Supplementary Files for „*Climate benefit of different tree species on former agricultural land in northern Europe*“ by Lutter, R.; Stål, G.; Arnesson Ceder, L.; Lim, H.; Padari, A.; Tullus, H.; Nordin, A.; Lundmark, T.

Description of growth modelling

The production estimates of the study were conducted by modeling the early growth (9 years) of the studied tree species (excpet willows) in the trials over Sweden[40]. After the growth simulations, the fractions of wood assortments were modelled (Suppl. figures 3). The modelling of the production is followed by the next steps:

1. Based on the mean early growth [40] of silver birch, hybrid aspen, poplar, Norway spruce and larch, the average height of each tree species was modelled in year basis with the according to Kivisite [50] and Kiviste & Kiviste [51] models (Equations S1–S4).

$$H_{A+1} = \frac{H+d+r}{2+\frac{4\cdot b\cdot (A+1)^{-a_1}}{H-d+r}}, \quad \text{(S1)}$$

$$b = a_0 - 1182; \quad \text{(S2)}$$

$$d = \frac{b}{50^{a_1}}; \quad \text{(S3)}$$

$$r = \sqrt{(H-d)^2 + 4\cdot b\cdot \frac{H}{A^{a_1}}}; \quad \text{(S4)}$$

where *b, d, r* are support coefficients, a_0 and a_1 are coefficients according to the tree species (Table S1), *A* is the age (yr) and *H* is the height (m).

Table S1. Coefficients of the equastions S1–S4 for the studied tree species

Tree species	a_0	a_1
Larch	8319	1.58
Norway spruce	12867	1.71
Silver birch	4990	1.48
Hybrid aspen and poplar	3882	1.30

2. The stand density (trees ha^{-1}) was calulated with the assumption of the natural tree mortality (Equation S5):

$$N_{A+1} = N \cdot 0.99, \quad \text{(S5)}$$

where *N* is the stand density (trees ha^{-1}), *A* is the age (yr) of the plantation

3. The annual growth (stem volume, m^3 ha^{-1} a^{-1}) of each tree species was calculated with the following steps (Equations S6–S12) according to the Forest Planning Guidance [76]:

$$T = \frac{N\cdot\pi\cdot\frac{D^2}{4}}{b_0+b_1\cdot H+b_2\cdot H^2+b_3\cdot\sqrt{H}}; \quad \text{(S6)}$$

$$\alpha = c_0\cdot\frac{33{,}5-H_{100}}{4}+c_1; \quad \text{(S7)}$$

$$\beta = \frac{c_2\cdot\alpha+c_3}{100}; \quad \text{(S8)}$$

$$\gamma = c_4 \cdot \alpha + c_5; \quad \text{(S9)}$$

$$K_{NSp} = \left[\left(\frac{10{,}44}{A} + 1.24\right) - \left(\frac{10{,}44}{A} + 0.24\right) \cdot T\right] \cdot T; \quad \text{(S10)}$$

$$K_{other} = \left[\left(\frac{1741}{A^2} + 0.87\right) - \left(\frac{1741}{A^2} - 0.13\right) \cdot T\right] \cdot T; \quad \text{(S11)}$$

$$\Delta V = \left\{\alpha \cdot \beta \cdot \gamma \cdot \left[1 - e^{-\beta \cdot A}\right]^{\gamma - 1} \cdot e^{-\beta \cdot A}\right\} \cdot K, \quad \text{(S12)}$$

where T (%) is the relative stand basal area to the standard at the given age, α, β, γ are supporting coefficients, N is the stand density (trees ha^{-1}), D is the quadratic mean stem diameter at breast height (cm), H is the average height of the plantation (m), H_{100} is the stand height at the age of 100 years (m), K_{NSp} is the correction to T value for spruce and K_{other} for the other studied tree species, A is the age (yr) of the plantation, b_0, b_1, b_2, b_3, c_0, c_1, c_2, c_3 c_4 and c_5 are coefficients according to the tree species (Table S2 and S3) and ΔV is the annual increment of stem volume (m^3 ha^{-1} a^{-1}).

Table S2. Coefficients of the equation S6 and S14 for the studied tree species

Tree species	b_0	b_1	b_2	b_3
Larch	-33.02	-3.8531	0.0226	30.2955
Norway spruce	-7.94	-0.5206	0.0069	10.8713
Silver birch	11.65	2.0183	-0.0155	-4.4908
Hybrid aspen and poplar	7.93	1.4932	-0.0076	-0.9684

Table S3. Coefficients of the equastions S7–S9 for the studied tree species.

Tree species	c_0	c_1	c_2	c_3	c_4	c_5
Larch	-127.1	1225.0	0.0007	1.0952	-0.0005	2.4787
Norway spruce	-145.8	1351.7	0.0005	1.7668	-0.0018	4.9657
Silver birch	-107.6	821.4	0.0011	1.7771	-0.0015	3.2267
Hybrid aspen and poplar	-150.7	1057.6	0.0007	1.9665	0.0002	1.7283

4. The dynamical (for the following growth year) quadratic mean stem diameter at the breast height (Equations S13–S15) is calculated according to the Forest Planning Guidance [76]:

$$T = \frac{V + \Delta V}{d_0 + d_1 \cdot H_{A+1} + d_2 \cdot H_{A+1}^2 + d_3 \cdot H_{A+1}^3}; \quad \text{(S13)}$$

$$G_{A+1} = T \cdot \left(b_0 + b_1 \cdot H + b_2 \cdot H^2 + b_3 \cdot \sqrt{H}\right); \quad \text{(S14)}$$

$$D_{A+1} = \sqrt{\frac{40000 \cdot G_{A+1}}{\pi \cdot N}}, \quad \text{(S15)}$$

where T (%) is the relative stand basal area to the standard at the following year, V is stem volume (m^3 ha^{-1}), ΔV is the annual increment of stem volume (m^3 ha^{-1} a^{-1}), H is the average height of the plantation (m), d_0, d_1, d_2, d_3, b_0, b_1, b_2, b_3 are coefficients according of the tree species (Table S2 and S4), G is stand basal area (m^2 ha^{-1}), N is stand density (trees ha^{-1}) and D is the quadratic mean stem diameter at breast height (cm).

Table S4. Coefficients of the equastion S13 for the studied tree species

Tree species	d_0	d_1	d_2	d_3
Larch	-23.7	17.9947	-0.0108	-0.0003
Norway spruce	-17.3	13.4278	0.1440	0.0029
Silver birch	50.2	-4.7970	0.9508	-0.0116
Hybrid aspen and poplar	33.5	-0.8948	0.8134	-0.0078

5. The applicability of thinnings was modelled with the principles of Equations S16 and S17. If $L > L_{re}$ then no thinning is applied in the management model. If $L < L_{re}$ then thinning rate was applied with the Equations of 18 and 19.

$$L_{re} = 0.95 \cdot (e_0 + e_1 \cdot D + e_2 \cdot H_{100}); \quad \text{(S16)}$$

$$L = \frac{10000}{\sqrt{N}}, \quad \text{(S17)}$$

where L_{re} is the stand sparsity before thinning (cm), D is the quadratic mean stem diameter at breast height (cm), H_{100} is the stand height at the age of 100 years (m), e_0, e_1, e_2 are coefficients according of the tree species (Table S5), L is the stand sparsity (cm) and N is the stand density (trees ha^{-1}).

$$L_{rj} = f_0 + f_1 \cdot D + f_2 \cdot H_{100}; \quad \text{(S18)}$$

$$N_{raie} = N - \frac{10^8}{L_{rj}^2}; \quad \text{(S19)}$$

$$Rk = \frac{N_{thin}}{N}, \quad \text{(S20)}$$

where L_{rj} is stand sparsity after thinning (cm), D is the quadratic mean stem diameter at breast height (cm), H_{100} is the stand height at the age of 100 years (m), $f0$, $f1$, $f2$ are coefficients according of the tree species (Table S5), N_{thin} the number of trees that were cut out during the thinning (trees ha^{-1}), N stand density before thinning (trees ha^{-1}) and R_k is the proportion of thinned trees from the stand density (thinning intensity).

Table S5. Coefficients of the equastions S16 and S18 for the studied tree species

Tree species	e_0	e_1	e_2	f_0	f_1	f_2
Larch	143.6	14.2	3.4	166.8	15.2	3.7
Norway spruce	91.8	12.9	1.2	121.6	13.3	1.9
Silver birch, hybrid aspen and poplar	71.4	14.7	0.0	105.0	16.8	0.0

6. The fractions of harvested stemwood assortments were calculated according to the stem diameter (at breast height) distribution classes. After dividing trees to the stem diameter classes, the mean height for each diameter class was modelled with Equation S21:

$$h = \frac{H \cdot \left[1.3 + g_0 \cdot \left(\frac{d}{d+g_1}\right)^{g_2}\right]}{1.3 + g_0 \cdot \left(\frac{D}{D+g_1}\right)^{g_2}}, \quad \text{(S21)}$$

where h tree height at the diameter class (m), H is the average height of the plantation (m), d is the mean diameter of the diameter class (cm), D is the quadratic mean stem diameter at breast height (cm) and $g0$, $g1$, $g2$ are coefficients according of the tree species (Table S6).

Table S6. Coefficients of the equastion S21 for the studied tree species.

Tree species	g_0	g_1	g_2
Larch	32.7621	1.1	9.9241
Norway spruce	37.2351	1.3	10.8580
Silver birch	31.9851	8.0	1.4625
Hybrid aspen and poplar	31.6953	4.3	2.4979

If the subject tree is less than 8 cm in diameter or 5 m in height, then only its volume is calculated (Equation S22). If the subject tree is more than 8 cm in diameter and more than 5 m in height, then the tree stem is divided to the following assortments: logs, pulpwood and energywood. The lenght of each assortment is 3.0 m. The fraction (%) of each assortment was calculated by using Ozolinš [52] stem taper model (Equations S23–S24). The fraction of bark was calculated with Padari [77] (Equation S25) and the diameter without bark with Equation S26. The volume of each wood assortment was calculated by using integrate method [52,77] (Equation S27). After that, the volumes of the calculated wood assortments will be summed with the normalization to the stand volume (Equation S28).

$$v_{tree} = 0.000019 + 0.00001142 \cdot (d+2)^{2.61614} \cdot h^{0.76489}, \quad \text{(S22)}$$

where v_{tree} is stem volume of an individual tree (m^3), d is the stem diameter at breast height, h is the tree height (m).

$$\gamma(x) = 1 + (x^2 - 0{,}01) \cdot \left(p \cdot (h - h_0) + q \cdot \left(d_{1,3} - d_0\right)\right); \quad \text{(S23)}$$

$$d_l = d_{1,3} \cdot \frac{\gamma\left(\frac{l}{h}\right) \cdot \left(a_0 + a_1 \cdot \left(\frac{l}{h}\right) + a_2 \cdot \left(\frac{l}{h}\right)^2 + a_3 \cdot \left(\frac{l}{h}\right)^3 + a_4 \cdot \left(\frac{l}{h}\right)^4 + a_5 \cdot \left(\frac{l}{h}\right)^5 + a_6 \cdot \left(\frac{l}{h}\right)^6\right)}{\gamma\left(\frac{1,3}{h}\right) \cdot \left(a_0 + a_1 \cdot \left(\frac{1,3}{h}\right) + a_2 \cdot \left(\frac{1,3}{h}\right)^2 + a_3 \cdot \left(\frac{1,3}{h}\right)^3 + a_4 \cdot \left(\frac{1,3}{h}\right)^4 + a_5 \cdot \left(\frac{1,3}{h}\right)^5 + a_6 \cdot \left(\frac{1,3}{h}\right)^6\right)}, \quad \text{(S24)}$$

where $\gamma(x)$ is the perturbation coefficient ($x = \frac{l}{h}$ või $\frac{1,3}{h}$), d_l is the stem diameter at distance l from the root collar (cm), $d_{1,3}$ is the stem diameter at breast height (cm), l is the distance from the root collar (m), h is the tree height (m) and a_0, a_1, a_2, a_3, a_4, a_5 a_6 are coefficients according of the tree species (Table S7).

Table S7. Coefficients of the equastion S24 for the studied tree species

Tree species	a_0	a_1	a_2	a_3	a_4	a_5	a_6
Larch	118.981	-277.578	1140.525	-3037.487	4419.682	-3361.78	997.657
Norway spruce	113.939	-203.061	827.209	-2161.251	2732.076	-1699.667	390.755
Silver birch	120.567	-312.074	1388.288	-3725.819	5197.005	-3788.858	1120.891
Hybrid aspen and poplar	120.224	-310.985	1450.125	-4238.703	6644.011	-5408.312	1743.64

$$Bark = h_0 \cdot \left(\frac{d + h_1}{d + h_1 + 1}\right)^{h_2}, \quad \text{(S25)}$$

where *Bark* is the fraction of bark (%), d is the stem diameter (cm) and h_0, h_1, h_2 are coefficients according of the tree species (Table S8).

Table S8. Coefficients of the equastion 25 for the studied tree species

Tree species	h_1	h_2	h_3
Larch and Norway spruce	0.080	2	–4.9
Silver birch	0.111	3	–4.9
Hybrid aspen and poplar	0.120	2	–3.2

$$d_{ub} = \frac{d_{ob}}{\sqrt{1+Bark}}, \quad \text{(S26)}$$

where d_{ub} is the stem diameter under the bark (cm), d_{ob} is the stem diameter over the bark (cm) and *Bark* is the share of the bark from the total volume (%).

$$v = \frac{\pi}{40000} \int_{l_1}^{l_2} d_l^2 \, dl \, , \quad \text{(S27)}$$

where v is the volume (m^3) of the wood assortment from the distance of root collar (l_1 to l_2), l is the distance from the root collar (m) and d_l is the stem diameter at distance l from the root collar (cm).

$$V_{assortment} = \frac{V \cdot \Sigma v_{assortment}}{\Sigma v_{tree}}, \quad \text{(S28)}$$

where $V_{assortment}$ is the volume of saw log, pulpwood or energywood in the plantation (m^3), V is the stem volume of the plantation (m^3), $v_{assortment}$ is the volume of wood assortment according to the diameter class (m^3) and v_{tree} is the volume of the tree in the diameter class (m^3).

The volume of obtained wood assortments was corrected with the share of potential stem damages according to Padari [77] model (Equation S29).

$$Dam = \left(\frac{A}{A+1}\right)^{\left[\left(\frac{i_0}{A}\right)^{i_1}\right]}, \quad \text{(S29)}$$

where *Dam* is the share of damaged wood (%), A is the age of the plantation (yr), i_0, i_1 coefficients according of the tree species (Table S9).

Table S9. Coefficients of the equastion 30 for the studied tree species

Tree species	i_0	i_1
Larch	9,000,000	0.5
Norway spruce	1,300,00	0.5

Silver birch	700	2
Hybrid aspen and poplar	145	2.5

Supplementrary figure 1 title: Site index curves

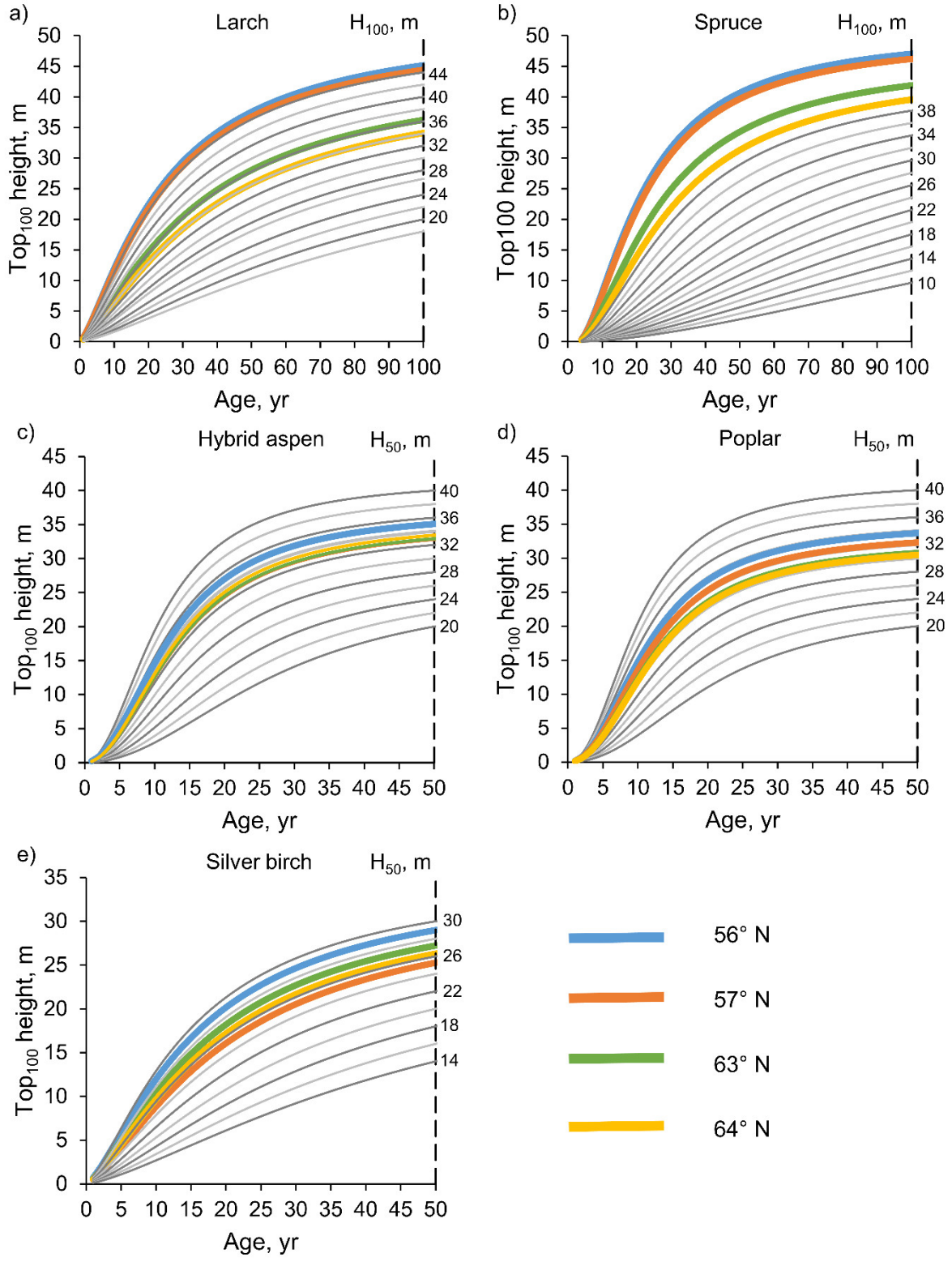

Figure S1. Site index curves for larch (a), spruce (b), hybrid aspen (c), poplar (d) and silver birch according to Johansson et al. [48] curve. The colored lines presents tree species trials at the latitudes from 56° to 64°N where the early growth (9 years) of the 100 thickest trees per ha was used (Adapted from [40]). The grey lines are presenting the site index curves for the given tree species in Sweden at the reference age of 50 or 100 [48].

Supplementrary figure 2 title: Predicted production

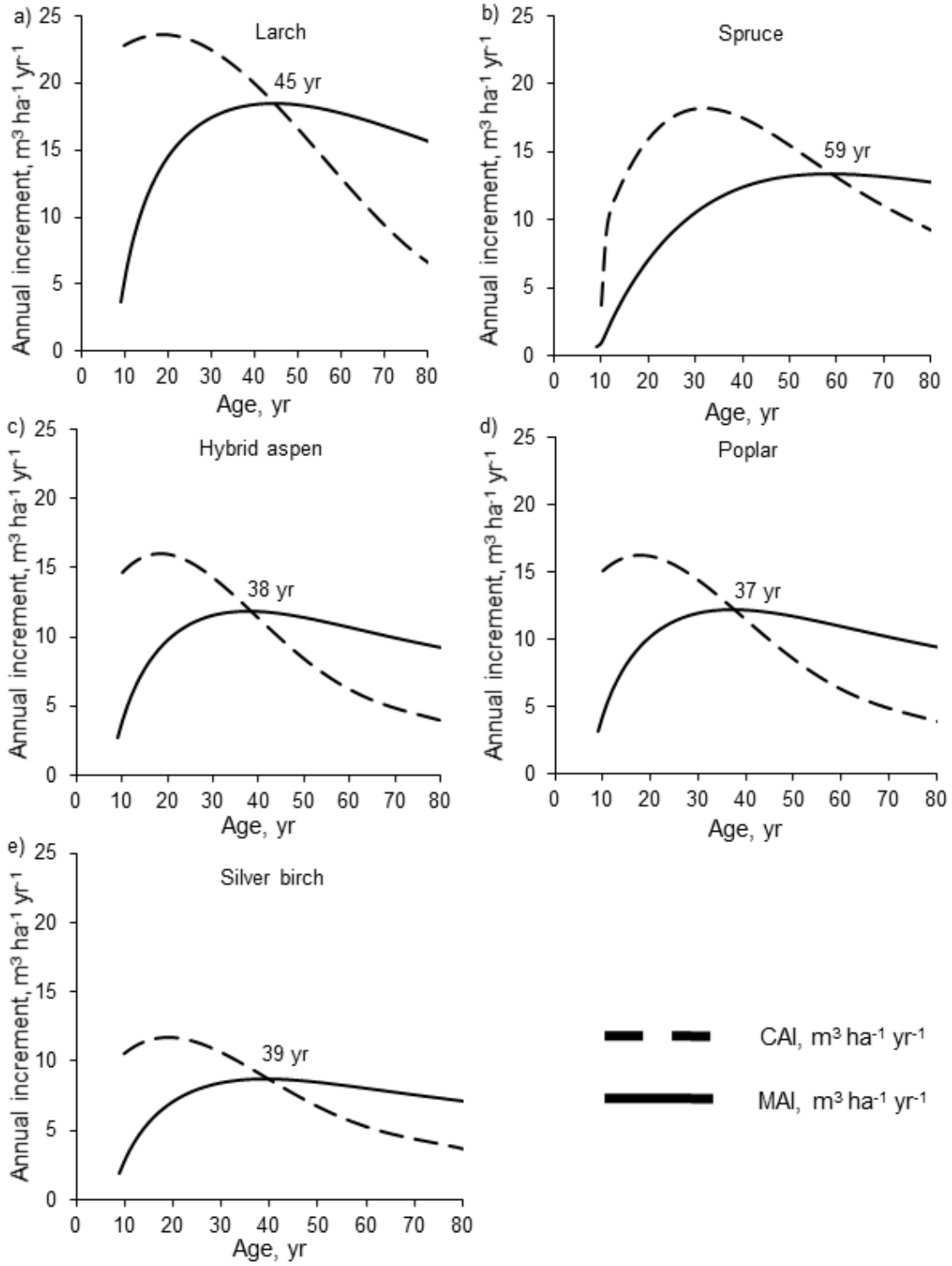

Figure S2. Current annual increment (CAI, m^3 ha^{-1} yr^{-1}) and mean annual increment (MAI, m^3 ha^{-1} yr^{-1}) of larch (a), spruce (b), hybrid aspen (c), poplar (d) and silver birch.

Supplementrary figure 3 title: Fraction of wood assortments

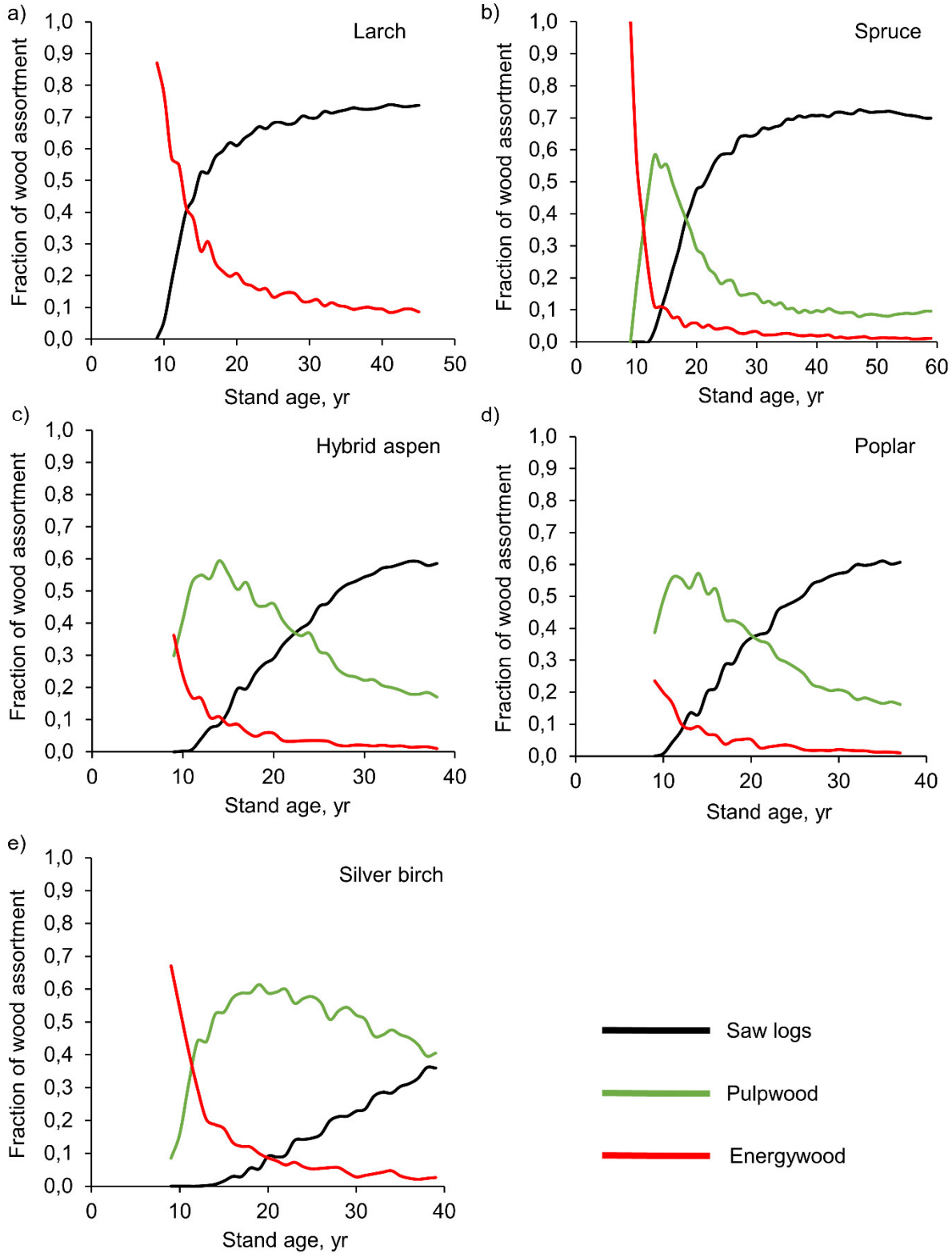

Figure S3. The dynamical development of wood assortment fractions (energywood, pulpwood and saw logs) of the studied tree species according to Ozolinš [52] model.