Scots pine timber for some new markets will be affected by variability in the timber quality of the existing resource. Stem form can be poor, with heavy branching resulting in a high incidence of knots, particularly dead knots, in sawn timber (Cooper, 2005). A survey of Scots pine growers, managers and timber processors highlighted key timber quality concerns. The most important were considered to be straightness, knottiness (number, size and condition of knots) and log dimensions (Macdonald *et al.*, 2008). Both growers and processors indicated that variability in quality within and between stands was a key issue, highlighting the need for techniques to identify better quality stands, and the best trees in stands.

This work is part of a project to develop, test and validate methods for assessing Scots pine timber quality in both standing trees and logs, and to link these to sawn timber properties and performance. We describe the use of visual assessments of stem straightness and branching to predict the yield of higher value 'green' category sawlogs (Forestry Commission, 1993) and portable acoustic tools (e.g. Wang *et al.*, 2007) to assess wood properties in standing trees and logs. The mechanical properties of Scots pine sawn timber are analysed in relation to the strength classes used to classify structural timber (CEN, 2003a), and the appearance grade of side boards is evaluated with reference to standards for non-structural timber (CEN, 2000).

Methods

Six sample stands were used in two linked studies to evaluate timber quality assessment methods for Scots pine.

Study 1

Three Scots pine sample stands aged between 77 and 81 years, growing at yield class 6–8 were selected for this study (Table 2). The age range and yield class were chosen to be representative of typical Scots pine stands towards the end of normal rotation lengths in the study area. Ten sample plots of 0.05 ha were randomly located within each stand. The diameter at breast

Table 2 Sample stand details.

Stand (Study no)	Location (NGR)	Elevation (m asl)	Exposure (DAMS) ¹	Planting year	Age at felling	Yield class	Stem straightness ²	Tree ³ acoustic velocity (km s ⁻¹)	Height ³ of lowest dead branch (m)	Number sample trees felled	Green log out-turn (%)	Number sample logs tested	Log acoustic velocity (km s ⁻¹)
Cawdor (1)	NH886489	150	13	1928	79	8	6 (4-6)	4.70	3.8	30	54.5	55	3.3
Munlochy (1)	NH624535	60	12	1926	81	6	6 (4-6)	4.61	4.6	30	58.9	54	3.5
Harriets (1)	NH776926	105	14	1930	77	6	4 (3-6)	4.73	2.8	30	41.4	51	3.3
Laiken (2)	NH900518	150	12	1953	55	14	4 (3-6)	4.40	1.4	32	41.7	-	-
Monaughty (2)	NJ113588	125	13	1928	80	8	6 (4-6)	4.65	3.9	30	58.7	-	-
Keppernach (2)	NH920478	155	14	1939	69	8	5 (4-6)	4.25	3.0	30	41.0	-	-

¹Detailed Aspect Method of Scoring (Quine and White, 1994); ²Stand median score (and interquartile range); ³Stand mean value.

height (DBH) of every live tree in these plots and stand top height were measured in accordance with standard mensurational procedures (Matthews and Mackie, 2006). On each tree stem straightness was assessed using the scoring system described by Macdonald *et al.* (2001) and acoustic velocity was measured on the north side of the stem using a portable standing-tree acoustic tool following standard procedures (e.g. Mochan *et al.*, 2009).

Figure 2 Assessing Scots pine with a standing tree acoustic tool.



Three trees were selected from each sample plot at random from those trees with a DBH of 28 cm or greater. For each selected tree the following branching characteristics were visually estimated:

- Height to the lowest dead branch, estimated to nearest 0.5 m. Only branches estimated to be 15 mm in diameter or greater, and 30 mm in length or greater were assessed.
- Height to the lowest live branch, estimated to nearest 0.5 m.
- Height of the lowest live whorl (lowest live whorl defined as the whorl where >75% of branches are green, representing the base of the living crown), estimated to nearest 0.5 m.
- Diameter of the lowest dead branch – to nearest cm.
- Diameter of the lowest live branch – to nearest cm.

These branch heights were also measured using a hypsometer to check the accuracy of the visual estimates. The two approaches were compared for each trait and stand using Lin's concordance correlation coefficient (Lin, 1989; 2000), which considers both the correlation and agreement between sets of observations.

Each sample tree was felled. The theoretical volume of higher value 'green' category sawlogs, identified according to specifications for log dimensions, log straightness, knot size and knot number (Forestry Commission, 1993), was assessed in relation to the total volume of sawlog sized material (measured to 16 cm top diameter overbark) for each sample tree (Matthews and Mackie, 2006). Log specifications for current Scots pine markets in the study area were used in this assessment (Table 3). Sleepers were given the highest priority, since they attract a price premium, followed by longer green log lengths.

Table 3 Specification for theoretical green log conversion.

Log category	Minimum top diameter	Length (m)
Sleeper	35 cm underbark	2.65
Green logs	16 cm underbark	3.1
		3.4
		3.7
		4.3
		4.9
Green pallet	25 cm underbark	2.5

Up to two 3.7 m long green category sawlogs were cut from each sample tree, provided stem form and branch size specifications were met. A total of 160 logs were cut and the following measurements made on each:

- Log length.
- Log top diameter over bark.
- Acoustic velocity using the log tool (Figure 3).

Each log was labelled to enable every piece of timber subsequently sawn from it to be related back to its source site, tree and log. Logs were processed into structural timber with dimensions of 47 mm × 100 mm, 47 mm × 150 mm and 47 mm × 200 mm, and falling boards (boards cut from the outer edge of the log) of 19 mm thickness with widths of 75 mm, 100 mm and 150 mm. The conversion in the sawmill was optimised to maximise yield of sawn material from the logs. All timber was kiln dried in a commercial kiln using a standard schedule for Scots pine.

Figure 3 Testing Scots pine logs with the log acoustic tool.

Falling boards were appearance graded following the G4 method in EN 1611-1:2000 (CEN, 2000), which applies to softwoods for non-structural applications (e.g. cladding, joinery and furniture). Each falling board was assigned a grade from G4-0 (the highest quality) through to G4-4 (the lowest quality) based on an assessment of all four faces.

A sub-sample of structural timber containing two pieces from each log was selected for mechanical testing. The sub-sample contained both 47 mm × 100 mm and 47 mm × 200 mm pieces (Table 4). Timber was destructively tested in four-point bending to determine global modulus of elasticity (MoE) and modulus of rupture (MoR) in accordance with EN 408 (CEN, 2003b). The 47 mm × 200 mm timber was 3.7 m long, which was less than the 3.8 m (i.e. 19 times the depth) recommended in the standard. Therefore, these specimens were ripped lengthways and one piece measuring approximately 47 mm × 100 mm retained for further testing. Following testing, a 40 mm-long sub-sample spanning the full cross-section of the timber was cut and its basic density (i.e. oven-dry mass of wood per unit green volume), bulk density (mass of wood per unit volume at ambient conditions), and moisture content were determined in accordance with EN 13183-1 (CEN, 2002) and EN408 (CEN, 2003b). The proportion of variation in basic density, MoE and MoR due to intra-tree, inter-tree and inter-site differences was calculated, and the relationships between MoE, MoR and density were investigated. The average MoE of the timber tested from each log was calculated and these average values compared with the dynamic modulus of elasticity predicted from acoustic velocity measurements made on the logs.

The use of portable acoustic tools to improve the grade out-turn of sawn timber was examined by setting various velocity thresholds and calculating the characteristic values for bending strength, stiffness and density of the timber sawn from those logs which had a velocity greater than this threshold value. These characteristics values were calculated using the procedures described in EN384 (CEN, 1995) and the timber assigned to appropriate strength class based on the requirements given in EN338 (CEN, 2003a).

Table 4 Characteristics of the sub-sample of structural timber.

Stand	Number of specimens		
	100 mm × 47 mm	200 mm × 47 mm	Total
Cawdor	83	26	109
Munloch	57	54	111
Harriets	75	26	101
Total	215	106	321

Study 2

Three additional stands (Laiken, Monaughty and Keppernach – Table 2) were selected to test the timber quality assessment method developed in Study 1, and to provide additional data for the predictive model linking stem straightness score and height of the lowest dead branch to green log yield.

Sample plots were located randomly within each stand, the number and size of the plots being determined according to the stand area and stocking density (8 × 0.03 ha plots at Laiken, 6 × 0.05 ha plots at Monaughty and 10 × 0.02 ha plots at Keppernach). DBH, top height, stem straightness score, acoustic velocity and the height of the lowest dead branch were assessed using the methods from Study 1. Thirty sample trees per stand (32 at Laiken) were felled and total log and green log volume calculated. No assessment of log stress wave velocity was made from these sample stands and timber was not removed for testing.

Results

Accuracy of visual assessing branch heights

There was consistently good reproducibility (between the visual assessment and the hypsometer measurements) across stands for height of lowest dead branch (concordance correlation coefficient of 0.95 to 0.98), variable reproducibility for height of lowest live branch (0.53 to 0.91) but consistently less reproducibility for height of lowest live whorl (0.75 to 0.85).

Predicting green log out-turn

Analysis of the data from Study 1 showed that, of the standing tree characteristics assessed, stem straightness score (s) and height of lowest dead branch (h) were best able to predict the green log yield per tree. There was no relationship with other branch indices tested or with DBH. Acoustic velocity measurements were not related to green log out-turn. The statistical model fitted to the data from the three stands sampled in Study 1 was able to explain approximately 32% of the variation in green log out-turn. When data from the three stands sampled in Study 2 were added to those from Study 1, giving a total of 122 trees, a new model was obtained that could explain approximately 49% of the variation of the green log out-turn for an individual tree from observations of s and h :

$$\text{GL \%} = 8.617 + s + 3.478h$$

where GL % = green log out-turn (green log volume per tree as a percentage of total log volume per tree), h is height of lowest dead branch (m) and the value of s depends on the stem

straightness score. For a stem straightness score of 1, the term s in the model is equal to 0, while its value is 11.66, 17.44, 22.71, 25.74, 40.60 and 44.20 for stem straightness scores of 2, 3, 4, 5, 6 and 7, respectively. The fitted model indicates that for a 1 m change in h there is a 3.5% change in predicted GL %.

Appearance grading of sawn timber

Across the three sites in Study 1, the majority (71%) of the falling boards were graded as G4-3 and poorer, with nearly 50% of boards graded in the lowest grade (G4-4) (Table 5). Downgrading of boards was generally as a result of the number of knots, particularly loose knots, in the boards.

The possibility of predicting falling board appearance grade from standing tree measurements was explored. Of the 792 boards 224 (28%) were assigned to the highest three categories of G4-0 to G4-2 and there was a consistent positive relationship across stands between height of lowest dead branch and the proportion of such boards. The model predictions indicated that a tree with a height of the lowest dead branch of 2 m would produce just under 23% of falling boards in grades G4-0 – G4-2, whilst a tree with a height of lowest dead branch of 8 m would produce just over 43%.

Table 5 Percentage of boards falling within each grade from each sample stand. Boards appearance graded in accordance with BS EN 1611-1:2000.

Sample stand	Board grade (%)				
	G4-0	G4-1	G4-2	G4-3	G4-4
Cawdor	6	7	21	19	47
Munlochy	3	3	23	30	41
Harriets	3	4	16	20	57
Overall	4	5	20	23	48

Mechanical and physical properties of timber

MoE determined from bending tests ranged from 3.88 kN mm⁻² to 16.65 kN mm⁻², with a mean of 9.31 kN mm⁻², while MoR ranged from 12.7 N mm⁻² to 86.2 N mm⁻², with a mean of 44.5 N mm⁻². There was a relatively strong relationship between MoE and MoR ($R^2 = 0.68$). Basic density of the wood ranged from 338 kg m⁻³ to 542 kg m⁻³, with a mean of 418 kg m⁻³. There were moderate relationships between basic density and both MoE and MoR ($R^2 = 0.64$ and 0.47, respectively).

Over 50% of the variation in MoE was due to differences between individual pieces of timber within a log, with a further 25% due to variation between individual trees within a site (Table 6). Less than 6% of the variation was due to differences between sites.

Table 6 Components of variation in MoE, MoR and basic density.

Stratum	% variation attributable to a stratum		
	MoE	MoR	Basic density
Site	5.59	3.39	<0.01
Plot	0.99	<0.01	0.50
Tree	24.88	7.95	9.75
Log	14.65	30.18	43.24
Batten	53.89	58.48	46.51
Total	100.00	100.00	100.00

There was a significant difference in MoE between timber cut from nearer the pith of the tree and that cut from nearer to the bark ($p < 0.001$). Similarly, there was a significant difference in MoE between timber cut from the butt log and timber cut from the second log ($p < 0.001$). On average, timber cut from nearer the bark had a value of MoE that was 1.41 kN mm^{-2} greater than that for timber from nearer the pith, while timber from the second log had an average value of MoE that was 1.24 kN mm^{-2} lower than timber from the butt log. Similarly, the majority of variation observed in MoR and basic density was due to within-tree differences with almost none of the variation associated with differences between plots or between sites (Table 6).

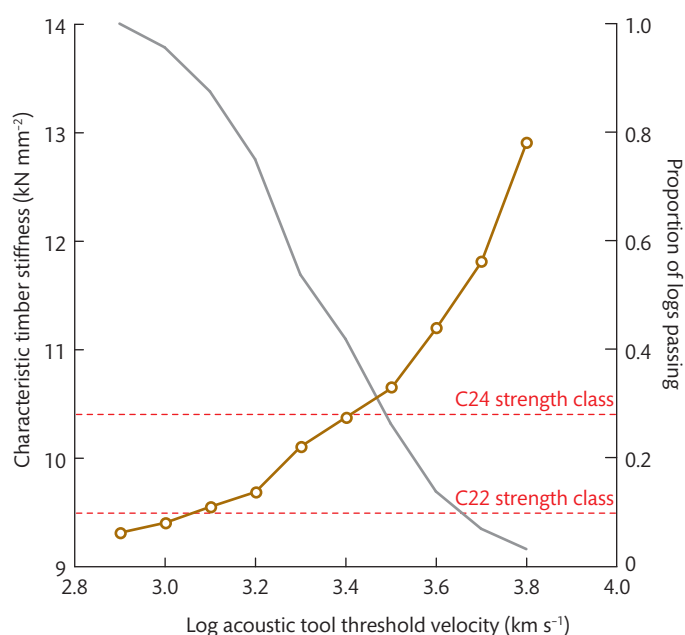
The characteristic bending strength of the entire population of timber was calculated using the approach described in EN384 (CEN, 1995). The 5th percentile value of MoR was 24.21 N mm^{-2} . After multiplying by factors which account for the size of the timber, the number of samples and the method of grading, this gave a characteristic bending strength of 21.0 N mm^{-2} . The mean density at 12% moisture content (504 kg m^{-3}) satisfied the requirement for the C20 strength class, while the mean value of MoE (9.31 kN mm^{-2}) exceeded 95% of the mean requirement for the C20 strength class (i.e. $0.95 \times 9.5 \text{ kN mm}^{-2}$). Therefore, the timber satisfied the strength, density and stiffness requirements of the C20 strength class.

Predicting sawn timber mechanical properties from acoustic measurements

At the log level, there was a significant relationship between acoustic velocity and the average MoE of sawn boards cut from the log ($R^2 = 0.43$), but this relationship was not as strong at the individual sawn board level ($R^2 = 0.32$). The effect of log segregation on the properties of the sawn timber is illustrated in Figure 4. This shows that there is an increase in the mean MoE of sawn timber with an increasing acoustic velocity threshold for logs. For example, if all logs with a stress wave velocity of less than 3.1 km s^{-1} were removed from the population, then the characteristic values of strength and stiffness increased to

22.0 N mm^{-2} and 9.55 kN mm^{-2} , respectively. These values were sufficient for the timber to meet the requirements for the C22 strength class. Only 20 logs (12.5% of the population) were removed using this criterion. In order to achieve the requirements of the C24 strength class, this threshold velocity needed to be set at 3.45 km s^{-1} (Figure 4). However, approximately 65% of the logs would be rejected in order for the timber to meet the requirements for C24.

Figure 4 Effect of log segregation using the log acoustic tool on the characteristic stiffness of sawn timber (—○—). The grey line indicates the proportion of logs meeting a particular threshold.



A similar analysis was undertaken using the acoustic velocity readings made on the standing trees. In this case there was not the same monotonic increase in characteristic timber stiffness with increasing velocity threshold as was observed with the log tool on cut lengths. However, it was still possible to meet the requirement for the C22 strength class by removing those trees with an standing tree acoustic velocity less than 4.5 km s^{-1} from the population. A total of 30 trees (33% of the population) failed to meet this velocity threshold.

Discussion

Predicting stand quality and green log out-turn

Results from the initial trial of different standing tree timber quality assessment methods in Study 1 indicated that stem straightness score and height of the lowest dead branch best predicted the green log yield per tree. This was confirmed when the methodology was further tested in Study 2. The model

developed from the data collected in the six sample stands explained almost 50% of the variation in green log out-turn at an individual tree level. This compares well with a similar model developed for Sitka spruce where plot median stem straightness score was used to predict plot green log out-turn (Macdonald *et al.*, 2009). However, the estimates of green log out-turn predicted from these assessments should be viewed as a broad indication of output and a means of differentiating between stands, rather than a precise forecast of actual green log recovery, which will vary according to individual stand characteristics and market conditions.

Stem straightness score and height of lowest dead branch assessment can be integrated with standard mensurational procedures, as described for the stem straightness assessment of Sitka spruce (Macdonald *et al.*, 2009). As with all visual assessments, assessors should undergo appropriate training and calibrate their measurements prior to using stem straightness score and height of lowest dead branch assessments in the field, in order to ensure consistency.

Appearance grading of sawn timber

The results of the appearance grading of falling board material are broadly similar to results achieved in previous studies of this type (Cooper, 2005; Cooper *et al.*, 2008) in which the proportion of boards meeting the requirements of the three highest appearance grades averaged approximately 30%. If Scots pine timber were to be used in more demanding applications, such as cladding or joinery, sorting in the sawmill to identify the boards which meet the requirements of the higher quality grades would be required.

The results of this study indicate that the height of the lowest dead branch assessment could be used as a preliminary means of identifying trees likely to produce a greater proportion of higher quality boards, facilitating segregation of this material at an earlier stage in the production chain. This is consistent with Uusitalo (1997), who found that height of the lowest dead branch was correlated with timber quality of the butt log.

Mechanical and physical properties of timber

Scots pine structural timber is able to meet the requirements for the C20 strength class, which means that it is suitable for a wide range of construction applications. For applications requiring higher strength class timber, our results show that in the order of 35–40% of the timber from the stands tested can meet the requirements for the C24 strength class. This is in agreement with results obtained for a wider range of sites by Holland (2009) as part of a study to develop grading machine settings for Scots pine.

Analysis of the sources of variation in MoE and MoR suggests that there is the potential to improve these values in a population of timber by initial segregation of trees and logs using portable acoustic tools. Segregation using the standing tree tool was not as efficient as sorting on the basis of the log tool measurements. However, it does have the advantage of allowing roundwood to be cut to length for specific products on the basis of predicted timber stiffness, whereas the log acoustic tool can only be used after decisions regarding log length have been made.

Sorting logs using acoustic tools offered a more efficient means of segregating out timber with inferior stiffness and improving the recovery of higher strength class material suitable for more demanding structural applications. This type of testing has the potential to be useful when sourcing logs for specific end uses where there are particular stiffness and strength requirements. At a larger scale, it is possible to integrate acoustic log testing technology with sawmill lines which offers timber processors the option of in-line sorting of logs to maximise output of higher strength class material by screening out logs with the lowest acoustic velocities. Future developments in this field include a prototype harvester-mounted acoustic tool, capable of measuring acoustic velocity of logs before they are cut, thus facilitating decision making regarding log specification.

Conclusions

This study has demonstrated that non-destructive assessments made on trees and logs can be used to predict log quality and timber properties in Scots pine as follows:

- Visual assessments of stem straightness and the height of the lowest dead branch can be used to estimate the proportion of green sawlog material in an individual tree.
- The height of the lowest dead branch can be used to predict the proportion of falling boards assigned to the three highest quality appearance grade classes.
- Portable acoustic tools can be used to assess the mechanical properties of Scots pine timber in standing trees and logs.
- Differences in wood properties between timber cut from different logs means that portable acoustic tools can be used to segregate out those logs which are likely to produce timber with inferior mechanical properties.
- Trees can also be segregated on the basis of acoustic measurements, although this is less efficient than segregating logs.

Integration of these non-destructive techniques for assessing timber quality in standing trees and logs with standard inventory procedures, pre-harvest assessments or log-sorting operations has the potential to improve the allocation of Scots pine timber to the most appropriate end products.

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