FEASIBILITY AND USEFULNESS OF DIRECTIONAL FELLING IN A TROPICAL RAIN FOREST

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CEDERGREN, J., FALCK, J., GARCIA, A., GOH, F. & HAGNER, M. 2002. **Feasibility and usefulness of directional felling in a tropical rain forest.** Control of logging damage is important for sustainable timber production in tropical rain forest. Method often recommended to control damage levels include directional felling and pre-felling climber cutting. The present study is an experimental evaluation of these methods. A total of 41 trees, with dbh ranging from 62 to 165 cm, were selected for directional felling in a hilly tropical rain forest in Sabah. Felling was done by an experienced instructor. An average of four potential crop trees were selected for retention per tree felled. Of trees selected for retention 94% were proven undamaged by felling. Pre-felling climber cutting, carried out one year before felling around 20 of the trees, had no influence on the proportion of selected trees retained nor on accuracy. Of the trees, 78% fell within 20° of the desired lay, 12% within 20 to 30°, and 10% fell beyond 60° of the desired lay. Average range of feasible felling directions was 181°, and mean difference between bearing of desired lay and tree lean was 46°. Of factors assumed to influence deviations from desired lay only tree size multiplied by ground inclination and evidence of rot in trunk were proved significant after outliers had been excluded. Results suggest that felling ranges can be reliably set and effectively utilised, and that trees can generally be felled within 20° of desired lay.

Key words: Selective logging - logging damage - rain forest silviculture - reduced impact logging - directional felling

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CEDERGREN, J., FALCK, J., GARCIA, A., GOH, F. & HAGNER, M. 2002. **Kebolehlaksanaan dan kebolehgunaan kaedah tebangan mengarah di hutan hujan tropika.** Kawalan kerosakan akibat pembalakan adalah penting untuk pengeluaran balak secara berterusan di hutan hujan tropika. Kaedah yang selalu disyorkan untuk mengawal tahap kerosakan termasuk tebangan mengarah dan potongan pepanjat pratebangan. Kajian ini merupakan ujian penilaian kedua-dua kaedah ini. Sejumlah 41 pokok bergaris pusat antara 62 hingga 165 cm dipilih untuk tebangan mengarah di hutan hujan tropika berbukit di Sabah. Tebangan dijalankan oleh seorang pengajar yang berpengalaman. Purata empat pokok tebangan akhir yang berpotensi dipilih untuk pengekalan bagi setiap pokok yang ditebang. Sebanyak 94% daripada pokok yang dipilih untuk dikekalkan didapati tidak rosak akibat tebangan. Potongan pepanjat pratebangan yang dijalankan setahun sebelum tebangan terhadap 20 pokok tidak mempengaruhi jumlah pokok yang dipilih untuk dikekalkan mahupun ketepatan. Sebanyak 78% daripada pokok tersebut tumbang di dalam kawasan 20° daripada arah yang diingini, 12% tumbang di dalam kawasan 20 hingga 30°, dan 10% tumbang di luar 60° daripada arah yang diingini. Julat purata kebolehlaksanaan arah tebangan ialah 181° dan min perbezaan antara bearing arah yang diingini dan kecondongan pokok ialah 46°. Daripada semua faktor yang dianggap mempengaruhi sisihan daripada arah yang diingini hanya saiz pokok yang didarab dengan kecondongan tanah dan tanda-tanda pereputan batang terbukti bererti selepas bacaan luaran tidak diambil kira. Keputusan kajian mengesyorkan bahawa julat penebangan dapat ditentukan dan digunakan dengan berkesan dan pokok pada umumnya dapat ditebang di dalam kawasan 20° daripada arah yang diingini.

Introduction

Sustainable timber production in tropical rain forests requires methods that cause less logging damage to residual stand than what conventional methods typically do (Nicholson 1979, Appanah & Weinland 1990). To achieve lower damage levels, logging can be organised in many ways depending on stand structure, tree size, topography and techniques and equipment available. In all harvests of timber the trees have to be felled. Most logging operations in tropical rain forests are selective (Hendrison 1990, Jonsson & Lindgren 1990), i.e. only big and healthy trees of commercial species are harvested. Although volumes removed may be modest, damage to the residual stand can be considerable (see reviews in Nicholson 1979, Jonsson & Lindgren 1990, Appanah & Weinland 1990).

Felling of trees and hauling of logs to landings are the two major direct sources of logging damage. Damage is inevitable as trees, however expertly felled, must fall somewhere, and must, somehow, be hauled to a landing.

Among the methods typically recommended to reduce logging damage are directional felling, pre-felling climber cutting, pre-alignment of skid trails and non-tractor based hauling (e.g. Anonymous 1989, Poore *et al.* 1989, Appanah & Weinland 1990, Vanclay 1993, Bruenig 1996). Experience on directional felling and pre-aligned skid trails in combination has been proven to reduce logging damage (e.g. Jonkers & Mattson-Marn 1981, Chuah 1986, Hendrison 1990, Pinard 1994). Pre-felling climber cutting has also been found to reduce logging damage (Fox 1968, Appanah & Putz 1984).

Directional felling means felling towards a pre-determined lay, hence referred to as desired lay. Important objectives of directional felling include avoiding damage to potential crop trees, facilitating hauling, and avoiding damage to the tree felled. When felling trees that have their crowns infested with climbers intertwining with other crowns, it is not unreasonable to assume that deviations from desired lays and damage to potential crop trees increase. The purpose of pre-felling climber cutting, hence referred to as climber cutting, is to release tree crowns from these intertwining climbers, thereby decreasing deviations from desired lays and reducing felling damage. To be effective, climber cutting needs to be carried out well before felling (Anonymous 1972).

The potential of directional felling to reduce logging damage is questioned in a review by Nicholson (1965). Fox (1972) refers to tests of directional felling and climber cutting as having failed to produce "worthwhile" results. It seems a reasonable assumption that the potential of directional felling to save selected residual trees, i.e. potential crop trees, from damage is greater than to generally reduce damage levels.

Information, although not detailed, on the feasibility of directional felling from Sarawak (in Malaysia) and Surinam is encouraging (Jonkers & Mattsson-Marn 1981, Chuah 1986, Hendrison 1990). In an evaluation of directional felling in Sarawak, 26% of the trees went "off course" (Bruenig 1996). In an ongoing project in Sabah fellers have been found able to consistently fell trees within 10° of the desired lay (Pinard *et al.* 1995). Conway (1976), in his textbook based on North American conditions, concludes that with normal working techniques it is possible to fell trees 30 to 45° from their lean, if lean is not too great, and that with special working techniques this might be extended to 90°, and finally that hydraulic jacks and cables can extend feasible felling ranges further. Conditions in Sabah, Malaysia are different from those in North America; climbers and buttresses are present on trees, canopy is often dense, clear felling is rare (except in land conversion schemes), and hardwoods dominate. Accessories other than wedges made by the fellers themselves are rare. In view of the current interest in reduced impact logging techniques in Sabah, detailed studies of directional felling are warranted.

A major concern among silviculturists working with selective systems is the potential of the residual stand to yield future crops. The potential of directional felling in this respect depends on the ability of the silviculturist to set guidelines for choice of felling direction and on the ability of the feller to follow those guidelines. Thus, to set realistic guidelines, silviculturists need a good understanding of what can be expected from fellers. Important issues include what deviations from desired lays are to be expected, how far from their lean can trees generally be felled, can fellers reliably state a sector (hence referred to as felling range) in which they are capable of felling a tree, how wide, big, generally, is the felling range, and what is the appropriate balance between avoiding damage to potential crop trees and facilitating hauling?

In this study the feasibility and usefulness of directional felling and the effect of climber cutting on this technique were tested in a primary dipterocarp forest in Sabah. The present study is an experimental evaluation of how reliably potential crop trees can be saved from felling damage. The study further evaluated the accuracy of directional felling and the influence thereon of climber cutting, topographical factors, properties of trees felled, and the size of felling ranges. It is part of a field experiment evaluating the impact on the residual stand of directional felling and climber cutting.

Materials and methods

The study was conducted in Gunung Rara Forest Reserve, Sabah, Malaysia (longitude 116° 45' E, latitude 4° 24' N). The forest type is a primary dipterocarp forest with steep and broken terrain. Trees were selected within a block of approximately 600 ha. The elevation ranges from 320 to 680 m asl. The soils were sampled from three pits at representative locations. The soil type is Orthic Acrisols.

In the design of the experiment there were two restrictions regulating. One, a tree felled was not allowed to interfere in the potential felling range of another tree felled. The tallest trees were estimated to be 70 m high. The minimum distance between the trees sampled for felling was set to 140 m. Two, because the experiment was so land demanding the disposal of land for the experiment was set to a little more than one year. This study has a single tree design with 22 replications per treatment.

From September till October 1991, a baseline parallel to the main direction of a logging road was established. Perpendicular to the baseline, 16 parallel corridors, 30-m wide, at a spacing of 160 m were made through the study area (Figure 1). For every corridor, the first loggable tree, i.e. an apparently healthy tree of commercial species of at least 60-cm diameter at breast height (dbh) (the minimum legal felling diameter in Sabah), encountered after 70-m from the baseline was selected for felling. After selecting a first tree along a corridor, a minimum spacing of 140 m between trees to be felled was required. The number of trees selected varied along each corridor, depending mainly on the boundary of the experiment area and protected riparian zones. A total of 88 trees were selected.

The study reported here is one-half of an experiment with a 2 × 2 factorial design, with felling (unsupervised, F_0, and directional, F_1) and climber cutting (no climber cutting, C_0, and climber cutting, C_1) as factors. All trees selected for felling were grouped into blocks of four. For each tree, five variables assumed to influence deviations from desired felling directions, and the influence of climbers on damage to residual stand and gap creation (not dealt with in this study), were measured. They were (1) number of climbers on the tree to be felled, (2) proportion of climber holding trees on four randomised circular plots (10-m radius) within 50 m of the tree to be felled, (3) ground inclination at the tree to be felled, (4) dbh of the tree to be felled and (5) number of trees inside the four circular plots. Mean and range of each variable were used to standardise the variables into values of one to ten. The variables were given weights, 4, 4, 3, 2 and 1 respectively, and added to form an index for each tree, giving climber abundance priority in blocking the trees. The trees were sorted by decreasing index and grouped into the blocks. Within blocks, treatments were randomised.

The design was a 1 × 1 factorial experiment, that was directional felling with and without climber cutting. Directional felling was allotted to 44 trees, the original material for this study. Of these, two trees could not be felled (a newly constructed water pipe was too close to one tree, and another had been struck and snapped by lightning), and data were missing for one tree (treatment F_1 C_1), reducing the number of trees treated with directional felling to 41 (21 trees of F_1C_0 and 20 of F_1 C_1).

Climber cutting, where allotted, was carried out from October till November 1991 in squares of 140 × 140 m, the size of the single tree plot, with the tree to be felled at the centre of the square. Climbers were cut close to the ground and, to avoid fusion after cutting, at a height of approximately 1 m.

Felling was carried out from October till November the following year (1992). Directional felling, done by an experienced felling instructor, was designed with retention of specific potential crop trees, hence referred to as PCTs, as an overriding goal. PCTs were trees of commercial species, big and healthy enough to be judged capable of forming the crop at the next harvest. Felling work largely followed techniques outlined by Anonymous (1980) and Klasson and Cedergren (1996). The chainsaw used was Husqvarna 394 XP with a power output of 5.2 kW (7.1 horsepower) and 0.8-m (32-inch) guidebar. Accessories were restricted to plastic wedges, which were used to secure trees, not to force them in any direction.

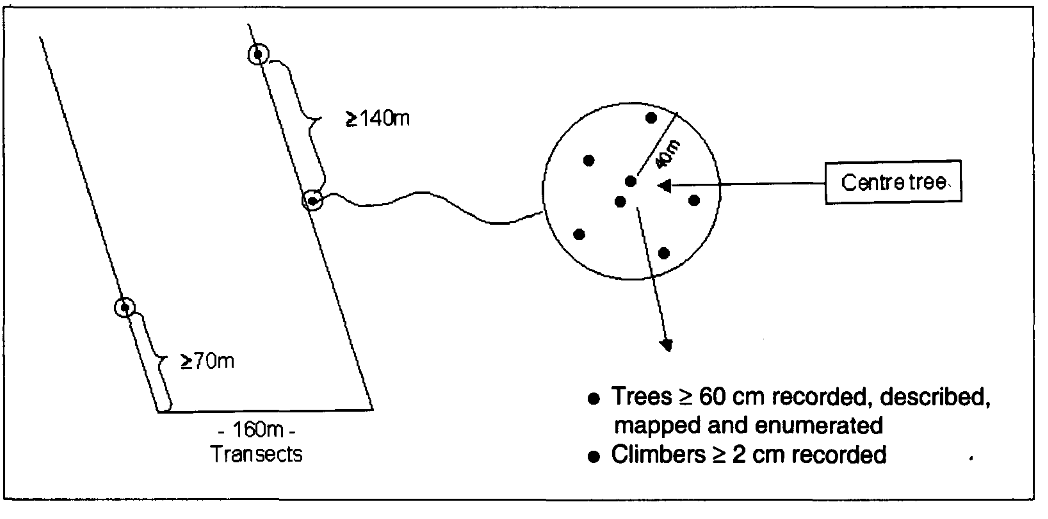

Figure 1 The design of the original experiment (from Cedergren *et al.* 1994)

For directional felling, an interval of felling range, was determined by the professional feller according to the following: (1) the presence and extent of rot which was visually assessed through inspection of the bole and of the sawdust from a vertical incision cut with the chainsaw, (2) the vertical projection of the centre of gravity of the crown, estimated by using a clinometer and (3) the horizontal direction to the gravity point and the distance between it and the, soon to be, stump centre which was estimated with a tape. Considering factors that could cause restrictions in working mode, e.g. dbh and ground inclination, the feller subjectively stated a felling range. Outer limits of the felling range represented directions where the feller estimated a 50 % likelihood of success in felling the tree in that direction.

After the feller had determined the felling range, obstacles inside it that should be avoided, e.g. risk of hangups, log breakage, streams and ravines were positioned by the feller and a trained forest ranger. The ranger also identified and positioned PCTs inside the felling range and within 70 m from the tree to be felled, and finally set desired lay, whereafter felling work commenced.

After felling, extent of rot at stump level (proportion of stump sectional area) and total tree height were measured with a tape. For trees that fell more than ± 20° from the desired lay, the feller stated what was seen as reasons for the mishaps. Finally, PCTs marked for retention were checked for damage. The influence of climber cutting on proportion of PCTs saved from felling damage was evaluated using a two sided *t*-test.

Influence of climber cutting on lay deviation, i.e. angular difference between actual and desired lay, was evaluated through analysis of variance (simple factorial, experimental method), with dbh, ground inclination and closeness (degrees) of desired lay to felling range border as covariates. Two trees with a felling range of 360° were excluded from this analysis, as no value for the latter covariate could be ascribed to them.

Influence on lay deviation of tree size (expressed as $dbh^2 \times$ total height) ground inclination, tree size multiplied by ground inclination plus 1 (to avoid multiplication by zero), moment (tree size × horizontal distance to gravity point), extent of rot, angular difference between bearing to gravity point and desired lay (aim deviation), and closeness of desired lay to felling range border was analysed using multiple regression, backward selection ($p_{out} = 0.05$). Two trees with missing values for extent of rot were excluded from this analysis.

Results

Average dbh of the 41 trees treated with directional felling was 89 cm, ranging from 62 to 165 cm dbh. Total heights ranged between 33.5 and 81.3 m, with an average of 51.8 m and average ground inclination was 19°, ranging from 0 to 45° (Table 1). An average of four PCTs (SD 3.2) per tree felled were marked for retention.

No statistically significant differences between F_1C_0 and F_1C_1 in terms of PCTs retained were found. For both treatments, 94% were retained.

Climber cutting did not reduce lay deviation (Table 2). Mean lay deviation was 17.0° for F_1C_0 and 20.5° for F_1C_1. Of the 41 trees, 78% fell within 20° of the desired lay and 12% showed a lay deviation of 20 to 30° (Table 3). Nearly 10% of the trees missed the desired lay by more than 60°, and the biggest tree deviated the most from the desired lay. Excluding the trees with a lay deviation of more than 60° resulted in a mean lay deviation of 9.7° for F_1C_0 and 8.3° for F_1C_1. The difference was not statistically significant.

No hangups occurred in the directional felling, nor did lateral split, "barberchair". Buttresses were not found to cause any problems in directional felling. Nine trees had a lay deviation of at least 20°. Out of this, five had presence of rot. For two trees the hinge broke too early, causing the tree to fall before work had been completed. For the remaining two trees, no apparent reason was found. Rot was present also on seven of the trees that fell within 20° of the desired lay. The hinge did not break too early on any of the trees that fell within 20°.

Aim deviation was as an average 46° (Figure 2). Influence of aim deviation on lay deviation was not significant, neither when used singly nor when multiplied by distance between gravity point and centre of stump.

Table 1 Basic information on the samples of trees

Treatment	No. of trees	Dbh range (cm)	Mean Dbh (cm)	Height range (m)	Mean height (m)	Ground inclination (degree)	Mean ground (degree)
Directional felling	41	62–165	89	33.5–81.3	51.8	0–45	19

Table 2 Results of climber cutting on feasibility of felling (outliers refer to trees with a lay deviations > 60°)

Treatment	Mean lay deviations (degree)	Mean lay deviations (outliers excluded) (degree)
Directional felling without climber cutting	17.0	9.7
Directional felling with climber cutting	20.5	8.3

Table 3 Feasibility of directional felling (percentage of total number of felled trees, n = 41)

Lay deviation	Percentage
< 20°	78
20–30°	12
30–60°	0
> 60°	10

Tree size × ground inclination and extent of rot had a significant effect on lay deviation (Table 4).

Average stated felling range was 181°, with a minimum of 93° and a maximum of 360° (Figure 3). Of factors assumed to influence felling range only distance to projected gravity point was significant (Table 5).

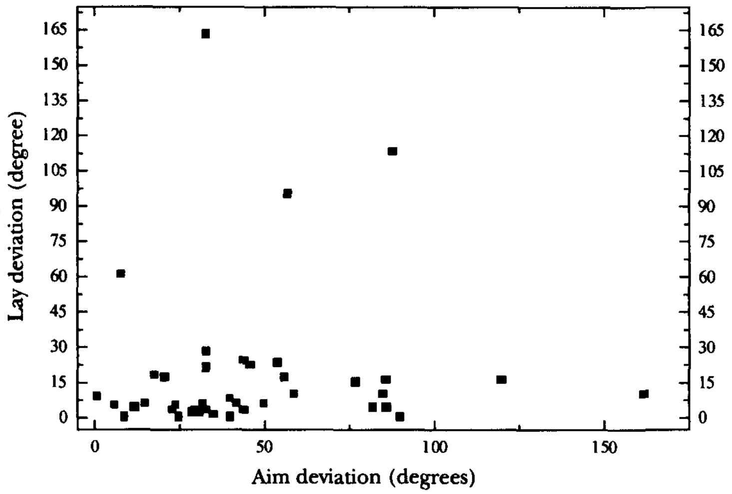

Figure 2 Lay deviation over aim deviation

Table 4 Analysis of factors assumed to influence deviation from desired lay, lay deviation (n = 37)

Variables	Regression coefficient	Significance of *t*	Adjusted r^2
Included			
Tree size × ground inclination (m × degrees)	0.002	0.000	0.541
Extent of rot at stump level (%)	0.818	0.011	
(Constant)	- 5.597	0.311	
Excluded			
Closeness of desired lay to felling range border (degrees)		ns	
Ground inclination (degrees)		ns	
Aim deviation (degrees)		ns	
Moment (m^3 × m)		ns	
Tree size (m^3)		ns	

P_{out} = 0.05

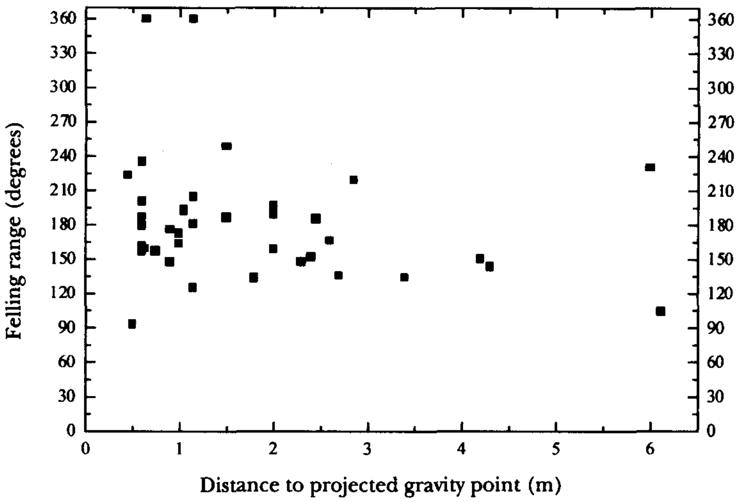

Figure 3 Felling range over distance to projected crown gravity point

Table 5 Analysis of factors assumed to influence felling range (n = 39)

Variables	Regression coefficient	Significance of *t*	Adjusted r^2
Included			
Distance to projected gravity point (m)	- 14.197	0.040	0.085
(Constant)	202.998	0.000	
Excluded			
Extent of rot at stump level (%)		ns	
Bole inclination (degrees)		ns	
Ground inclination (degrees)		ns	
Tree size × ground inclination (m^3 × degrees)		ns	
Tree size (m^3)		ns	

$P_{out} = 0.05$

Discussion

Selecting the nearest tree from a given point may have introduced a systematic bias in favour of solitary trees, or trees at the edge of clusters. Such trees might differ slightly in terms of difficulty in directional felling. Furthermore, a small number of trees that, in normal logging operations, would have been rejected by the feller at time of felling because of signs of rot, might have been included in this study. It is our belief, however, that in general the trees felled in this study were a representative sample of loggable trees in the area.

This study indicated that directional felling can be used to save potential crop trees from damage, provided that the amount of potential crop trees is similar to that of this study.

Results suggest that a trained feller should usually be able to fell trees within 20° of the desired lay, but that "bull's eye" accuracy cannot be expected, as logs often bounce and slide downhill and/or sideways in manners difficult to predict. Allowances for deviations must thus be made when determining desired lays. For a tree 50-m high a lay deviation of 20° means a sideways deviation of 17 m from the desired lay at the top of the tree. Directional felling appears to have been more successful in the study by Pinard *et al.* (1995), but, as is stressed by the authors, fellers may have rejected trees they felt uncertain about giving them undue influence on results, a possibility denied to the feller in this study.

No effect of climber cutting on lay deviation was detectable. An explanation could be that when trees as big as these fall, their kinetic energy is so great that climbers are too weak to have any influence on falling direction.

The observed influence of tree size combined with ground inclination on lay deviation (Table 4) suggests that extra care must be taken when deciding whether or not to fell big trees in steep slopes. The potential of felling such trees using accessories, e.g. hydraulic jacks and cables, needs a separate study.

Stated felling ranges seemed reliable and possible for full utilisation, as the feller was asked to fell trees 46° away from their lean. This did not influence lay deviation. Results are thus well in agreement with Conway (1976).

Occasional trees will fall in an unpredictable direction. Factors that could cause a total loss of control include bad misjudgement of projected gravity point (not unlikely if crowns are only partly visible), weakened or irregular fibres in the hinge and also wind when trees fall (even slight blows of wind may entirely change falling direction). In Malaysia, mishaps occur in one tree out of ten (Klasson, pers. comm.), which was also the case in this study. The 26% "off course" quoted from Sarawak by Bruenig (1996) are difficult to compare with, as it is unclear what is meant by "off course", and no mention is made about how well-trained fellers were. Thus, we could not compare their level of experience with that of the feller in this study.

Desired lays were in this study selected by trained forest rangers. If directional felling is to be widely applied, this may be unpractical. Combining directional felling with pre-aligned skid trails, however, made selection of desired lays easier. Ease of skidding would then be the first priority, and PCTs the second. Trained fellers could probably select desired lays themselves in such a system. As feasible felling ranges were mostly around 180°, trees could generally be felled towards a skid trail, while considerations were taken to PCTs. Lay differences recorded for unsupervised felling gave some cause for concern. A major reason for the discrepancy was probably lack of training and guidelines. Training will prove necessary if directional felling is to be implemented on a larger scale. Also there is scope to improve work safety through training, as large lay differences are a major safety problem.

This study showed that directional felling can be used to save potential crop trees and is feasible in steep and broken tropical rain forest, if deviations of 20° can be tolerated. Trained fellers can reliably set ranges in which they are capable of felling trees accurately. Ranges should typically be around 180°, somewhat less if distance to projected gravity point is great. The influence of distance to gravity point, in other words, the lean combined with the size of the tree, on felling range was significant (Table 5 and Figure 3). To the silviculturist this means that selected potential crop trees can be saved, and that damage from skidding can be reduced through felling towards pre-aligned skid trails.

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