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Biomass production of young lodgepole pine (*Pinus contorta* var. *latifolia*) stands in Latvia

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Biomass as a source of renewable energy is gaining an increasing importance in the context of emission targets set by the European Union. Large areas of abandoned agricultural land with different soils are potentially available for establishment of biomass plantations in the Baltic states. Considering soil and climatic requirements as well as traits characteristic for lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm) and the scarcity of published knowledge, we assessed the above-ground biomass of *Pinus contorta* in comparison to that of native Scots pine (*Pinus sylvestris* L.) and factors affecting biomass production. Data were collected in 3 experimental trials, located in two sites in central part of Latvia: Zvirgzde and Kuldiga (56°41' N, 24°28' E and 57°03' N, 21°57' E, respectively). Trials were established with density 5000 tree ha^{-1}, using seed material from Canada (50°08'-60°15' N, 116°25'-132°50' W) and two *Pinus contorta* stands with unknown origin growing in Latvia. Results reveal that absolute dry aboveground biomass of *Pinus contorta* reaches 114 ± 6.4 t ha^{-1} at age 16 on a fertile former arable land, 48 ± 3.6 and 94 ± 9.4 t ha^{-1} at age 22 and 25, respectively, on a sandy forest land (*Vacciniosa* forest type). The biomass is significantly ($p < 0.01$) and considerably (more than two-fold) higher than that of the native *Pinus sylvestris* and the productivity is similar (in fertile soils) or higher (on poor soils) than reported for other species in energy-wood plantations. Provenance was a significant factor affecting the above-ground biomass, and the ranking of provenances did not change significantly between different soil conditions. It provides opportunities for further improvement of productivity using selection.

Keywords: Introduced Species, Productivity, Provenance, Above-ground Biomass

Introduction

Use of biomass for energy has increased in Baltic Sea region countries in the last decade. It is partly a price-driven process and partly related to strategic goals of European Union to increase share of renewable energy in the total energy consumption (EC 2009). In Latvia this share has to reach 40% in year 2020. Increased use of renewable energy decreases the dependence on imported fossil materials and is an important aspect in climate change mitigation effort (EC 2008). In forest-rich countries as Fenoscandia and Baltic states, biomass from wood is an important component in the total renewable energy production. Use of logging residues and stumps from clear-cuts is rapidly increasing and is expected to rise in the next years as a consequence of strategic decisions of countries (Malinen et al. 2001, Wikström 2007). Technologies have been developed to facilitate the use of logging residues from thinning. However, this source of biomass has several limitations: in some areas soil depletion and loss of increment in next rotation cycles (Helmisaari et al. 2011), quality of biomass, accessibility, transportation distance. Therefore establishment of plantations for biomass production has been considered in the Baltic states, where large areas of abandoned agricultural land suitable to this purpose are available. In Latvia, the above areas cover approximately 1.44 million ha (VZD 2011). Currently, broadleaved trees - hybrid aspen (*Populus tremuloides* x *P. tremula*), grey alder (*Alnus incana*) and bushes (*Salix* spp. breeds) are used and recommended for the establishment of biomass plantations (LAD 2011). All the above species require fertile soils and/or fertilization to ensure productivity (Miezite 2008, Lazdina et al. 2009). However, the abandoned agricultural lands are often on poor soils, therefore looking at alternative species (including *Pinus contorta*) is a relevant objective for biomass production.

Native range of *Pinus contorta* in north-western America spreads from latitude 30 to 64° N and from 0 to 3900 m in elevation (Wheeler & Critchfield 1985). Establishment of *Pinus contorta* plantations at commercial scale in Sweden started around 1970 (Elfving et al. 2001), and was based on earlier research results on superior productivity of this species in comparison to native *Pinus sylvestris* (Liss & Wirman 1985). Natural regeneration of *Pinus contorta* occurs after forest fires or clear cuts and is often very dense. High density of stands can be retained throughout the rotation period, so that even at the age of 90 years there are still not less than 2000 trees ha^{-1} (Smithers 1962). Furthermore, greater survival, earlier exposure of new needles, longer needles with a larger surface area, fast root development and a higher productivity per unit of nitrogen (Norgren & Elfving 1995) make *Pinus contorta* a suitable species for biomass production.

Biomass equations and estimates have been developed and published for stands in the native range of *Pinus contorta* (Pearson et al. 1984). For Europe, a very limited amount of such studies is available and usually only stem biomass is calculated (Mattsson & Bergsten 2003, Mattson et al. 2007). Comprehensive analysis of biomass equations by Zianis et al. (2005) reveals only one available equation for total above-ground biomass of *Pinus contorta*, developed in Iceland.

Considering the potential of the species and the lack of comprehensive information on its biomass production, the aim of this study was to assess the above-ground biomass of *Pinus contorta* Dougl. var. *latifolia*

Tab. 1 - Characteristics of the experimental plots studied.

Exp. No	Site	Soil	Forest type	*Pinus contorta* provenances	Age
82	Zvirgzde	poor, sandy	*Vacciniosa*	3 from Canada	25
707	Zvirgzde	poor, sandy	*Vacciniosa*	14 from Canada; 2 from Latvia	22
702	Kuldiga	fertile, clay	*Oxalidosa*	13 from Canada; 1 from Latvia	16

Engelm. in comparison to the native *Pinus sylvestris* and factors affecting biomass production.

Material and methods

Study was based on 3 experiments (Tab. 1), located in two sites in central part of Latvia: Zvirgzde and Kuldiga (56° 41' N, 24° 28' E and 57° 03' N, 21° 57' E, respectively). Trials in Zvirgzde (No 82 and No 707) were located on poor, sandy soil, *Vacciniosa* forest type (according to classification by Bušs 1976), while the trial in Kuldiga (No 702) was on fertile clay soil, former arable land, approximately corresponding to the *Oxalidosa* forest type. Soil ploughing was carried out in rows prior to planting. Initial spacing in all trails was 2x1m (5000 trees ha^{-1}), two-years-old bare-rooted plants were used, no thinning carried out prior to measurement. Experiments No 702 and No 707 consist of the same set of *Pinus contorta* provenances from Canada (50° 08' - 60° 15' N, 116° 25' - 132° 50' W), and one seed lot from a *Pinus contorta* stand from Latvia (Tab. 2). Experiment No 82 includes only 3 provenances (54° 24' - 58° 38' N, 122° 45' W), each represented by 5 open-pollinated families.

Each seed lot (provenance or family) was represented by 50 to 60 tree block plots (in experiments No 702, 707 and 82, respectively), randomly distributed in 4 replications. One to two Latvia's *Pinus sylvestris* provenances were used as controls in every experiment. Height and diameter was measured for every tree at age 16 (trial No 702), 22 (No 707) and 25 (No 82). To improve representation of *Pinus sylvestris* for comparison among species, sample plots (500m^2) were established in 20 randomly selected stands (age: 22 years) in the same forest type and tree heights and diameters were measured. For comparison purposes, material for experiment No82 was increased using data from neighboring *Pinus sylvestris* trial No 19, established at the same year with the same spacing. Moreover, data from altogether 20 seed lots from phenotypically selected seed orchards, representing different regions of Latvia, were included in the analysis.

Above-ground biomass (including whole trunk and all branches with needles) was estimated with equations based on measurements of 221 sample trees of *Pinus contorta* from experiment No 82 and 90 trees of *Pinus sylvestris* from experiment No 19 and forest stands (Jansons et al., unpublished - eqn. 1):

$$\ln(biomass) = -8.0284 + 0.9743 \cdot D^2 \cdot H$$

for *Pinus sylvestris* and (eqn. 2)

$$biomass = 256.5622 \cdot (D^2 \cdot H)^{0.9783} (2)$$

for *Pinus contorta*, where D is the diameter at breast height, and H is the total height of the tree.

Both equations provided precise estimates of above ground biomass for the respective species and tree dimensions in Latvia (R^2 = 0.93 and R^2= 0.96, respectively).

Equations were estimated using linear and non-linear regression analysis; significance of differences was determined using *t*-test and ANOVA when the assumptions of parametric tests were met, or using Mann-Whitney U-test and Kruskal-Wallis test when assumptions were violated. Pearson's correlation coefficient was used as a measure of linear dependency. All the analyses were performed using the software R (R Development Core Team, version 2.12.1).

Results and discussion

Results reveal that above-ground biomass of *Pinus contorta* reaches 114 ± 6.4 t ha^{-1} at the age of 16 years on a fertile former arable land (Fig. 1). It is more than two-fold of that observed for *Pinus sylvestris* in the same conditions (50 ± 15.9 t ha^{-1}), and significantly higher ($p < 0.01$) in comparison to older *Pinus contorta* trials on poor sandy forest soils at age 22 and 25 (48 ± 3.6 t ha^{-1} and 94 ± 9.4 t ha^{-1}, respectively). Also in trials on forest land, above-ground biomass of *Pinus contorta* significantly exceeded ($p < 0.05$) the above-ground biomass of *Pinus sylvestris*.

Higher productivity of *Pinus contorta* in comparison to *Pinus sylvestris* has been found in extensive trials in Sweden. For example, on average two-fold yield difference between the above-mentioned species was detected at the age of 23 years (Hagner 1993) and 36-38% difference in wood dry mass was found at age 20 (Elfving & Norgren 1993) in trials located in similar climatic conditions as in Latvia. These results were the basis for an intensive introduction of this species in Sweden (Elfving et al. 2001, Liziniewicz et al. 2012).

Part of the detected differences in biomass production on per ha basis can be explained by differences in survival rate, which was 81 ± 3.1 % for *Pinus contorta* and only 44 ± 11.8 % for *Pinus sylvestris* at the age of 16 years. Similar significant differences in survival among pine species were observed also in older trials: 72 ± 4.7 % *vs.* 37 ± 8.7 % and 58 ± 4.2 *vs.* 41 ± 2.4 % at age 22 and 25, respectively.

High survival of *Pinus contorta* provenances from latitude above 50° N was found also in Estonia at the age of 19 years (67 %) and in Sweden at the age of 18 years (71-92 % on average) in trials with climatic conditions similar to those in Latvia (Lindgren 1993, Erik 1999). A general trend of higher survival for *Pinus contorta* in comparison with *Pinus sylvestris* was also reported from

Tab. 2 - *Pinus contorta* provenances represented in trials in Latvia. (*): seeds form unknow origin from *Pinus contorta* stands growing in Latvia.

Provenance	Latitude	Longitude	Altitude	No702	No707	No82
Teslin, Yukon	60°15'	132°50'	750	X	X	-
Fort Nelson	58°38'	122°41'	495	-	-	X
Pink Mountain	57°00'	122°15'-45'	850	X	X	X
Cecil Lake	56°25'	120°	700	X	X	-
Hudson Hope	56°00'-05'	121°35'-59'	500-800	X	X	-
Moberly Lake	55°40'	121°25'	750	X	X	-
Muskey Lake	55°30'	-	900	X	X	-
Fort St. James	54°30'	124°10'	900	X	X	-
Summit Lake	54°24'	122°37'	813	-	-	X
Smithers	54°15'	127°00'	650	X	X	-
Valemount	53°	119°	850	X	X	-
Rocky Mountain House	52°37'	115°20'	1000	-	X	-
Nordegg	52°20'	116°25'	1400	X	X	-
Falkland	50°32'	119°40'	1300	X	X	-
Lac le Jeune	50°29'	120°29'	1250	X	X	-
Monashee	50°08'	118°30'	950	X	X	-
Skriveri*	56°40'	25°10'	29	X	X	-
Bukulti*	57°01'	24°14'	12	-	X	-

a comprehensive analysis of sets of 10 to 20-years-old stands in Sweden (Ericsson 1988, Elfving & Norgren 1993). Difference in survival between species was ranging from 15 to 45 % at the age of 23 years (Hagner 1993). The observed differences could be partly explained by the influence of needle cast (*Lophodermium seditiosum* Minter, Staley & Millar) reducing the survival of young *Pinus sylvestris* (Baumanis et al. 1982, Baumanis 1993, Hanso & Drenkhan 2007), but not of *Pinus contorta*. Differences between species may also be due to the self-thinning rate, since the initial density in trials is rather high (5000 trees ha^{-1}).

If the biomass of *Pinus sylvestris* in trial No 702 is recalculated using average survival rate of *Pinus contorta*, it reaches 90.4 t ha^{-1}, *i.e.*, on average 80 % of that found for *Pinus contorta*. Even larger relative differences among species remain in older trials on forest land: survival-adjusted biomass of *Pinus sylvestris* reached only 45 % of that estimated for *Pinus contorta* (Fig. 1). Moreover, differences in average tree dimensions between species were more pronounced in older trials (Fig. 2). Increasing differences in average tree dimensions were found also from the analysis of sample trees from trial No 82 (Jansons et al. - unpublished). It can be concluded that *Pinus contorta* has a remarkably higher above-ground biomass than *Pinus sylvestris* on both poor and fertile soils and superiority is related to differences in both survival and growth rate.

Mean annual dry biomass production of *Pinus contorta* on fertile soil at the age of 16 years reached 7.1 ± 0.40 t ha^{-1}, but on poor soils it was only 2.2 ± 0.17 t ha^{-1} at age 22 and 3.8 ± 0.36 t ha^{-1} at age 25. In all trials, biomass production of *Pinus contorta* significantly exceeded ($p < 0.01$) that of *Pinus sylvestris*. Provenance had also a statistically significant influence ($p < 0.01$) on biomass production. In experiment No 702 production was ranging from 5.7 to 8.2 t ha^{-1} y^{-1}, while in experiment No 707 was 1.6-2.8 t ha^{-1} y^{-1} (Fig. 3). Ranking of provenances was stable in both sites, with notably different growth conditions: the mean correlation among provenance was $r = 0.74$ ($p < 0.01$).

Significant effect of genotype (clones, breeds) and soil conditions on above-ground biomass production has been detected also for other species grown or proposed for biomass production in the Baltic Sea region: *Alnus glutinosa*, *Populus tremula*, *Salix* spp., *Populus* spp. For example, two-fold differences in dry above-ground biomass production of *Salix* breeds on fertilized and unfertilized plots were detected in Estonia in trials with 4-year rotation period (Heinsoo et al. 2002). Analysis of common aspen stands on former agricultural lands at the age from 5 to 24 years reveals notable variation of dry biomass production: 2.9 to 9.2 t ha^{-1} y^{-1}, with the lowest productivity for stands growing on sandy soils (Johansson 1999). Depending on *Salix* breed, biomass production in 4-5 year rotation period on fertilized soils reaches from 8 to 14 t ha^{-1} y^{-1} in southern part of Sweden (Willebrand et al. 1993), with similar climatic conditions as in Latvia. In the same region, biomass production at the age of 6 years on former arable land for poplars was 7.5 t ha^{-1} y^{-1}, for hybrid aspen, for grey alder 4.5 t ha^{-1} y^{-1} and for birch 2.3 t ha^{-1} y^{-1} (Telenius 1999). These figures are similar or lower than those found for *Pinus contorta* in experiment No 702. Above-ground biomass production in 4 to 40-years-old grey alder stands, typically located on fertile soils, in Scandinavian and Baltic States reaches 3-5 t ha^{-1} y^{-1} (Bjorklund & Ferm 1982, Saarsalmi et al. 1985, Saarsalmi & Mälkönen 1989, Johansson 2000, Uri et al. 2002, Miezite 2008). These figures are consistent with our results for *Pinus contorta* on poor, sandy soils (trials No 707 and No 82). Higher biomass production (4.5 to 10 t ha^{-1} y^{-1}) was found for hybrid aspen and poplars, where regeneration by sprouting was carried out (Johansson 1999, Telenius 1999, Kunze et al. 2006, Rytter 2006). Productivity is mostly (but not always) higher also in *Salix* plantations, where fertilizer is used: for example, in Latvia and Lithuania it reaches 2.2-13 t ha^{-1} y^{-1} (Smaliukas et al. 2007, Lazdina et al. 2009). Results reveal that *Pinus contorta* has similar or higher pro-

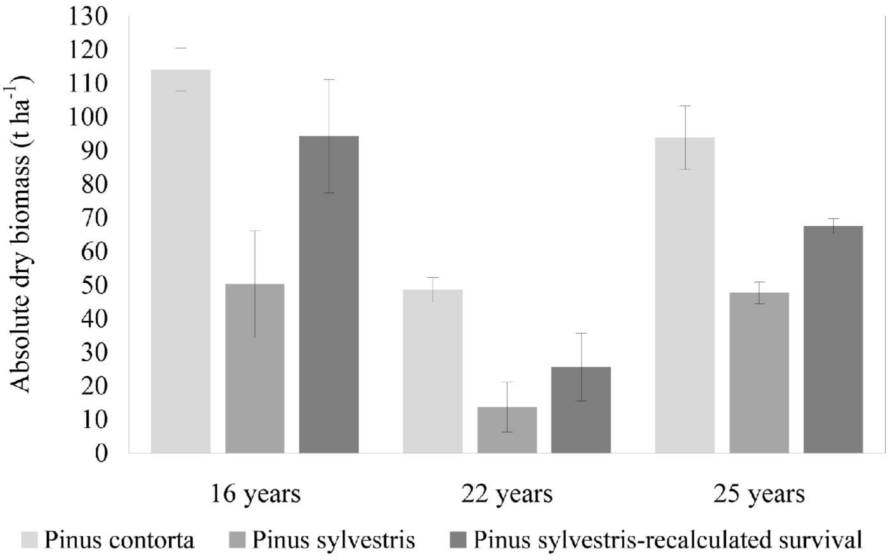

Fig. 1 - Above-ground biomass of young *Pinus contorta* and *Pinus sylvestris* stands in Latvia. *Pinus sylvestris* biomass was recalculated assuming the same survival as for *Pinus contorta* in a particular trial. For more details, see text.

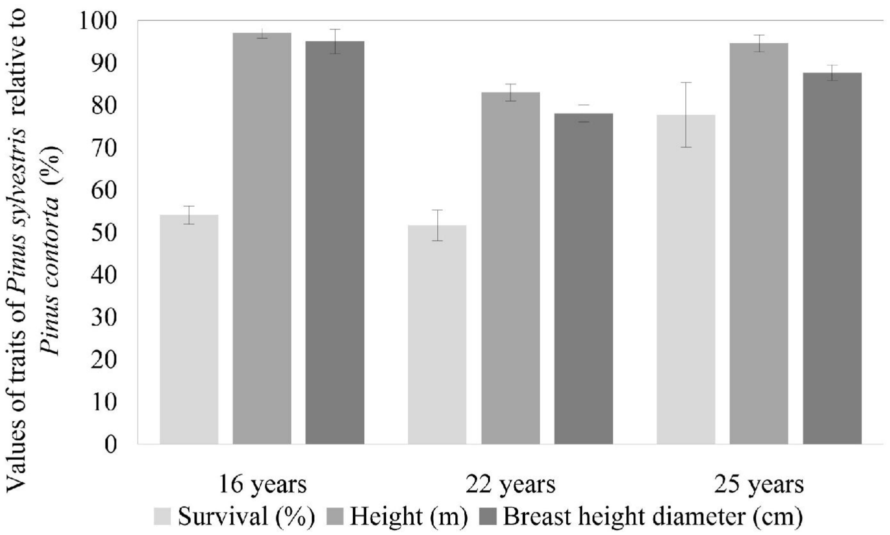

Fig. 2 - Productivity and survival of *Pinus sylvestris* relative to that observed for *Pinus contorta* in a particular trial.

Fig. 3 - Above-ground biomass production *vs.* latitude of origin for different *Pinus contorta* provenances in Latvia.

ductivity than other species recommended for establishment of biomass plantations in the Baltic Sea region, especially on poor, sandy soil where fertilization is not applied.

In the plantation biomass could be obtained not only by clear felling, but also by thinning. Results reveal that light thinning from below (according to current legislation in Latvia), leaving 1000 tallest trees ha^{-1}, would provide on average 33.3 t ha^{-1} dry biomass in experiment No 707 and 61.8 t ha^{-1} biomass in experiment No 702. Biomass production of suppressed trees on poor sandy soil at the age of 22 years ranges from 1.4 to 2.6 t ha^{-1} y^{-1} (1.9 ± 0.20 t ha^{-1} y^{-1} on average) and could ensure notable income in thinning.

The analysis carried out failed to reveal any specific trend in productivity of *Pinus contorta* (biomass, height, diameter) in relation to the geographical location of provenance (latitude, longitude, altitude). Results are coherent with the earlier findings in Sweden from sites with similar climatic and photoperiodic conditions as in Latvia: best growing provenances originated from latitudes 51°-56° N, and no trend between provenance origin and its height growth was found (Hagner 1993, Stål & Stål 1993). Within this geographical range, individual seed source has an important impact on the plantation success (productivity, survival - Lindgren 1993).

Conclusions

Currently, most of the biomass consumed in the growing number of modern district heating plants in cities and municipalities is supplied by logging residuals, but the share of wood chips from clearing of naturally over-grown abandoned agricultural lands is increasing. It is likely that this source will need to be replaced with wood from plantations in the future. Our results suggest that properly selected provenances of *Pinus contorta* can be the best alternative for the establishment of such plantations on poor soils, since the biomass is significantly ($p < 0.01$) and considerably (more than two-fold) higher than that of the native *Pinus sylvestris*. On fertile soils, establishment of plantations for biomass production is currently carried out at small scale by *Populus* spp., and *Alnus incana* (less than 30 ha in year 2011), but predominantly by *Salix* spp. clones (152 ha). Our results prove that *Pinus contorta* is a competitive alternative also in these conditions, producing similar amount of biomass (7.1 ± 0.40 t ha^{-1} y^{-1}) and not requiring fertilization and intensive management.

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References

Baumanis I (1993). A complex research project: factors in Latvia affecting the health of pine (planting stock and young plantations), and recommended protective measures. Proceeding of the Latvian Academy of Sciences 7 (552): 79-80.

Baumanis I, Pirags D, Spalvinš Z (1982). Resistance trials of Scots pine clones in Latvian SSR. In: Proceedings of the "3rd International Workshop on the Genetics of Host-Parasite Interactions in forestry - Resistance to diseases and pests in forest trees" (Heybroek HM, Stephan BR, Weissenberg K eds). Wageningen (NL) 14-21 September 1980, pp. 448-449.

Bjorklund T, Ferm A (1982). Biomass and technical properties of small sized birch and grey alder. Folia Forestalia 500: 1- 37.

Bušs K (1976). Fundamentals of forest classification in Latvia SSR. Apskats, Riga, Latvija, pp. 24. [in Latvian]

EC (2008). Climate change and international security. In: "The high representative and the European commission to the european council". [online] URL: http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/reports/99387.pdf

EC (2009). Directive 2009/28/EC of the European parliament and of the council. [online] URL: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF

Elfving B, Norgren O (1993). Volume yield superiority of Lodgepole pine compare to Scots pine in Sweden. In: Proceedings of the Meeting IUFRO WP 2.02.06 and Frans Kempe Symposium "*Pinus contorta* - from Untamed Forest to Domesticated Crop" (Lindgren D ed). Umeå (Sweden), 24-28 August 1992. Report 11, Department of Forest Genetics and Plant Physiology, Swedish University of Agricultural Sciences, Uppsala, Sweden, pp. 69-80.

Elfving B, Ericsson T, Rosvall O (2001). The introduction of lodgepole pine for wood production in Sweden - a review. Forest Ecology and Management 141: 15-29 - doi: 10.1016/S0378-1127(00)00485-0

Ericsson T (1988). Scots pine seed orchard tests in northern Sweden: results from assessments in summer 1984 of field trials planted 1973-1975. Rapport, Institutet for skogsforbattring, Uppsala, Sweden, pp. 44. [in Swedish with English summary]

Erik U (1999). Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) in Söe arboretum (Jõgeva county). Dendrological Researches in Estonia 1: 76-78. [in Estonian with English summary]

Hagner SOA (1993). SCA's provenance experiments with Lodgepole pine in north Sweden. In: Proceedings of the Meeting IUFRO WP 2.02.06 and Frans Kempe Symposium "*Pinus contorta* - from Untamed Forest to Domesticated Crop" (Lindgren D ed). Umeå (Sweden), 24-28 August 1992. Report 11, Department of Forest Genetics and Plant Physiology, Swedish University of Agricultural Sciences, Uppsala, Sweden, pp.146-161.

Hanso M, Drenkhan R (2007). Retrospective analysis of *Lophodermium seditiosum* epidemics in Estonia. Acta Silv. Lign. Hung., Spec. Edition, pp. 31-45.

Heinsoo K, Sild E, Koppel A (2002). Estimation of shoot biomass productivity in Estonian *Salix* plantations. Forest Ecology and Management 170: 67-74. - doi: 10.1016/S0378-1127(01)00784-8

Helmisaari HS, Hanssen KH, Jacobson S, Kukkola M, Luiro J, Saarsalmi A, Tamminen P, Tveite B (2011). Logging residue removal after thinning in Nordic boreal forests: long-term impact on tree growth. Forest Ecology and Management 261: 1919-1927. - doi: 10.1016/j.foreco.2011.02.015

Johansson T (1999). Biomass equations for determining fractions of European aspen growing on abandoned farmland and some practical implications. Biomass and Bioenergy 17: 471-480. - doi: 10.1016/S0961-9534(99)00073-2

Johansson T (2000). Biomass equations for determining fractions of common and grey alders growing on abandoned farmland and some practical implications. Biomass and Bioenergy 18: 147-159. - doi: 10.1016/S0961-9534(99)00078-1

Kunze M, Nielsen HK, Ahlhaus M (2006). Yield of woody biomass from southern Norway and their suitability for combustion and gasification purposes depending on the harvest frequency. In: Proceedings of "Use of Bioenergy in the Baltic sea region. The 2nd International Baltic Bioenergy Conference" (Barz M, Ahlhaus M eds). Stralsund (Germany) 2-4 November 2006. University of Applied Sciences, pp. 176-185.

LAD (2011). Rural support service, statistics. Web site. [online] URL: http://www.lad.gov.lv/files/elvgf_elgf_elfla_ezf_izmaksas_kalend_gadiem_31122011.pdf

Lazdina D, Lazdins A, Komorovska A, Zeps M (2009). Carbon stock in short rotation Salicaceae. In: "Use of biomass for energy purposes in business" (Jasiulewicz M ed). Koszalin, Poland, pp. 43-50.

Lindgren K (1993). Where to use which *Pinus contorta* provenance? In: Proceedings of the Meeting IUFRO WP 2.02.06 and Frans Kempe Symposium "*Pinus contorta* - from Untamed Forest to Domesticated Crop" (Lindgren D ed). Umeå (Sweden), 24-28 August 1992. Report 11, Department of Forest Genetics and Plant Physiology, Swedish University of Agricultural Sciences, Uppsala, Sweden, pp.162-180.

Liss PE, Wirman S (1985). Provenance trials with Lodgepole pine, *Pinus contorta* var. *latifolia*. Institutet för Skogsförbättring, Skogsträdsförädling, no. 8, pp. 4. [in Swedish with English summary]

Liziniewicz M, Ekö PM, Agestam E (2012). Effect of spacing on 23-year-old lodgepole pine (*Pinus contorta* Dougl. var. *latifolia*) in southern Sweden. Scandinavian Journal of Forest Research 27: 361-371. - doi: 10.1080/02827581.2011.639798

Malinen J, Pesonen M, Määttä T, Kajanus M (2001). Potential harvest for wood fuels (energy wood) from logging residues and first thinnings in Southern Finland. Biomass and Bioenergy 20: 189-196. - doi: 10.1016/S0961-9534(00)00075-1

Mattsson S, Bergsten U (2003). *Pinus contorta* growth in northern Sweden as affected by soil scarification. New Forests 26: 217-231. - doi: 10.1023/A:1024425205712

Mattson S, Bergsten U, Mörling T (2007). *Pinus contorta* growth in boreal Sweden as affected by combined lupin treatment and soil scarification. Silva Fennica 41: 649-659.

Miezite O (2008). Structure and productivity of grey alder stands. PhD thesis, Latvia University of Agriculture, Jelgava, Latvia, pp. 127.

Norgren O, Elfving B (1995). Pine or lodgepole pine - the choice between stability and growth. Fakta skog Nr15, Sveriges Lantbruksuniversitet, Umeå, Sweden. [in Swedish]

Pearson JA, Fahey TJ, Knight DH (1984). Biomass and leaf area in contrasting lodgepole pine forests. Canadian Journal of Forest Research 14: 259-265. - doi: 10.1139/x84-050

Rytter L (2006). A management regime for hybrid aspen stands combining conventional forestry techniques with early biomass harvests to exploit their rapid early growth. Forest Ecology and Management 236: 422-426. - doi: 10.1016/j.-foreco.2006.09.055

Saarsalmi A, Palmgreen K, Levula T (1985). Biomass production and nutrient and water consumption in an *Alnus incana* stands. Folia Forestalia 628: 1-24. [in Finnish with English summary]

Saarsalmi A, Mälkönen E (1989). Biomass production and nutrient consumption in *Alnus incana* stands. Folia Forestalia 728: 1-16. [in Finnish with English summary]

Smaliukas D, Noreika R, Karalius D (2007). Clonal selection of *Salix* L. taxa perspective for biofuel production, evaluation of their dendrometric characteristics and accumulation of biomass in short rotation plantations. Biologija 53: 59-62. [online] URL: http://www.lmaleidykla.lt/ojs/index.php/biologija/article/view/739

Smithers LA (1962). Lodgepole pine in Alberta. Canada Department of Forestry, Bulletin no. 127, pp. 153.

Stål PH, Stål EG (1993). Six year results from a *Pinus contorta* provenance trial series in southern Sweden. In: Proceedings of the Meeting IUFRO WP 2.02.06 and Frans Kempe Symposium "Pinus contorta - from Untamed Forest to Domesticated Crop" (Lindgren D ed). Umeå (Sweden), 24-28 August 1992. Report 11, Department of Forest Genetics and Plant Physiology, Swedish University of Agricultural Sciences, Uppsala, Sweden, pp.137-145.

Telenius BF (1999). Stand growth of deciduous pioneer tree species on fertile agricultural land in southern Sweden. Biomass and Bioenergy 16: 13 - 23. - doi: 10.1016/S0961-9534(98)00073-7

Uri V, Tullus H, Lõhmus K (2002). Biomass production and nutrient accumulation in short-rotation grey alder (*Alnus incana* (L.) Moench) plantation on abandoned agricultural land. Forest Ecology and Management 161: 169-179. - doi: 10.1016/S0378-1127(01)00478-9

VZD (2011). State land service report 2011. Website. [online] URL: http://www.vzd.gov.lv/sakums/publikacijas-un-statistika/parskats/?id=846

Wheeler NC, Critchfield WB (1985). The distribution and botanical characteristics of lodgepole pine: biogeographical and management implications. In: "Lodgepole pine: the species and its management" (Baumgartner DM ed). Pullman, Washington State University, USA, pp. 1-13.

Wikström F (2007). The potential of energy utilization from logging residues with regard to the availability of ashes. Biomass and Bioenergy 31: 40-45. - doi: 10.1016/j.biombioe.2006.05.002

Willebrand E, Ledin S, Verwijst T. (1993). Willow coppice systems in short rotation forestry: effects of plant spacing, rotation length and clonal composition on biomass production. Biomass and Bioenergy 4: 323-331. - doi: 10.1016/0961-9534(93)90048-9

Zianis D, Muukkonen P, Mäkipää R, Mencuccini M (2005). Biomass and stem volume equations for tree species in Europe. Silva Fennica Monographs 4: 63.