

Factors influencing the branchiness of young Scots pine trees

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We studied the relationship between stand- and tree-level variables and branchiness of young Scots pine (*Pinus sylvestris* L.) trees. Branchiness class (branchy–not branchy) was visually determined based on the future saw timber quality. The study material consisted of tree-level inventory data for 140 young Scots pine stands, which were repeatedly measured over 15 years, comprising 1976 trees in total. The plots covered the most common site types for Scots pine in all the important wood production regions in Finland. The mean stand height was 3.4 and 8.8 m at the first and last measurement, respectively. The high stand density and the pre-commercial thinning that was performed were related to the lower probability of branchiness. On the other hand, a tree's large diameter growth resulted in a higher probability of branchiness. The results indicated that the branchiness of young Scots pine trees can be anticipated based solely on the stand-level information available at the initial phase of stand development. However, tree-level information will slightly improve the prognosis of future branchiness.

Introduction

The production of high-quality timber is the main management goal of Finnish Scots pine (*Pinus sylvestris* L.) stands (Hyvän metsänhoidon suositukset, Anonymous 2006). The size and straightness of the stem and the branchiness in particular are the most important factors affecting the timber quality of Scots pine (Nordic timber..., Anonymous 1994). The initial development of a stand is crucial because the quality of the butt log is determined during the first decades after regeneration.

Stand density, regeneration method and site fertility affect branchiness. Trees with wide spacings usually have thick branches (e.g. Baldwin *et al.*, 2000; Tong and Zhang, 2005; Liziniewicz *et al.*, 2012), but the relationship between branch diameter and stand density is not linear. In young Scots pine stands, when the stand density exceeds 2500 trees ha⁻¹, the effect of stand density on branch diameter decreases and eventually levels off (Kellomäki and Tuimala, 1981; Kellomäki, 1984; Pukkala *et al.*, 1992). Heavy and early pre-commercial thinning usually increases the branchiness of several tree species, e.g. Scots pine (Varmola and Salminen, 2004), Douglas-fir (Briggs *et al.*, 2008), loblolly pine (*Pinus taeda* L.) (Baldwin *et al.*, 2000), red spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.) (Weiskittel *et al.*, 2009). In Scots pine, the stand density after pre-commercial thinning has a greater effect on branch diameter than the exact timing of pre-commercial thinning (Ulvcrona *et al.*, 2007). Moreover, branch diameter can be decreased by increasing stand density at the expense of tree growth only. Varmola (1980), Mäkinen and Colin (1998) and Gort *et al.* (2010) showed that site fertility and stand density had no effect on branchiness if stem dimensions were taken into account.

Natural regeneration and sowing are usually favoured when producing high-quality timber (Varmola, 1996; Agestam *et al.*, 1998). For example, Uusvaara (1991) found thicker branches in planted and seeded Scots pine stands than in naturally regenerated ones. Kärkkäinen and Uusvaara (1982) noted that the regeneration method does not *per se* affect branchiness, but the differences in branchiness are due to the higher growth rate in the planted stands. Fertile sites are usually planted with relatively low seedling density, in contrast to the naturally regenerated infertile sites. However, increasing site fertility generally results in thicker branches (Kellomäki, 1984; Turkia and Kellomäki, 1987; Lämsä *et al.*, 1990; Uusvaara, 1991). Fahlvik *et al.* (2005) also noted that the differences in branchiness between the regeneration methods were caused by the differences in initial stand density. Accordingly, Strand *et al.* (1997) noted small differences in branchiness between planted and naturally regenerated stands of the same age and initial density.

In recent years, the branchiness of Scots pine has been studied quite often (e.g. Varmola and Salminen, 2004; Fahlvik *et al.*, 2005; Ulvcrona *et al.*, 2007). In Finland and Sweden, most of the previous studies have been based on planting density or pre-commercial thinning experiments or on mature stands. The experiments were usually in pure Scots pine stands with a homogenous spatial structure. Thus, the results do not completely represent the development of normal commercial forests. In addition, most of the studies were only based on one measurement occasion.

Both empirical (e.g. Houllier *et al.*, 1995; Mäkinen and Colin, 1998, 1999; Petersson, 1998) and process-based models (e.g. Mäkelä and Mäkinen, 2003; Ikonen *et al.*, 2009) have been

developed to compare the effects of different management regimes on branch properties along Scots pine stems. The branch models combined with growth models enable the predictions of the 3D structure of stems and logs. However, the prediction of wood properties without detailed 3D models can provide adequate information for practical stand management and decision making (Lyhykäinen *et al.*, 2009). Less detailed models are adequate, for example, in young stands for comparing the forthcoming timber quality under different management regimes. When combined with a stand growth simulator, models producing at least rough estimates of the end product distribution obtained from a stand permit us to take into account not only the yield but also the timber quality.

In this study, we used an extensive inventory data on young Scots pine stands, measured repeatedly over 15 years. The aim of our study was to analyse the relationship between stand and tree-level variables available at different phases of stand development and future branchiness. In particular, we aimed to evaluate which easily measurable variables usually measured for forest management purposes or in forest inventories provide information on future branchiness.

Materials and methods

Study plots

The material consisted of repeatedly measured inventory growth plots throughout Finland (TINKA) established by the Finnish Forest Research Institute during 1984–1986 (Gustavsen *et al.*, 1988) (Figure 1). The TINKA data are a sub-sample of the plots measured in the Seventh National Forest Inventory (NFI7) in Finland (Tomppo, 2006). The data represent successfully regenerated young Scots pine stands with a dominant height below 5 m at the first measurement (Gustavsen *et al.*, 1988). The regeneration methods were natural regeneration, sowing and planting. The sites were classified as fresh, dryish and dry according to Tonteri *et al.* (1990), corresponding to Cajander's (1949) *Myrtillus*, *Vaccinium* and *Calluna* forest site types, respectively. The sample plots were established as hidden plots, i.e. were unbeknownst to the forest owner, so the presence of the sample plot had no effect on stand management practices.

After establishment (1984–1986), the plots were re-measured twice: 5 (1989–1991) and 15 years later (2000–2001). In this study, stands for which the first commercial thinning was performed during the measurement period or the heights of the sample trees were below 1.3 m at the first measurement and those that were not measured at the third measurement occasion were excluded. The remaining dataset consisted of 140 stands. The data from the first and third measurements was used because of the short interval (5 years) between the first and second measurement. The data from the TINKA plots have previously been used for growth modelling (Hynynen *et al.*, 2002; Huuskonen and Miina, 2006; Siipilehto, 2008) and studying the effects of silvicultural practices on stand characteristics (Huuskonen *et al.*, 2008).

Measurements

In each stand, a cluster of three plots was established. The first plot was located in the centre of the NFI7 plot, and the other plots with a distance of 40 m between the plots (Gustavsen *et al.*, 1988). The size of the circular plots varied between 250–1794 m² (average, 705 m²) according to the stand density, so that ~100 crop trees were measured as tally trees in each stand. In each stand, the size of all the plots was, however, the same. A concentric, smaller circular sample tree plot was located within each tally tree plot, the area being equal to one-third of the tally tree plot. Thus, ~30 crop trees were measured as sample trees in each stand.

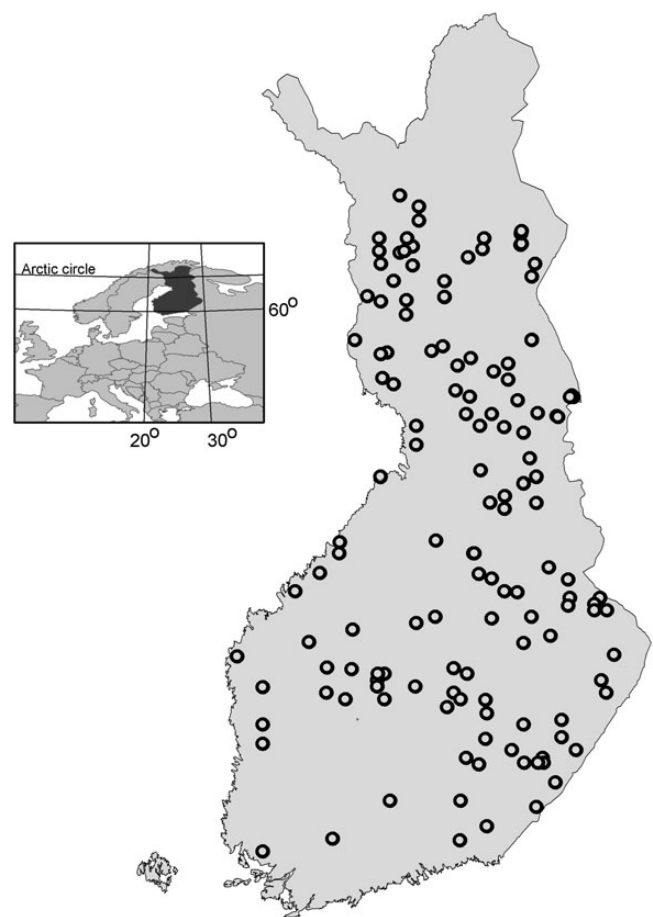


Figure 1 Location of the plots used in this study ($N = 140$).

A tree was defined as a crop tree if it was assumed to reach merchantable stem size at the time of the first commercial thinning. The detailed criteria for a crop tree varied according to the regeneration method and the management history of the stand. In managed stands, i.e. those for which an initial clearing of sapling stand was carried out, all conifers (height > 10 cm) were classified as crop trees. In managed stands, broad-leaved trees were also accepted as crop trees if they were shorter than the coniferous trees. The spatial distribution and relative tree height compared with the neighbour trees were also taken into account. In the naturally regenerated and sowed unmanaged stands, ~30–35 of the most vigorous trees per tally tree plot (≈ 3000 trees ha⁻¹) were defined as crop trees (Gustavsen *et al.*, 1988).

At the first measurement, the site characteristics and past stand management were determined. In addition, the tree species, regeneration method, tree height, diameter at stump height ($d_{0.1m}$), diameter at breast height and diameter at 30 per cent height ($d_{0.3}$) were recorded for the tally trees. For all sample trees, the height of the crown base and diameter of the thickest branch were measured. The crown base was defined as the lowest whorl with at least one living branch that was separated from the other living whorls above it by no more than one dead whorl. The age at breast height was measured for three sample trees, and the total age was measured for one sample tree per plot. Tree age was determined based on either the number of whorls or the increment cores.

At the third measurement, the stem diameter at breast height was measured for all the tally trees. The tree height and the height of the crown base were measured for the sample trees. At each re-measurement, the stand management actions performed after the

previous measurement were also recorded. In addition, each sample tree was visually assigned to a branchiness class (branchy–not branchy) based on the future saw timber quality (Gustavsen *et al.*, 1988). The future timber quality in lower part of the stem was assessed based on the number and size of the branches, according to the final-product oriented classification, including three classes: (I) branch-free, (II) sound knots and (III) dead knots (Heiskanen and Siimes, 1960). The not-branchy trees were assumed to fulfil the requirements of Classes I or II when mature. The congruency of the visual classification was ensured by the detailed instructions and training of the field teams before the measurements.

The dataset consisted of 1976 sample trees. Almost half (43 per cent) of them were naturally regenerated, 23 per cent were seeded, and 34 per cent were planted (Figure 2). The sample trees were located on every typical mineral site for Scots pine: fresh (30 per cent), dryish (53 per cent) and dry (17 per cent) (Figure 2). At the first and third measurement, the average dominant heights of the stands were 4.3 and 10.0 m, and the mean heights of the sample trees were 3.4 and 8.8 m, respectively. The dominant height was calculated as the mean height of the 100 thickest trees ha^{-1} of the main tree species. At the first and third measurement, there were on average 1688 and 1980 crop trees ha^{-1} , respectively.

Data analysis

Stand-level variables were calculated using the KPL software developed by the Finnish Forest Research Institute (Heinonen, 1994). In the calculation, plots within the same stand were combined. At the third measurement, the heights of the tally trees within a given plot were predicted using a height model based on the height measurements of the sample trees on the plot using Näslund's height curve (Näslund, 1936). The mean diameter was calculated as the arithmetic mean diameter of the crop trees. The long-term average (1951–1980) of the annual effective temperature sum (degree days (dd) sum of degrees by which the daily average temperature exceeds $+5^{\circ}\text{C}$), was predicted for each stand using the interpolation method by Ojansuu and Henttonen (1983). The interpolation was based on data from the weather stations of the Finnish Meteorological Institute.

A modelling approach was adopted in order to reveal general relationships and trends within our data. Three models were developed for predicting branchiness at the third measurement. In the first model, only the information available at the regeneration phase (regeneration method, site type, temperature sum and their interactions) was used as the independent variables (Table 1). In addition to the variables used in the first model, the second model included the tree- and stand-level variables from the first measurement (diameter growth rate at stump height,

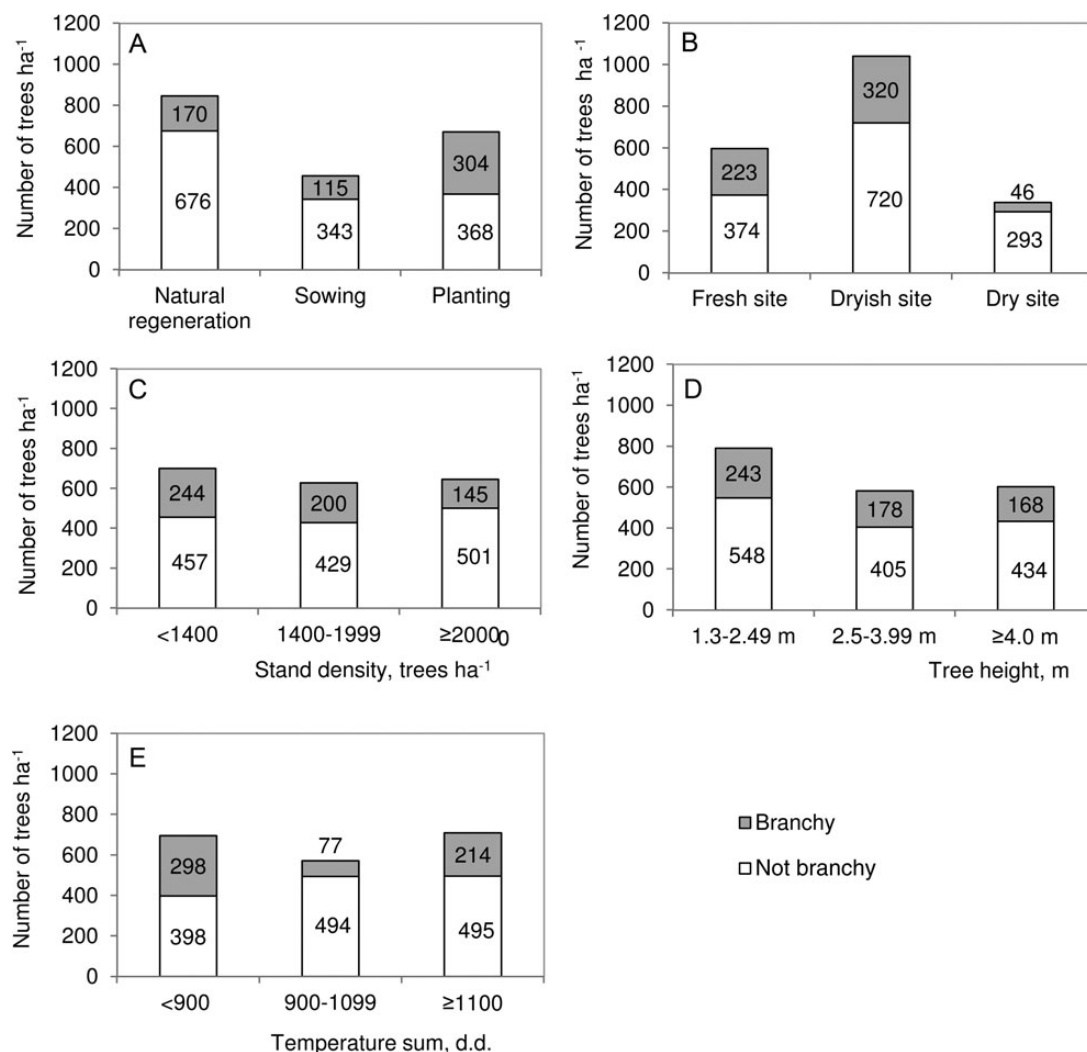


Figure 2 Average and total (within the bars, $N=1976$) number of the sample trees in the branchiness classes (branchy, not branchy) at the first measurement by (A) regeneration method, (B) site type, (C) stand density, (D) tree height and (E) temperature sum.

Table 1 Description of the variables used in the models

Variable	Description	Scale
Natural regeneration	Regeneration method	0/1
Sowing		0/1
Planting	Site type	0/1
Fresh		0/1
Dryish		0/1
Dry		0/1
Temperature sum	Effective temperature sum, sum of daily average temperatures above +5C/1000	°C year ⁻¹
Height growth	Average annual height growth of a tree from its birth to the first measurement	dm year ⁻¹
Diameter growth	Average annual diameter growth of a tree from its birth to the first measurement, measured at stump height	mm year ⁻¹
Crown ratio	Crown length/tree height × 100, at the first measurement	%
Pre-commercial thinning	Pre-commercial thinning performed before the first measurement	0/1
Stand density 1	Stem number of crop trees at the first measurement/1000	trees ha ⁻¹
Stand density 3	Stem number of crop trees at the third measurement/1000	trees ha ⁻¹

height growth rate, crown ratio, number of crop trees ha⁻¹ and their transformations) (Table 1). In the third model, the number of crop trees ha⁻¹ at the third measurement was also used (Table 1).

The logistic model was used because the binomial distribution of dependent variable. The mixed model with random effect at stand level was used because of the hierarchical structure of the data. The logistic regression was defined for the probability of a branchy tree (branchy = 1, not branchy = 0) as follows:

$$\text{logit}(P_{ij}) = \ln \left[\frac{P}{1 - P} \right] = \beta_0 + X_{ij}\beta_{ij} + u_i \tag{1}$$

where P is the probability that an event occurs and X_{ij} are the independent variables for stand (i) and tree (j). u_i is the random effect for a stand. The dependent variable (branchy – not branchy) was assumed to follow a binomial distribution. The independent variables were successively added to and removed from the models based on their P -values ($P < 0.05$). When the categorical variables were formed, the most common situation of the stands was selected as the reference level, e.g. dryish site, natural regeneration and pre-commercial thinning performed. The models were compared according to the goodness-of-fit statistics ($-2 \log \text{likelihood}$), Akaike's information criterion (AIC) and Bayesian information criterion (BIC). To detect multicollinearity among the independent variables, a linear regression analysis was conducted with the variables of interest to examine the tolerance statistic (Allison, 2012). The predicted probabilities were transformed back to the original scale. The commonly used value of 0.5 as the separation between the events and non-events has been questioned in cases of rare binary events (Hein and Weiskittel, 2010). Therefore, cut point analysis was used to test the effect of optimal cut point value for classifying the predictions into binary outcomes (branchy – not branchy).

Odds ratios can be used to characterize the effect of explanatory variables on binary responses (Rita and Komonen, 2008). The effects of the independent variables on the probability of branchiness were compared based on the odds ratios (Rita and Komonen, 2008). The odds ratio is a measure expressing the relative increase (odds ratio > 1.0) or decrease (odds ratio < 1.0) of the dependent variable when the independent variable increases by one unit (Hosmer and Lemeshow, 1989). The effects of changes in the explanatory variables on binary responses were compared based on the odds ratios ($a^x = b$), where a and b are the odds ratios of explanatory variables a and b (Rita and Komonen, 2008). The NLMIXED, LOGISTIC and REG procedures of SAS 9.3 were used in the analysis.

Results

Stand-level information: Model 1

The regeneration method and temperature sum were related to the probability of branchiness. Planting increased the probability of branchiness compared with natural regeneration and sowing, but sowing and natural regeneration did not significantly differ from each other (Table 2). Furthermore, with increasing temperature sum, the probability of branchiness decreased. Stand was found to be significant as a random effect.

The comparison of the effects of the variables included in the models was based on the odds ratios. Thus, the change of the regeneration method from natural regeneration to planting increased the branchiness as much as a decrease of 526 dd in the temperature sum (Table 2).

Tree- and stand-level information: Model 2

Adding tree- and stand-level information from the first measurement gave rise to a more accurate model fit (Table 2). The high diameter growth rate at stump height resulted in a higher probability of branchiness. On the other hand, a high height growth rate was related to a lower probability of branchiness. In addition, with increasing crown ratio, the probability of branchiness increased. In the stands with pre-commercial thinning, the probability of branchiness was lower, but the crop tree density at the first measurement *per se* was not significant. In contrast to Model 1, regeneration methods and temperature sum were not significant. However, on dry site the probability of branchiness was lower than on dryish and fresh sites. The fresh site did not significantly differ from dryish site.

Comparison of model estimates based on the odds ratios of Model 2 showed that, the effects of planting and sowing, compared with natural regeneration, were of approximately the same magnitude but in the opposite direction (Table 2). The decrease in the probability of branchiness due to pre-commercial thinning is equivalent to the decrease in diameter growth rate of 1.14 mm year⁻¹ at stump height. Increasing annual height growth

Table 2 Parameters, *P*-values and odds ratios of the logistic regression models for the probability of branchiness

Variable	Model 1				Model 2				Model 3			
	Estimate	<i>P</i> -value	Odds ratio	Confidence interval of odds ratio, 95%	Estimate	<i>P</i> -value	Odds ratio	Confidence interval of odds ratio, 95%	Estimate	<i>P</i> -value	Odds ratio	Confidence interval of odds ratio, 95%
Constant	0.7128	0.5026			−26.9852	<0.0001			−29.0242	<0.0001		
Sowing ¹	0.2515	0.6135	1.286	0.48–3.43								
Planting ¹	1.3476	0.0011	3.848	1.73–8.55								
Fresh site type ¹					0.4648	0.4182	1.592	0.51–4.94	0.3190	0.5593	1.376	0.47–4.04
Dry site type ¹					−1.7174	0.0243	5.570 ^{−1}	0.04–0.80	−1.4790	0.0417	4.389 ^{−1}	0.05–0.95
Temperature sum	−2.5637	0.0163	12.984 ^{−1}	0.01–0.62								
Height growth					−2.1493	<0.0001	8.579 ^{−1}	0.07–0.20	−2.1197	<0.0001	8.329 ^{−1}	0.07–0.21
Diameter growth					1.6117	<0.0001	5.011	3.89–6.46	1.5944	<0.0001	4.925	3.83–6.34
Crown ratio					0.2665	<0.0001	1.305	1.22–1.39	0.2822	<0.0001	1.326	1.24–1.42
PCT ¹					−1.8418	0.0006	6.308 ^{−1}	0.06–0.45	−1.4106	0.0061	4.098 ^{−1}	0.09–0.66
Stand density 1									−1.5767	0.007	4.839 ^{−1}	0.07–0.65
Stand density 3									1.5695	<0.0001	4.804	3.32–9.95
δ ²	3.2413	<0.0001			6.5410	<0.0001			5.6797	<0.0001		
AIC	1948				1470				1454			
BIC	1963				1494				1484			
−2 log L	1939				1454				1434			

¹The references of the models were natural regeneration, dryish site and no pre-commercial thinning (PCT).

rate by 10 cm year^{-1} decreased the probability of branchiness as much as decreasing the diameter growth rate at stump height by $0.75 \text{ mm year}^{-1}$. Furthermore, increasing crown ratio by 1 per cent increased the probability of branchiness as much as decreasing the annual height growth rate by 1.2 cm.

Current tree-level information: Model 3

In addition to the variables used in Models 1 and 2, the current crop tree density (stems ha^{-1}) was used in Model 3, which further improved the model fit. The high crop tree density during the first measurement and low density at the third measurement resulted in a lower probability of branchiness (Table 2).

The odds ratios of Model 3 showed that the decrease in the probability of branchiness due to the site being dry instead of dryish is equivalent to the decrease due to a lower diameter growth rate of 0.9 mm year^{-1} at stump height (Table 2). An increase in the crop tree density at the first measurement by $1000 \text{ trees ha}^{-1}$ decreased the probability of branchiness as much as a decrease in the diameter growth rate of $0.99 \text{ mm year}^{-1}$. Furthermore, increasing the crop tree density at the third measurement by $1000 \text{ trees ha}^{-1}$ increased the probability of branchiness as much as the decreasing the annual height growth rate by 7.4 cm year^{-1} .

Comparison of the stand and tree-level information

The use of more detailed information on the stands and trees resulted in a more accurate model fit (Figure 3); 79.6, 87.2 and 87.5 per cent of observations were correctly predicted (branchy tree vs not branchy) by Models 1, 2 and 3, respectively. Table 3 shows the number of trees predicted as being in the correct or incorrect branchiness class (branchy–not branchy) by Models 1, 2 and 3. The sensitivity of the model in terms of true positive

(branchy) hits increased from 59.3 to 74.7 per cent from Model 1 to 3 (Table 3). The specificity of the model in terms of true negative (not branchy) hits varied only slightly among the models (88.2–92.9 per cent) (Table 3). When the cut point for classifying the tree was changed from the commonly used value of 0.5 to the optimal one, the sensitivity increased and was highest (86.6 per cent) for Model 3 and lowest for Model 1 (83.4 per cent) (Table 3).

Discussion

We studied the branchiness of young Scots pine trees and examined how accurately branchiness can be anticipated based on different stand- and tree-level variables available at different development stages of the stand. The model approach was used in order to reveal general trends and relationships. The logistic models were used instead of linear regression models because of the binary distribution (branchy–not branchy) of dependent variable.

Adding the tree-level information from the first measurement slightly improved the models; 80 and 87 per cent of the trees were classified correctly using Models 1 and 2, respectively. This finding indicates that based solely on the stand-level information, the overall branchiness of Scots pine trees can be predicted at the early stage of stand development.

Furthermore, the exact stand density information did not markedly improve the accuracy of the branchiness estimated within the stand densities commonly applied in the commercial forests. The branchiness was predicted correctly with 87 per cent of trees with Model 2, and when the stand density information from the first and third measurements was added, the correct prediction was 88 per cent with Model 3.

The results of this study showed that high stand density decreased the probability of branchiness. This result is in accordance with earlier studies (e.g. Tong and Zhang, 2005; Auty *et al.*, 2012; Liziniewicz *et al.*, 2012). Based on our results, the probability of branchiness was especially low in the stands pre-commercially thinned with low intensity, i.e. when only the defected trees were removed (cf., Varmola and Salminen, 2004; Fahlvik *et al.*, 2005; Ulvcróna *et al.*, 2007). The probability of branchiness also decreased with increasing temperature sum (Model 1). However, stand density varied in the south–north direction; in the regions with temperature sums below 900 dd and over 1100 dd., the average stand density was 1261 and 2134 trees ha^{-1} , respectively. Therefore, in Model 1, the relationship between temperature sum and the probability of branchiness could also be due to the differences in stand density.

Our results showed that the regeneration method was significantly related to branchiness (Model 1). In the planted stands, the probability of branchiness was higher, which is in line with earlier studies (Uusvaara, 1991; Agestam *et al.*, 1998). According to Kärkkäinen and Uusvaara (1982), the differences between the regeneration methods are caused by differences in the growth rate induced by the lower stand density in the planted stands. This is in line with our result that if growth rate in terms of height and diameter growth were included in the Model (2 and 3) regeneration method was not significant variable.

The growth rate was also related to branchiness. In our models, the high diameter growth rate increased the probability of branchiness (cf., Nikinmaa, 1992; Mäkelä and Vanninen, 2001). Our results

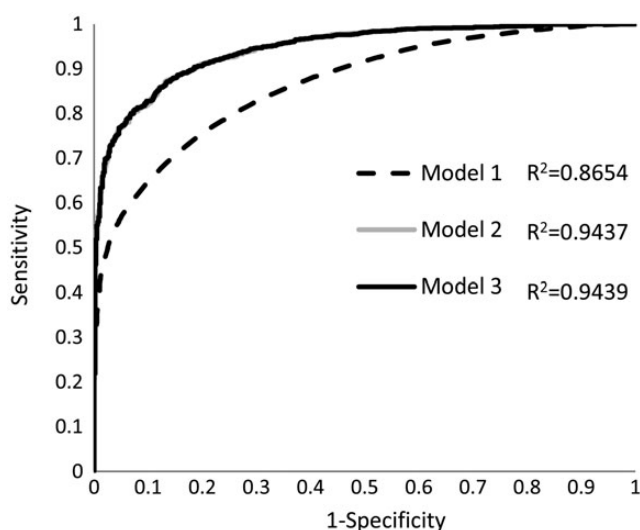


Figure 3 ROC curves of different models. The height of the ROC curve describes the ability of the model to predict the phenomenon, and the area under the ROC curve (AUC) depicts the model accuracy. The ROC curves of Model 2 and Model 3 follow nearly the same line and thus the line of Model 2 is not well visible.

Table 3 Observed and predicted (Models 1, 2 and 3) portion of trees (%) in the branchiness classes (branchy, not branchy) using two different cut points: 0.5 and the optimal cut points (displayed within the brackets)

Observed	Predicted	Model 1		Model 2		Model 3	
		Not branchy	Branchy	Not branchy	Branchy	Not branchy	Branchy
	Not branchy	88.2 (72.4)	11.8 (27.6)	92.6 (87.3)	7.4 (12.7)	92.9 (87.1)	7.1 (12.9)
	Branchy	40.7 (16.6)	59.3 (83.4)	25.3 (13.2)	74.7 (86.8)	25.3 (13.4)	74.7 (86.6)

Optimal cut points: Model 1 = 0.557, Model 2 = 0.741 and Model 3 = 0.737.

also showed that the high height growth rate slightly decreased the probability of branchiness when the diameter growth rate was already included in the model. Thus, a high h/d ratio resulted in a lower probability of branchiness.

We found that the increasing site fertility increased the branchiness (Models 2 and 3). The probability of branchiness was lower for the dry (infertile) sites than for the fresh and dryish sites. On the more fertile sites, the trees allocate more photosynthates to branch growth at the expense of root growth (Brouwer, 1962; Nikinmaa, 1992). However, Varmola (1980) and Mäkinen and Colin (1998) showed that site fertility and stand density had no effect on branchiness when tree size was taken into account. In contrast, according to our results, when the diameter growth rate was included in the model, the probability of branchiness was still significantly lower for the dry site than the more fertile sites. Thus, our results support the hypothesis of site-fertility-induced changes in the allocation pattern of photosynthates within a tree. In the Model 1 the site fertility was not significant variable when the regeneration method was significant. This is due to correlation between regeneration method and site type. Infertile sites were commonly naturally regenerated or sown and more fertile sites were planted.

Based on our results, crown ratio increased the probability of branchiness. Lämsä *et al.* (1990) found for Scots pine that dominant position, in terms of greater relative stem diameter, increased the number of branches. In addition, Varmola (1996) reported that the diameter of the thickest branch of a tree increased with increasing relative stem diameter. Earlier studies have shown that the crown ratio decreases with increasing stand dominant height and that at a given height, the crown ratio increases with increasing stem diameter (Assmann, 1970; Hynynen, 1995; Huuskonen *et al.*, 2008).

This study was based on extensive inventory data including the most common site types on mineral soil, the common regeneration methods of Scots pine, and all important wood production areas in Finland. Moreover, the data covered 15 years of stand development during the most influential period in terms of the formation of butt log properties. Most of the previous studies on the branchiness of Scots pine are based on well-managed spacing and pre-commercial thinning experiments with homogenous growing conditions. In contrast, the NFI data represent a large sample, including a wide range of sites and stand conditions, and thus represent the various conditions and management practices occurring in forestry practice.

Several field teams measured the dataset and visually classified the external branchiness of the stems. To evaluate the quality of the assessment, we checked for a possible effect of tree size on

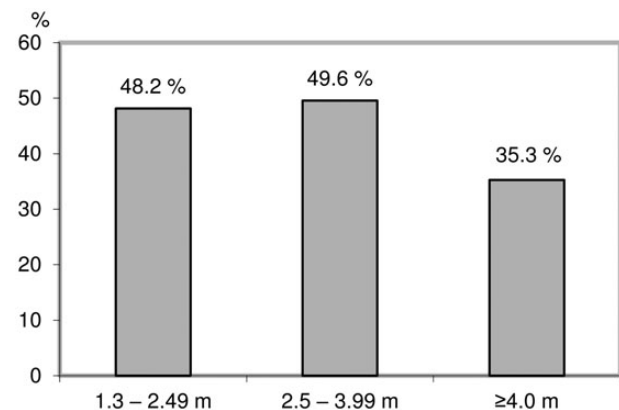


Figure 4 Proportion of branchy dominant trees (relative height > 1.2) in relation to the number of sample trees in each stand by height class at the third measurement ($N = 853$).

branchiness classification, i.e. whether larger trees were more likely to be classified as branchy. However, the proportion of branchy dominant trees was approximately the same in all size classes, and the largest trees actually had the lowest proportion of branchy trees (Figure 4).

The cut point analysis showed that when predicting relatively rare events, the use of an optimal cut point for each model, instead of the commonly used P -value of 0.5, resulted in a clear improvement in the correct classification of trees (cf., Hein and Weiskittel, 2010). In our case, the use of optimal cut points increased the sensitivity (true positives, the observed branchy/predicted branchy) of the models but had no marked effect on the specificity (true negatives, observed not branchy/predicted not branchy) of the models.

Conclusions

The results of this study provide an overview of branchiness and the factors affecting it. The results of this study showed that the future branchiness of young Scots pine trees can be fairly accurately anticipated based solely on the information available during the regeneration phase. Anticipating branchiness can be further improved by incorporating information about the diameter growth rate, tree height growth rate and stand density at the early stage of the stand development. Light pre-commercial thinning proved to be an effective means of reducing the average branchiness of the remaining crop trees to be harvested during the stand rotation. Thus, the forest owner is able to affect the

branchiness by selecting sites and management regimes in appropriate way.

Conflict of interest statement

None declared.

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