XV WORLD FORESTRY CONGRESS
Building a Green, Healthy and Resilient Future with Forests
2–6 May 2022 | Coex, Seoul, Republic of Korea

Modelling pine and spruce wood mechanical properties in different initial stand density plantations in Lithuania

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Scope and main objectives

Two main parameters of wood quality in constructions are wood modulus of elasticity (MOE) and bending strength (MOR). To understand what kind of quality wood we are growing in our forests and how environment and forest management could affect wood quality parameters, we need to model these parameters by stand, tree, and sample results. This would help to predict MOE and MOR for the future stands.

To determine the influence of stand density and thinning intensity on wood mechanical and physical properties of Scots pine and Norway spruce, the data was obtained from experimental trials plots, which were established in 1990 by Institute of Forestry. The experimental object was divided to a smaller trial plots with different initial stand density: 2 plots with 3000-4400 trees per hectare, 2 plots with 2000-2400 trees per hectare, 2 plots with 1000-1200 trees per hectare. In these trial plots different thinning programs were used 3; 2; 1 time. From each trial plot 6 model trees were chosen (38 Spruce and 76 Pine trees). Models were created by SAS statistical package. General linear regression models were chosen to create 4 models for prediction of: dynamic modulus of elasticity for log (MOElog); dynamic modulus of elasticity for samples (MOEdyn); global static modulus of elasticity (MOE) and bending strength (MOR) All parameters for creating models were chosen as random effects. Stand parameter was stand density (SD). Tree parameters were diameter at breast high (DBH), competition index (CI), and log high (LH). Sample parameters were knot at fracture point (K) and sample wood density (WD).

Results

The correlation coefficients between stand and tree characteristics with wood quality parameters for Scots pine and Norway spruce are presented in Tables 1 and 2, respectively. Generally, the stand and tree characteristics showed various degrees of correlation with the wood quality parameters. Both MOE and MOR were found to be highly correlated. There were significant relatively weak correlations between wood properties and most tree characteristics. For example, relatively weak correlations between MOE and MOR with tree DBH and WD were observed.

Table 1. Correlation coefficients among tree characteristics and wood quality parameters for the model Norway spruce trees.

Norway Spruce	LH	CI	DBH	K	WD	MOElog	MOEdyn	MOE	MOR
SD	-0.00090	**0.23369**	**-0.28677**	**-0.14236**	**0.23424**	**0.29680**	**0.27024**	**0.26541**	**0.18395**
LH		0.01550	-0.01059	0.11263	0.10309	**0.23759**	**0.38187**	**0.32944**	**0.22235**
CI			**-0.21350**	-0.02895	-0.08680	0.01237	0.01159	0.00396	0.03057
DBH				-0.01409	**-0.23320**	**-0.20703**	**-0.26073**	**-0.22479**	**-0.17936**
K					0.03022	-0.06198	**-0.17041**	**-0.22943**	**-0.38071**
WD						0.03695	**0.41313**	**0.40216**	**0.27149**
MOElog							**0.32107**	**0.28920**	**0.21051**
MOEdyn								**0.91306**	**0.69611**
MOE									**0.76941**

Table 2. Correlation coefficients among tree characteristics and wood quality parameters for the model Scots pine trees.

Scots Pine	LH	CI	DBH	K	WD	MOElog	MOEdyn	MOE	MOR
CI	-0.00526	**0.48620**	**-0.32510**	**-0.24867**	**0.17347**	**0.34038**	**0.35029**	**0.30452**	**0.13002**
LH		-0.00381	0.06343	0.05330	**-0.10301**	**0.24339**	**0.12273**	**0.12935**	-0.08030
CI			**-0.52403**	**-0.24144**	**0.19113**	**0.22414**	**0.23632**	**0.24917**	**0.15615**
DBH				**0.32669**	**-0.20162**	**-0.28301**	**-0.21765**	**-0.21384**	**-0.23733**
K					-0.00081	**-0.12992**	**-0.23468**	**-0.24983**	**-0.39968**
WD						0.06301	**0.24747**	**0.26943**	**0.21692**
MOElog							**0.33463**	**0.31930**	**0.12200**
MOEdyn								**0.90640**	**0.65207**
MOE									**0.68115**

Bold correlation parameters shows probability <0,05

The models determined by the stepwise procedure are given in Table 3 and Table 4. When determined the linear regression models, it became clear that the MOElog was mainly influenced by log height (LH), mean ring width (RW), and DBH. Meanwhile, the competition index (CI) had a significant impact in the spruce model. In the MOE models, the main variables were: density of wood samples (WD) and MOEdyn. For Norway spruce model, the diameter of the branch (K) was also included. The main variable for the MOR model, often provided by other authors, was the MOE. For Scots pine, the LH and DBH included to the model, and for Norway spruce, the K variable was additionally included.

Table 3. Linear regression models for the Norway spruce objects.

Linear regression model	R^2	R^2 Ajusted	RMSE	Variance coeficient
Norway spruce				
MOElog*=8676,19+0,40SD+632,06LH-90,74DBH-286,47RW-1,35RD-267,95CI+ ε	0,17	0,15	1226,43	17,36
MOElog=7446,92+0,42SD+629,54LH-118,85DBH+ ε**	0,16	0,15	1227,80	17,38
MOEdyn*=15099+0,29SD+1170,56LH-174,89DBH-308,39RW-12,45RD-388,81CI+0,17MOElog+ ε	0,30	0,29	1413,61	14,50
MOEdyn=15236+0,32SD+1170,47LH-218,35DBH-13,72RD-372,95CI+0,17MOElog+ ε**	0,30	0,29	1412,71	14,49
MOE*=-2780,07+0,054SD-87,32LH+47,49DBH-203,70RW+3,79RD+13,14CI-29,22K+2,01WD-0,010MOElog+ 0,917MOEdyn+ ε	0,86	0,85	658,91	8,19
MOE=-1323,49-31,88K+2,52WD+0,896MOEdyn+ ε**	0,85	0,85	656,37	8,15
MOR*=10,52+0,0002SD-0,514LH-0,163DBH-0,493RW-0,0036RD-0,09CI-0,47K-0,0007WD-0,0002MOElog+0,0005MOEdyn+0,0036MOE+ ε	0,65	0,63	5,72	19,22
MOR=3,52-0,465K+0,004MOE+ ε**	0,65	0,64	5,65	19,00

Table 4. Linear regression models for the Scots pine objects.

Linear regression model	R^2	R^2 Ajusted	RMSE	Variance coeficient
Scots pine				
MOElog*=11814+0,47SD+897,65LH-162,16DBH+593,98RW-21,66RD-99,33CI+ε	0,37	0,36	1375,35	24,22
MOElog=11450+0,44SD+894,06LH-150,06DBH+600,17RW-21,51RD+ε**	0,36	0,36	1375,24	24,21
MOEdyn*=8891,37+0,38SD+327,05LH+35,49DBH-812,08RW-11,66RD+88,51CI+0,21MOElog+ ε	0,22	0,21	1584,58	29,47
MOEdyn=9196,23+0,39SD+342,79LH-740,74RW-11,07RD+0,20MOElog+ ε**	0,22	0,21	1582,73	29,43
MOE*=1468,28-0,012SD+65,32LH+14,21DBH-4,95RW+0,054RD+12,51CI-6,29K+1,39WD+0,038MOElog+0,70MOEdyn+ ε	0,84	0,83	596,03	9,57
MOE=1890,82+1,24WD+0,723MOEdyn+ ε**	0,82	0,82	604,26	9,56
MOR*=7,69-0,0011SD-2,13LH-0,40DBH-0,26RW+0,031RD-0,62CI-0,21K+0,004WD-0,00003MOElog+0,0014MOEdyn+0,002MOE + ε	0,58	0,56	5,08	23,46
MOR=5,94-0,0012SD-2,25LH 0,362DBH+0,0346RD0,202K+0,0015MOEdyn+0,002 MOE+ ε**	0,57	0,57	5,07	23,40

- Model with non-significant ($p > 0.05$) parameters; ** Model with significant ($p < 0.05$) parameters.

Conclusions

The strongest linear model of pine and spruce was obtained by modeling the static modulus of elasticity. The model of modulus of elasticity for pine was mostly influenced by the wood density, while the model for spruce was mainly influenced by the wood density and the branch diameter of the sample. The bending strength model also had a high coefficient of determination and was best explained by the static modulus of elasticity.