REPORT

ON IMPLEMENTATION OF THE RESEARCH PROGRAM

ELABORATION OF FOREST REFERENCE LEVEL FOR LATVIA FOR THE PERIOD BETWEEN 2021 AND 2025

ACTIVITY

VERIFICATION OF AGM MODEL

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Title	**Verification of AGM model**
Authors	G. Šņepsts, A. Lazdiņš, D. Lazdiņa
Figures and drawings	G. Šņepsts
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Contact information	Riga street 111, Salaspils, LV-2169 Phone: +37167942555 E-mail: inst@silava.lv Web address: www.silava.lv
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TERMS AND DEFINITIONS

Listed below are terms and definitions which have been used when making the equations:

Tree	-	a perennial plant which usually forms one lignified trunk and a clearly defined crown.
The above- and below-ground part of the tree	-	Categorized according to the lined formed by the top layer of the soil/ground, the surface part consists of the lateral part of the tree and the crown, but the underground part of tree roots.
Trunk	-	The surface part of the main shoot with apical dominance. The trunk consists of a stump, stem (middle part) and top.
Height	-	The height of an individual tree from the base point to the tree top.
Circumference at breast height	-	The circumference of an individual tree 1.3 m above the base point.
Treestand	-	A collection of trees within a forest stand.
Simple treestand	-	A stand in which the trees are of similar height (the deviance does not exceed 20%).
Compound treestand	-	A stand in which the trees are of two or more heights.
Pure stand	-	A stand in which the dominating tree species forms at least 95% of the stand.
Mixed stand	-	A stand in which the dominating tree specias forms less than 95% of the stand.
Dominating tree species	-	A tree species which has the greatest wood stock (if the dominatig species has a d≥10 cm or h≥12 m) or number of trees within the stand.
Dominating stand	-	Trees within the forest stand with the greatest wood stock and the height of which has a deviance of less than 10% from the average height of the group.
Forest stand	-	An area of forest with similar growing conditions, similar tree species and age structure which is different from the surrounding forest area.
Forest element	-	A collection of trees of the same species, generation, origin and development stange which interact in the same conditions in growth and development. Trees are of the same generation if their age differs by no more than 2 age groups. When modelling trees of the same species and height are considered a forest element.
Undergrowth	-	A collection of young trees under a stands older trees or in a clearing after the clearing of older trees which canlater form a new stand and become a forestry object.
Kraft classes	-	Classification of trees to describe their social state: • class 1st – (virsvaldkoki) – the tallest trees and trees with the greatest circumference with a well developedd crown and the treetops of which rise above the crown of the surrounding trees; • Class II – (valdkoki) – form the main crown cover, the trunks are a little smaller than those of class 1st trees; • class III – (līdzvaldkoki) – the tree crowns are relatively less developed, less wide, placed inbetween class 1st and II tree crowns in the bottom part of the crown cover; • class IV – (nomāktie koki) – the crowns are smaller than those of class III trees. The treetops reach the bottom part of the crown cover. The trees noticably fall behind class 1st – III trees. The trees are divided into 2 subclasses: IV a – trees with narrow, but consistent crowns and which reach into the crown cover; IV b subclass – the crown is on one side of the tree and the top does not reach the crown cover, and the bottom part of the crown is very shaded or dead; • class V – (stipri nomāktie koki) – placed under the crown cover of the dominating stand. Trees with a small dying crown are classified as Va, but trees with a dead crown as class Vb.
Site index	-	A classification unit used to describe the productivity, of a forest stand, it is determined by the height of a tree at a certain age.
Biological or chronological age	-	Time from the sprouting of the seeds or blossoming of off-sping buds

Breast height age	-	The age of a forest element at 1.3 m from base point.
Site index at dominant height	-	A classification unit used to describe the productivity of a forest stand, determined by the dominant height of the dominating tree species at a certain age.
Density factor		The actual number of trees divided by a normal number of trees or the actual area of a basal divided by a normal basal area.
Density	-	The number of trees per ha
Stand of normal density	-	A stand with a basal area equal to a normal basal area
Square average diameter	-	The diameter at breast height of a tree with an average basal area.
Average diameter of the dominating stand	-	The square average diameter of the trees i the dominating stand.
Average height	-	A height of a forest element corresponding to the square average diameter according to the height curve.
Height of dominating stand	-	Tree height which corresponds to the square average diameter of the dominating trees.
Dominant height	-	A height which corresponds to the square average diameter of dominating trees.
Basal area	-	The sum (m^2) of the tree trunk basal areas at breast height (1.3 m from base point) of tthe trees in one hectare.
Wood stock	-	The volume of tree trunks of a forest element from stump to tree top. Can be determined with or without the bark of a tree.
Tree	-	a perennial plant which usually forms one lignified trunk and a clearly defined crown.
The above- and below-ground part of the tree	-	Categorized according to the lined formed by the top layer of the soil/ground, the surface part consists of the lateral part of the tree and the crown, but the underground part of tree roots.
Trunk	-	The surface part of the main shoot with apical dominance. The trunk consists of a stumo, bole (middle part) and stem top.

ABBREVIATIONS

$\mathbf{a_0}$	–	The biological age of a forest element, years
$\mathbf{a_{1.3}}$	–	The age of a forest element at breast height, years
$\mathbf{a_1}$	–	The age of a forest element at the height of 1.3 m in the beginnning of the actualization period, years
$\mathbf{a_2}$	–	The age of a forest element at the height of 1.3 m at the end of the actualisation period, years
$\mathbf{\Delta a}$	–	The age difference between stump height and at 1.3 m (a_0-$a_{1.3}$), years
B	–	Orlov's site index
$\mathbf{d_{ij}}$	–	average diameter of individual 1st floor trees at the height of 1.3 m , cm
d	–	average diameter of forest elements at the height of 1.3 m, cm
$\mathbf{d_1}$	–	average diameter of forest elements at the height of 1.3 m in the beginning of actualization
$\mathbf{d_2}$	–	average diameter of forest elements at the height if 1.3 m at the end of the actualization period, cm
g	–	basal area of a forest element, m^2ha^{-1}
G	–	basal area of a forest stand, m^2ha^{-1}
$\mathbf{g_1}$	–	basal area of a forest element in the beginning of actualization period, m^2ha^{-1}
$\mathbf{g_2}$	–	basal area of a forest stand at the end of actualization period, m^2ha^{-1}
$\mathbf{g`_2}$	–	estimated basal area of an individual tree at the end of actualization period, m^2ha^{-1}
GL	–	sum of basal areas of forest elements which are the same or greater than the chosen forest element (if a forest element of the 1st floor, then a basal of the 1st floor, if a forest element of the II floor, then a sum of the basal areas of both the 1st and II floors) in the beginning of actualization period, m^2ha^{-1};
$\mathbf{g_{max}}$	–	The greatest possible basal area of a forest element, m^2ha^{-1}
$\mathbf{G_{max}}$	–	The greatest possible basal area of 1st storey, m^2ha^{-1}
$\mathbf{g_{norm}}$	–	Normal basal of a forest element, m^2ha^{-1}
$\mathbf{G_{norm}}$	–	Normal basal area of trees of 1st storey, m^2ha^{-1}
h	–	Average height of forest element, m
$\mathbf{h_1}$	–	Average height of forest element in the beginning of actualization, m
$\mathbf{h_2}$	–	Average height of forest element at the end of actualization, m
$\mathbf{h_{dom}}$	–	Dominant height of forest element, m
$\mathbf{h_{dom1}}$	–	Dominant height of forest element in the beginning of actualization, m
$\mathbf{h_{dom2}}$	–	Dominant height of forest element at the end of actualization, m
$\mathbf{h_{20,50,100}}$	–	Estimated height of forest element at a particular age at breast height (20, 50 or 100 years), m
$\mathbf{k_{ij}}$	–	Composition coefficient of indiviual 1st storey forest element
m	–	Wood stock of a forest element, m^3ha^{-1}
M	–	Wood stock of a forest stand, m^3ha^{-1}
$\mathbf{m_1}$	–	Wood stock of a forest element in the beginning of actualization period, m^3ha^{-1}
$\mathbf{m_2}$	–	Wood stock of a forest element at the end of actualization period, m^3ha^{-1}
n	–	Number of trees in a forest element, ha^{-1}
N	–	Number of 1st floor trees in a forest stand, ha^{-1}
$\mathbf{n_1}$	–	Number of trees in a forest element in the beginning of actualization period, ha^{-1}
$\mathbf{n_2}$	–	Number of trees in a forest element at the end of actualization period, ha^{-1}
$\mathbf{n_{max}}$	–	highest possible number of 1st floor trees in a forest element, ha^{-1}
$\mathbf{N_{max}}$	–	highest possible number of 1st floor trees in a forest stand, ha^{-1}
RB	–	Relative density of 1st floor trees in a forest stand
SI	–	Site index of (virsaugstuma) in a forest stand, m
t	–	Duration od actualization period, years

BASIC PRINCIPLES APPLIED IN THE MODEL

This LVMI Silava forest research long-term prognosis model (AGM) is developed as a simulation model. The structure and calculation principles are described in details in the report on the development of AGM model (Šnepsts u.c., 2018).

In forest research modelling data from the National Forest inventory (NFI) database was used, but it is possible to use data from the State Forest Service (SFS) registry by changing the format according to the NFI data.

Changes to the forest stand in the programme are modelled on a forest element level where a collection of individuals of the same species, generation and level are considered a forest element. Changes in forest resources are modelled in five year periods.

The process of existing tree stand modelling is deterministic, but renewing and harvesting are stohastic processes. In modelling the growing process of tree stands growing process models developed by LVMI Silava were used. (Donis et al, 2017)

The default forest resource long term prognosis model works according to current (last five years) management practice, but users will be able to set a variety of management scenarios.

Changes in forest resources are modelled according to current forest management practice in the default setting, but it is possible to set a variety of management scenarios.

The process of forest resource prognosis consists of three stages:

1. creating a data table suitable for modelling;
2. defining a management scenario and criteria of suitable sectors;
3. modelling changes in forest resources for n periods in the future.

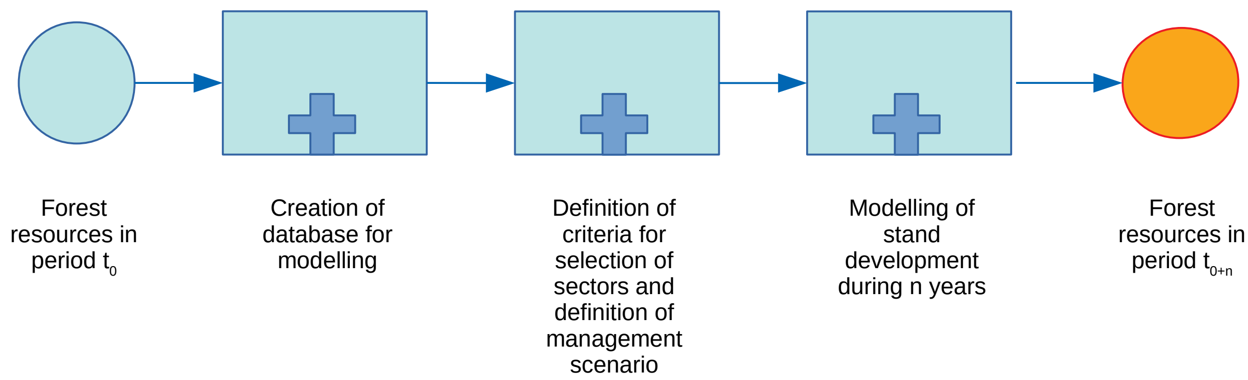

Figure 1 Scheme of the LVMI Silava changes in forest resources projections process based on NFI data.

VERIFICATION METHOD

225 sampling plots measured in the third cycle are selected from the MSI database in which:

- the dominating tree species is pine, spruce or birch,
- sampling plots are not divided into sectors,
- there has been no felling between stock-taking.

Sampling plots used in data analysis represent a wide range of age, height and density. (Table 1).

Table 1: Initial taxation indicators of sampling plots used in projections of changes in tree stand taxation data

Taxation unit	Statistical indicators	Dominating tree species			
		pine	spruce	birch	all
Age of dominating tree species of the I floor of the tree stand, years	Arithmetic average	79	63	47	68
	Minimum	15	21	12	12
	Maximum	189	156	87	189
	Standard deviation	30	30	16	30
Average diameter of the dominating tree species of the I floor of the tree stand, cm	Arithmetic average	22.5	22.1	18.0	21.3
	Minimum	2.6	9.2	2.9	2.6
	Maximum	42.8	36.7	34.7	42.8
	Standard deviation	8.3	6.5	7.7	8.0
Average height of the dominating tree species of the I floor of the tree stand, m	Arithmetic average	18.3	19.7	19.0	18.7
	Minimum	1.5	7.9	4.9	1.5
	Maximum	30.3	30.1	29.9	30.3
	Standard deviation	7.0	5.3	5.9	6.4
Total wood stock of the tree stand, m^3ha^{-1}	Arithmetic average	230.0	268.5	209.1	232.5
	Minimum	0.2	39.2	10.2	0.2
	Maximum	738.5	524.2	523.6	738.5
	Standard deviation	147.5	130.6	113.2	137.2
Wood stock of the I floor of the tree stand, m^3ha^{-1}	Arithmetic average	214.0	248.1	180.1	212.3
	Minimum	0.2	39.2	9.9	0.2
	Maximum	633.3	524.2	388.9	633.3
	Standard deviation	132.0	125.7	95.0	124.1
Sampling plots	Quantity	140	51	64	255
Elements	Quantity	414	207	294	915

Equations approximated by LVMI Silava were used for changes in taxation data (Donis, Šņepsts, & Šēnhofs, 2015; Donis, Šņepsts, Šēnhofs, Treimane, & Zdors, 2015).

Height

If the height of the forest element is less than 1.3 m

Height increase is modelled for each species according to the site quality of the forest type. The site quality of the previous stand is used in modelling if such information is available.

Model of projection for increase in average height of a forest element in Microsoft Excel format:

$$\mathbf{h_2=h_1+(\alpha_1+(\alpha_2*B^\wedge\alpha_3)/(\alpha_4{}^\wedge\alpha_3+B^\wedge\alpha_3))*\Delta t/(\Delta a+5))}\text{, where} \quad (1)$$

h_2 – average height of forest element at the end of the update period, m;
h_1 – average height of forest element at the beginning of the update period, m;
B – site quality of forest element (0–6);
Δt – duration of update period, years;
Δa – difference between biological and chest height age of forest element, years;
α_{1-3} – coefficients (Table 2).

Table 2: Coefficient values for projection model of increase in average height for forest elements with height under 1.3 m (formula 1)

Tree species	Tree species code	α_1	α_2	α_3	α_4
Pine	1	4.71974	−5.35203	0.99450	4.87410
Spruce	3	3.71000	−3.40971	1.00456	3.52752
Birch	4	4.33958	−5.50837	0.94706	6.16190
Black alder	6	5.03930	−6.88795	0.97118	6.49472
Aspen	8	5.02983	−7.69748	0.99068	8.22900
Grey alder	9	4.88003	−11.24780	0.99298	15.12452
Oak (regular)	10	4.71974	−5.35203	0.99450	4.87410
Ash	11	3.71000	−3.40971	1.00456	3.52752
Linden	12	4.33958	−5.50837	0.94706	6.16190
Larch	13	3.71000	−3.40971	1.00456	3.52752
Other pines	14	4.71974	−5.35203	0.99450	4.87410
Other spruces	15	3.71000	−3.40971	1.00456	3.52752
Elm	16	4.33958	−5.50837	0.94706	6.16190
Beech	17	3.71000	−3.40971	1.00456	3.52752
Hornbeam	18	4.88003	−11.24780	0.99298	15.12452
Poplar	19	5.02983	−7.69748	0.99068	8.22900
Willow	20	5.02983	−7.69748	0.99068	8.22900
Goat willow	21	5.02983	−7.69748	0.99068	8.22900
Fir	23	3.71000	−3.40971	1.00456	3.52752
Maple	24	4.33958	−5.50837	0.94706	6.16190
Rowan	32	4.88003	−11.24780	0.99298	15.12452
Cherry	56	4.33958	−5.50837	0.94706	6.16190

If the height of forest element is above 1.3 m

Model of projection for increase in average height of a forest element in Microsoft Excel format:

$$\mathbf{h_2=1.3+a_2\wedge\alpha_1/(\alpha_2+\alpha_3*100*((a_1\wedge\alpha_1/(h_1-1.3)-\alpha_2)/(\alpha 3*100+a_1\wedge\alpha_1))+((a_1\wedge\alpha_1/(h_1-1.3)-\alpha_2)/(\alpha_3*100+a_1\wedge\alpha_1))*a_2\wedge\alpha_1)}\text{, where} \quad (2)$$

h_2 – average height of forest element at the end of update period, m;
h_1 – average height of forest element at the beginning of update period, m;
a_1 – age of forest element at the height of 1.3m at the beginning of the update period, years
a_2 – age of forest element at the height of 1.3m at the end of the update period, years
α_{1-3} – coefficients Table 3.

Table 3: Coefficient values for projection model of increase in average height for forest elements with height above 1.3 m (formula 2)

Tree species	Tree species code	Floor I			Floors II and III			H_{max}
		α_1	α_2	α_3	α_1	α_2	α_3	
Pine	1	1.18111	−42.59724	21.10918	1.18111	−42.59724	21.10918	45
Spruce	3	1.29005	−38.14248	20.15906	1.20905	−34.00184	12.99559	45
Birch	4	1.33418	−35.78521	16.11630	1.33418	−35.78521	16.11630	39

Tree species	Tree species code	Floor I			Floors II and III			H_{max}
		α_1	α_2	α_3	α_1	α_2	α_3	
Black alder	6	1.13922	−32.09572	15.97676	1.13922	−32.09572	15.97676	39
Aspen	8	1.32442	−26.07775	15.64465	1.32442	−26.07775	15.64465	45
Grey alder	9	1.32873	−23.04796	7.32721	1.32873	−23.04796	7.32721	30
Oak (regular)	10	1.18111	−42.59724	21.10918	1.18111	−42.59724	21.10918	39
Ash	11	1.29005	−38.14248	20.15906	1.29005	−38.14248	20.15906	39
Linden	12	1.33418	−35.78521	16.11630	1.33418	−35.78521	16.11630	39
Larch	13	1.29005	−38.14248	20.15906	1.20905	−34.00184	12.99559	45
Other pines	14	1.18111	−42.59724	21.10918	1.18111	−42.59724	21.10918	45
Other spruces	15	1.29005	−38.14248	20.15906	1.20905	−34.00184	12.99559	45
Elm	16	1.33418	−35.78521	16.11630	1.33418	−35.78521	16.11630	39
Beech	17	1.29005	−38.14248	20.15906	1.20905	−34.00184	12.99559	39
Hornbeam	18	1.32873	−23.04796	7.32721	1.32873	−23.04796	7.32721	39
Poplar	19	1.32442	−26.07775	15.64465	1.32442	−26.07775	15.64465	39
Willow	20	1.32442	−26.07775	15.64465	1.32442	−26.07775	15.64465	27
Goat willow	21	1.32442	−26.07775	15.64465	1.32442	−26.07775	15.64465	27
Fir	23	1.29005	−38.14248	20.15906	1.20905	−34.00184	12.99559	45
Maple	24	1.33418	−35.78521	16.11630	1.33418	−35.78521	16.11630	39
Rowan	32	1.32873	−23.04796	7.32721	1.32873	−23.04796	7.32721	24
Cherry	56	1.33418	−35.78521	16.11630	1.33418	−35.78521	16.11630	30

The height of a forest element is updating until it reaches the respective maximum height (Table 3). The height of the forest element is taken to remain the same if it is higher than the maximum height.

Diameter

If the height of the forest element is above 1.3 m

The average diameter at chest height is modelled as a secondary parameter using average height and taking the H/D proportion to be 1,2.

Model for the calculation of average diameter in Microsoft Excel format:

$$\mathbf{d=h/1.2}, \text{ where} \tag{3}$$

d – average diameter at chest height of forest element, cm;
h – average height of forest element, m.

If the height of the forest element is above 1.3 m

The average diameter at chest height is modelled from the initial average diameter, age and relative density of the I floor.

Model for the calculation of average diameter of forest element at chest height Microsoft Excel format:

$$\mathbf{d_2=1.3+a_2{}^\wedge\alpha_1/(\alpha_2{}^*RB+\alpha_3{}^*100{}^*((a_1{}^\wedge\alpha_1/(d_1-1.3)-\alpha_2{}^*RB)/(\alpha 3{}^*100+a_1{}^\wedge\alpha_1))+((a_1{}^\wedge\alpha_1/(d_1-1.3)-\alpha_2{}^*RB)/(\alpha_3{}^*100+a_1{}^\wedge\alpha_1))^*a_2{}^\wedge\alpha_1)}\text{, where} \quad (4)$$

d_2 – average diameter at chest height of forest element at the end of update period, cm;
d_1 – average diameter at chest height of forest element at the beginning of update period, cm;
a_1 – age at 1.3 m height of forest element at the beginning of update period, years;
a_2 – age at 1.3 m height of forest element at the end of update period, years;
RB – relative density of the I floor of the forest stand;
α_{1-3} – coefficients (Table 4).

Table 4: Coefficient values for projection model of increase in average diameter of forest elements with height above 1.3 m (formula 4)

Tree species	Tree species code	α_1	α_2	α_3
Pine	1	1.06700	−9.98500	5.03500
Spruce	3	1.08900	−5.69800	4.61700
Birch	4	1.04300	−7.79300	3.65200
Black alder	6	0.91200	−1.44400	1.38800
Aspen	8	1.29000	−13.95300	9.78600
Grey alder	9	0.92400	−8.15200	2.78100
Oak (regular)	10	1.06700	−9.98500	5.03500
Ash	11	1.08900	−5.69800	4.61700
Linden	12	1.04300	−7.79300	3.65200
Larch	13	1.08900	−5.69800	4.61700
Other pines	14	1.06700	−9.98500	5.03500
Other spruces	15	1.08900	−5.69800	4.61700
Elm	16	1.04300	−7.79300	3.65200
Beech	17	1.08900	−5.69800	4.61700
Hornbeam	18	0.92400	−8.15200	2.78100
Poplar	19	1.29000	−13.95300	9.78600
Willow	20	1.29000	−13.95300	9.78600
Goat willow	21	1.29000	−13.95300	9.78600
Fir	23	1.08900	−5.69800	4.61700
Maple	24	1.04300	−7.79300	3.65200
Rowan	32	0.92400	−8.15200	2.78100
Cherry	56	1.04300	−7.79300	3.65200

Number of trees

If the height of the forest element is below 1.3 m

An annual natural mortality of 1% is modelled for forest elements with height below 1.3 m.

Model of change in tree number in forest elements in Microsoft Excel format:

$$\mathbf{n_2=(1\text{-}0.01*t)*n_1}, \text{ where} \tag{5}$$

n_2 – number of trees in forest element at the end of update period, ha^{-1};
n_1 – number of trees in forest element at the beginning of update period, ha^{-1}.

If the height of forest element is above 1.3 m

The number of trees is calculated as a secondary parameter from projected forest element cross section area and diameter.

Algorithm for calculating the number of trees in a forest element in Microsoft Excel format:

$$\mathbf{n=40\,000*g/pi()/d\text{^}2}, \text{ where} \tag{6}$$

n – number of trees in forest element, ha^{-1};
g – cross section area of forest element, m^2ha^{-1};
d – average diameter at chest height of forest element, cm.

Basal area

If the height of forest element is below 1.3 m

The cross section area of a forest stand (forest element) before reaching a height of 1.3 m is 0 m^2ha^{-1} , but after reaching a height of 1.3 m the cross section area is determined using projected number of trees and diameter:

$$\mathbf{g = pi()*d\text{^}2*n/40\,000}, \text{ where} \tag{7}$$

g – Cross section area of forest element, m^2 ha^{-1};
d – Diameter of forest element at chest height, cm;
n – Number of trees in forest element, ha^{-1}.

If the height of forest element is above 1.3 m

Changes in the cross section area of the forest element depend on the projected cross section area difference and maximum cross section area.

The calculation the cross section area difference depends on the length of the projection period, cross section area and age of the forest element. If the cross section area of the forest element is less than 10 m^2ha^{-1} or the age at chest height more than the cross section update border age (A_{lim}) given in table 4, or the update period more than 20 years, formula 9 is used, in other cases formula 8 is used.

Model of cross section area difference of forest elements in Microsoft Excel format:

$$\mathbf{g`_2=g_1+(\alpha_0+\alpha_1*a_1/100+\alpha_2/(a_1/10)\text{^}2+\alpha_3*g_1/a_1+\alpha_4*GL/a_1+\alpha_5*SI/a_1)*(a_2\text{-}a_1)} \tag{8}$$

$$\mathbf{g`_2=g_1+g_1*(\alpha_0+\alpha_1*a_1/100+\alpha_2/a_1\text{^}2)*(a_2\text{-}a_1)}, \text{ where} \tag{9}$$

$g`_2$ – projected cross section area of forest element at the end of period, m^2ha^{-1};
g_1 – cross section area of forest element at the beginning of update period, m^2ha^{-1};
a_1 – age of forest element at 1.3 m high at the beginning of update period, years;
a_2 – age of forest element at 1.3 m high at the end of update period, years;
GL – sum of cross section area for forest element equal or higher than the selected forest element

(if forest element of floor I, the cross section area of floor I, if floor II forest element, then the sum of cross section area of floor I and II, if floor II forest element, then the total cross section area of the tree stand), m^2ha^{-1};
SI – projected height of forest element (formula 113) at a specific age at chest height (Table 5, A_{SI}), m;
α_i;β_i – coefficients (Table 5 and 6).

Table 5: Coefficient values for cross section area difference model for forest elements with heights above 1.3 m (formula 8)

Tree species	Tree species code	α_0	α_1	α_2	α_3	α_4	α_5
Pine	1	0.12790	−0.05718	0.02512	0.83096	−0.36719	0.15517
Spruce	3	0.19233	−0.11625	0.04781	0.82474	−0.23711	0.12125
Birch	4	0.23598	−0.25059	−0.06415	0.60903	−0.24720	0.16372
Black alder	6	0.19929	−0.23874	−0.08695	0.84685	−0.18952	0.07761
Aspen	8	0.45672	−0.46009	0.24801	0.96946	−0.23032	0.00000
Grey alder	9	0.66125	−1.72237	0.05124	0.96525	−0.46311	0.12640
Oak (regular)	10	0.12790	−0.05718	0.02512	0.83096	−0.36719	0.15517
Ash	11	0.19233	−0.11625	0.04781	0.82474	−0.23711	0.12125
Linden	12	0.23598	−0.25059	−0.06415	0.60903	−0.24720	0.16372
Larch	13	0.19233	−0.11625	0.04781	0.82474	−0.23711	0.12125
Other pines	14	0.12790	−0.05718	0.02512	0.83096	−0.36719	0.15517
Other spruces	15	0.19233	−0.11625	0.04781	0.82474	−0.23711	0.12125
Elm	16	0.23598	−0.25059	−0.06415	0.60903	−0.24720	0.16372
Beech	17	0.19233	−0.11625	0.04781	0.82474	−0.23711	0.12125
Hornbeam	18	0.66125	−1.72237	0.05124	0.96525	−0.46311	0.12640
Poplar	19	0.45672	−0.46009	0.24801	0.96946	−0.23032	0.00000
Willow	20	0.45672	−0.46009	0.24801	0.96946	−0.23032	0.00000
Goat willow	21	0.45672	−0.46009	0.24801	0.96946	−0.23032	0.00000
Fir	23	0.19233	−0.11625	0.04781	0.82474	−0.23711	0.12125
Maple	24	0.23598	−0.25059	−0.06415	0.60903	−0.24720	0.16372
Rowan	32	0.66125	−1.72237	0.05124	0.96525	−0.46311	0.12640
Cherry	56	0.23598	−0.25059	−0.06415	0.60903	−0.24720	0.16372

Table 6: Coefficient values for cross section area difference models for forest elements with height above 1.3 m (formula 9) and border age values for cross section updates

Tree species	Tree species code	α_0	α_1	α_2	A_{lim}	A_{SI}
Pine	1	0.01800	−0.01139	12.01519	120	100
Spruce	3	0.02787	−0.02145	12.57435	100	100
Birch	4	0.05146	−0.06896	8.81694	80	50
Black alder	6	0.05924	−0.08500	3.36282	80	50
Aspen	8	0.05660	−0.06663	12.13606	80	50
Grey alder	9	0.06862	−0.16547	6.29221	50	20

Tree species	Tree species code	α_0	α_1	α_2	A_{lim}	A_{SI}
Oak (regular)	10	0.01800	−0.01139	12.01519	120	100
Ash	11	0.02787	−0.02145	12.57435	100	100
Linden	12	0.05146	−0.06896	8.81694	80	50
Larch	13	0.02787	−0.02145	12.57435	100	100
Other pines	14	0.01800	−0.01139	12.01519	120	100
Other spruces	15	0.02787	−0.02145	12.57435	100	100
Elm	16	0.05146	−0.06896	8.81694	80	100
Beech	17	0.02787	−0.02145	12.57435	100	100
Hornbeam	18	0.06862	−0.16547	6.29221	50	100
Poplar	19	0.05660	−0.06663	12.13606	80	50
Willow	20	0.05660	−0.06663	12.13606	80	20
Goat willow	21	0.05660	−0.06663	12.13606	80	50
Fir	23	0.02787	−0.02145	12.57435	100	100
Maple	24	0.05146	−0.06896	8.81694	80	50
Rowan	32	0.06862	−0.16547	6.29221	50	50
Cherry	56	0.05146	−0.06896	8.81694	80	50

A_{lim} – border age at chest height, for picking the cross section area difference equation ,
A_{SI} – age at chest height used to calculate the height describing tree stand productivity.

Formulas 10 and 11 are used to project the potential cross section area of the forest element, however it may not exceed the theoretically possible cross section area.

Model of the maximum cross section area of forest element in Microsoft Excel format:

$$\mathbf{g_{max}=\alpha_1/(1+(d/\alpha_2)\hat{}\alpha_3)*ip} \quad (10)$$

$$\mathbf{g_{max}=\beta_1*(1-exp(-\beta_2*h))*ip}\text{, where} \quad (11)$$

g_{max} – maximum cross section area of forest element, m^2ha^{-1};
d – projected average diameter of forest element at chest height, cm;
h – projected average height of forest element, m;
ip – proportion of forest element;
$\alpha_i;\beta_i$ – coefficients (Table 7).

Formula 10 is used to calculate the maximum cross section area of a forest stand in which thinning has been done in the last 18-22 years, if there has been no thinning for a prolonged period of time, the maximum cross section area is calculated using formula 11.

Table 7: Coefficient values for maximum cross section area models for forest elements higher than 1.3 m (formulas 10 and 11)

Tree species	Tree species code	α_1	α_2	α_3	β_1	β_2
Pine	1	63.45877	13.46633	−1.51447	37.34807	0.07615
Spruce	3	56.98437	9.33710	−1.70296	38.74357	0.07334
Birch	4	44.21425	6.02039	−1.37711	43.54122	0.03710
Black alder	6	50.01593	9.26982	−1.87173	39.56055	0.06983

Tree species	Tree species code	α_1	α_2	α_3	β_1	β_2
Aspen	8	55.63098	5.97114	−1.49469	43.24735	0.04973
Grey alder	9	39.01299	3.96501	−2.04227	37.40094	0.07388
Oak (regular)	10	63.45877	13.46633	−1.51447	37.34807	0.07615
Ash	11	56.98437	9.33710	−1.70296	38.74357	0.07334
Linden	12	44.21425	6.02039	−1.37711	43.54122	0.03710
Larch	13	56.98437	9.33710	−1.70296	38.74357	0.07334
Other pines	14	63.45877	13.46633	−1.51447	37.34807	0.07615
Other spruces	15	56.98437	9.33710	−1.70296	38.74357	0.07334
Elm	16	44.21425	6.02039	−1.37711	43.54122	0.03710
Beech	17	56.98437	9.33710	−1.70296	38.74357	0.07334
Hornbeam	18	39.01299	3.96501	−2.04227	37.40094	0.07388
Poplar	19	55.63098	5.97114	−1.49469	43.24735	0.04973
Willow	20	55.63098	5.97114	−1.49469	43.24735	0.04973
Goat willow	21	55.63098	5.97114	−1.49469	43.24735	0.04973
Fir	23	56.98437	9.33710	−1.70296	38.74357	0.07334
Maple	24	44.21425	6.02039	−1.37711	43.54122	0.03710
Rowan	32	39.01299	3.96501	−2.04227	37.40094	0.07388
Cherry	56	44.21425	6.02039	−1.37711	43.54122	0.03710

The cross section area of individual forest elements is projected as the minimum cross section area from the potential cross section area of the forest element and from the calculated maximum cross section area of the forest element:

$$\mathbf{g_2=min(g`_2;g_{max})}\text{, where} \tag{12}$$

g_2 – cross section of the forest element at the end of the update period, m^2ha^{-1};
$g`_2$ – projected cross section area of the forest element at the end of the update period (formula 8 or 9), m^2ha^{-1};
g_{max} – maximum cross section area pf the forest element (formula 10 or 11), m^2ha^{-1}.

Growing stock

The wood stock of a forest stand is taken to be 2 m^3ha^{-1} before reaching a height of 2m (height of the dominating tree species of floor I), but the wood stock of individual forest elements is calculated from their proportion:

$$\mathbf{m=2*ip}\text{, where} \tag{13}$$

m – wood stock of the forest element m^3ha^{-1};
ip – proportion of the forest element.

After reaching a height of 2 m the wood stock is calculated using the I. Liepa formula for individual tree volume (Liepa, 1996) using number of trees, average tree height and square average diameter:

$$\mathbf{m = \psi*h^\wedge\alpha*d^\wedge(\beta*log10(h)+\varphi)*n}\text{, where} \tag{14}$$

m – Wood stock of the forest element, m^3 ha^{-1};
h – Average height of forest element, m;

d – Average diameter of forest element at chest height, cm;
n – Number of trees in forest element, ha^{-1};
ψ; α; β; ϕ – Coefficients.

The following statistical indicators are used to describe changes in projected wood stock (Von Gadow & Hui, 1999):

Mean deviation

$$MRES=\frac{\sum(y_i-\hat{y}_i)}{n} \tag{15}$$

Mean relative deviation

$$MRES\%=\frac{\frac{\sum(y_i-\hat{y}_i)}{n}}{\acute{y}_i}100 \tag{16}$$

Mean absolute deviation

$$AMRES=\frac{\sum|y_i-\hat{y}_i|}{n} \tag{17}$$

Standard deviation

$$RMSE=\sqrt{\frac{\sum(y_i-\hat{y}_i)^2}{n-1-p}} \tag{18}$$

Coefficient of variation

$$RMSE\%=\frac{\sqrt{\frac{\sum(y_i-\hat{y}_i)^2}{n-1-p}}}{\acute{y}_i}100 \tag{19}$$

, where

y_i – Measured value;
$\hat{y}_i$ – Calculated value;
$\acute{y}_i$ – Arithmetic average measured value;
$\acute{\hat{y}}_i$ – Arithmetic average calculated value;
p – Number of parameters in equation;
n – Number of observations.

RESULTS

Measured and projected total and wood stock in floor I of the tree stand are compared to describe the precision of the projection system. Statistical evaluation of other taxation indicators (H, D, G) is done during equation development (Donis, Šņepsts, & Šēnhofs, 2015). Wood stock difference depending on dominating tree species is not analyzed separately as in the sampling plots there are forest elements of species other than the dominating one.

Arithmetic average deviation int floor I of the tree stand (the difference between measured and projected values) is 7 m^3ha^{-1}, but the total wood stock deviance is 1 m^3ha^{-1} (Table 8). In both cases the deviance does not exceed 5%. The variation coefficient of projected wood stock in floor I of the tree stand is 13%, but for total wood stock – 12%, so the variation in dispersion of the projected wood stock can be considered to be sufficiently stable.

Table 8: Statistical indicators of the projected wood stock

Indicator	Dominating tree species	Ave.	MRES	MRES %	AMRES	RMSE	RMSE %	R	N
Wood stock in floor I	P	264	10	4	23	32	12	0.981	140
	S	339	13	4	30	44	13	0.963	51
	B	244	−2	−1	27	40	17	0.933	64
	All	274	7	3	25	35	13	0.971	255
Total wood stock	P	288	6	2	23	32	11	0.984	140
	S	362	1	0	32	45	12	0.957	51
	B	290	−11	−4	31	43	15	0.957	64
	All	303	1	0	27	36	12	0.975	255

According to the Shapiro test the distribution of the deviance (difference between measured and projected wood stock) of the total wood stock is a normal distribution (p=0,0058), but the distribution of deviance of the wood stock in floor I of the tree stand is not a normal distribution. (0,0029; Figure 2).

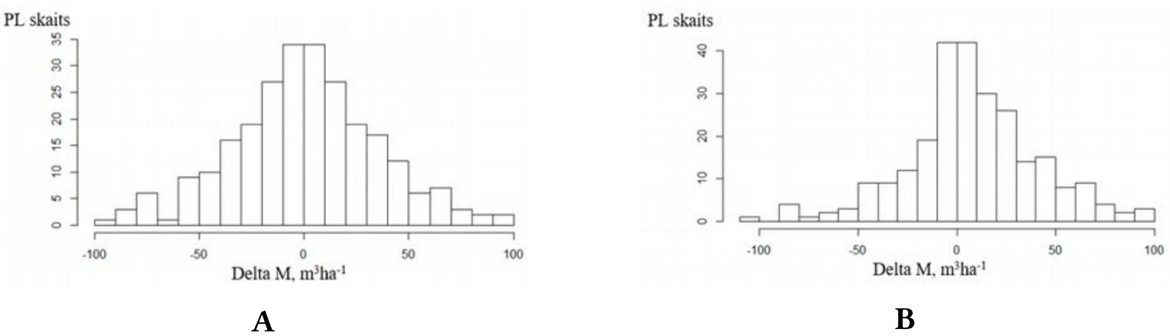

Figure 2: Number of sampling plots sorted by difference between measured and projected wood stock (Delta M), where A – total wood stock in stand, B – wood stock in floor I of the stand.

Since the wood stock deviance in floor I of the tree stand is not distributed in a normal distribution and selection of sampling plots is random without checking if the selected sampling plots objectively describe the situation in Latvia, the Wilcoxon test was used to compare projected and measured wood stock. During the test it was observed that there is not a notable difference between the projected and measured total wood stock (p=0.7888), but the wood stock in floor I of the tree stand is consistently projected with lower values (p=0.0001).

The deviance of the projected wood stock (total and floor II) is observed to have a weak linear correlation with initial age and site quality of the tree stand (Figure 3). Due to the large number of observations this statistical correlation is important, however they look more like a chaotic collection of values (Figure 3). Therefore projected wood stock can be considered independent from the age and productivity of the stand.

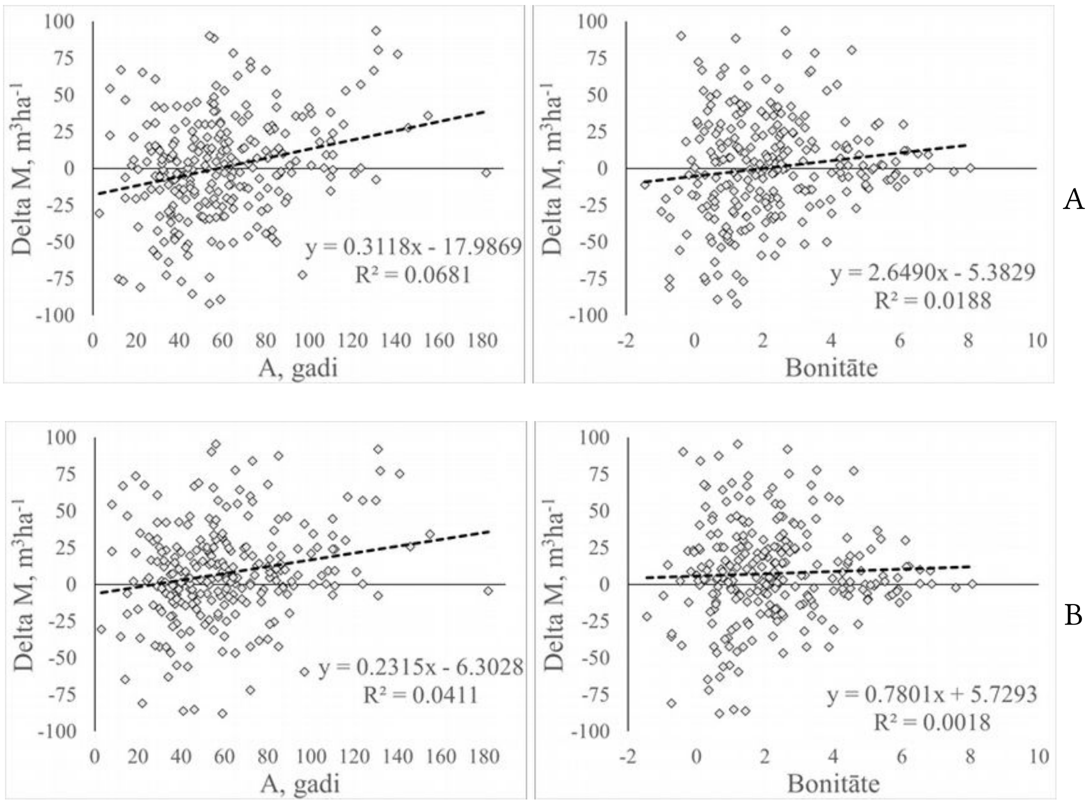

Figure 3: Difference between measured and projected wood stock (Delta M) and initial age (A) and site quality of the stand, where A – total wood stock in stand, B – wood stock in floor I of the stand.