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BIRCH SAP HARVESTING IN CHANGING SPRING CONDITIONS AND ITS IMPACT ON TREES GROWTH

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Abstract

The collection of birch sap in spring has become, in the past decades, a regular practice in Romania, because of its multiple health benefits. Over the years, many collectors experienced unsatisfactory results in terms of the amount of sap harvested, usually attributed to the unpredictable spring weather of some years, with large variations from a day to another. The results of this study revealed that independently of weather conditions in spring, the best period of sap harvesting in North-East of Romania was between 25th of March - 5th of April, when the air temperatures did not exceed 15°C. Trees higher than 20 m were most productive. At the end of the growing season, tapped trees were smaller than those untapped. These results suggest that in time, the tapped trees are less productive due to loss of vigour rather than spring weather conditions.

Key words: *Betula pendula, climatic changes, sap production, trees height.*

INTRODUCTION

European countries are affected by global warming, which has a significant impact on the climate (Anders et al., 2014). Seasons are frequently abnormal in terms of both temperature and precipitation' regimes, with implications on vegetation (Sukopp & Wurzel, 2003; Gloning et al., 2013; Loupian et al., 2017; Liu et al., 2020). Climatic changes affect woody plants communities all around in Europe. Various effects were observed, from forest scale, such as distribution of species (Heuertz et al., 2010; Czúcz et al., 2011; Silva et al., 2012; Matías & Jump, 2014) and biodiversity/composition (Ruiz-Labourdette et al., 2013; Morin et al., 2018; Vacek et al., 2021) to individuals, for instance, species interactions (Kleinbauer et al., 2010; González-Muñoz et al., 2014), drought-induced dieback (Martinez-Vilalta et al., 2012), and changes in growth (Vieira et al., 2020; Zhirnova et al., 2021). Climate change have an essential impact on the non-wood forest products (Kirilenko & Sedjo, 2007; Murphy et al., 2012; Gurung et al., 2021), because their quantities and qualities depend on the ability of trees to manage with the new conditions. In case of silver birch (*Betula pendula*), which is a common species in Europe, it revealed an excellent acclimation capacity to light and temperature (Rousi et al., 2012). However, although the outset of spring bud burst is controlled by photoperiod and heat sum (Hänninen & Tanino, 2011; Hawkins & Dhar, 2012), birch trees' survival and adaptation to climate changes seems to be dependent by nitrogen soil availability (Possen et al., 2021).

In Romania, the collection of birch sap in spring has become, in the past decades, a regular practice, mainly because of its benefits on different organs such as kidneys, liver, lungs, stomach or skin (Svanberg et al., 2012; Papp et al., 2014). Birch sap can be harvested from both rural and urban trees, without but it may have a different composition when those experience environmental stress (Grabek-Lejko et al., 2017).

The birch sap harvest begins in March and ends in May, before the foliage state (Papp et al., 2014). Over the years, in Romania, many collectors experienced unsatisfactory results in terms of the amount of sap harvested, usually attributed to the unpredictable spring weather of some years, with large variations from a day to another. Therefore, the present research identifies the ability of birch trees to deal with climate change in terms of sap production and the impact of this practice on trees growth.

MATERIALS AND METHODS

Investigations were carried in 2020 and 2021, on twenty silver birch trees (*Betula pendula* Roth.) growing in a forest near Râşca village (47°21′25″N, 26°14′4″E, 399 m altitude), Suceava County, România. Birches grow here on a podzolic soil of normal humidity.

During the two years of studies, the weather conditions in the region were quite different. Thus, the mild winter of 2019/2020 was followed by a spring with a cold start, recording 13 days with minimum negative temperatures in March and eight days in April. Also, during March and April, warm days were frequently followed by intense cooling. At the end of March, the last snowfall covered the soil with 8 cm of snow and after that, April was completely dry. In contrast, winter 2020/2021 was colder, with frequent episodes of frost and snow. First part of spring was also cold, with 17 days of minimum negative temperatures in March and the last snowfall was recorded in the second decade of the same month. After that, spring was warm and relatively dry.

Birch sap was harvested from the same marked trees during March-April of the two years. Trees were tapped on 10th March, prior to the start of sap flow. In each trunk at a height of 50 cm above soil surface, a single hole was open in the same position on each tree, with the diameter of 10 mm and 3-4 cm depth, using a drill. Then a plastic tube was inserted into the hole and the other end attached to a plastic container. Sap was collected and measured for each individual, daily.

Growth of the tapped trees was evaluated by measuring their height, using a Haglöf Vertex 5 Hypsometer and diameter at breast height (dbh), using a tree caliper. Data were recorded in March, before extracting the sap, and at the end of growing season, in November. For comparison, the same measurements were made simultaneously for non-tapped birch trees. Also, the age of every tree was determined, using a Pressler borer.

Statistical analysis were applied to evaluate the influence of trees parameters (tree height, crown height, diameter at breast height and age) on the sap production, using linear regression and Pearson test. The impact of sap harvest on trees growth was analysed using one-way ANOVA test, which was applied on the data representing the differences among height and dbh of both tapped and untapped trees, before and after growing season, then statistical differences between means were estimated with the Least Significant Difference (LSD) test at 5% level of significance.

RESULTS AND DISCUSSIONS

Sap started to flow in the second decade of March, independent of spring weather conditions in 2020 and 2021(Figure 1). The highest average amount of sap was harvested between 25th of March and 5th of April, representing 65% of the total sap collected. Even if in 2020, a few warm days in March initiated the sap flow a week earlier (on 19th March), the sudden cooling that followed, stopped it.

The sap harvesting takes place in almost same period also in some other European countries such as Denmark (Sancho et al., 2022), Germany (Westhoff et al., 2008), Finland (Harju and Huldén, 1990), Lithuania (Mingaila et al., 2020), Latvia (Kūka et al., 2013), Poland (Zajączkowska et al., 2019; Staniszewski et al., 2020), and Ukraine (Zyryanova et al., 2010). Although Europe has a varied climate, continental weather experienced a similar warming trend in recent years (Van Heerwaarden et al., 2021). Therefore, higher temperatures in Northern Europe accelerated the springtime phenological evens of birch trees (Emberlin et al., 2002; Ahas et al., 2002; Olsson & Jönsson, 2014; Minin et al., 2016) and sap can be collected around the same period as in Eastern Europe.

Values of air temperature at the time of harvesting had an important impact on the sap flow rate. At negative temperatures during day, complete cessation of sap flow was observed for all trees.

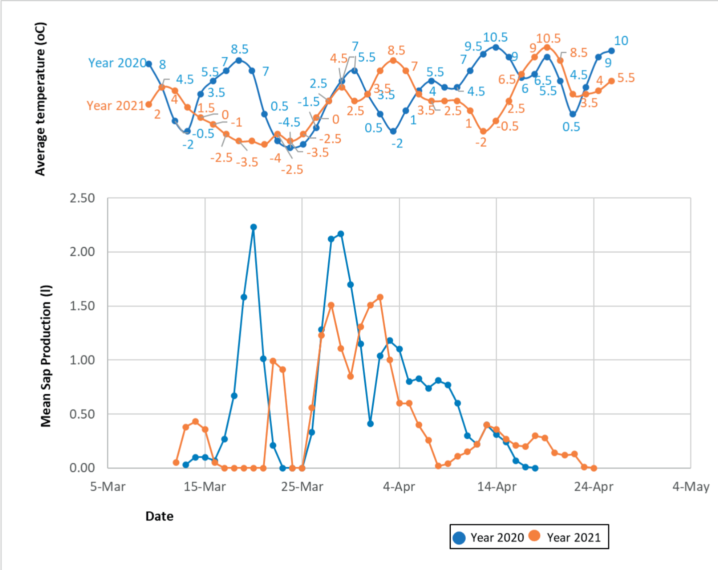

Figure 1. Mean quantity of sap (l) collected from silver birch trees, during the spring of 2020 and 2021

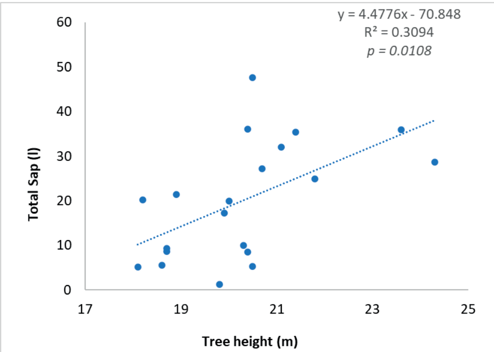

Figure 2. Positive correlation between total sap and tree height (significant at $p < 0.05$)

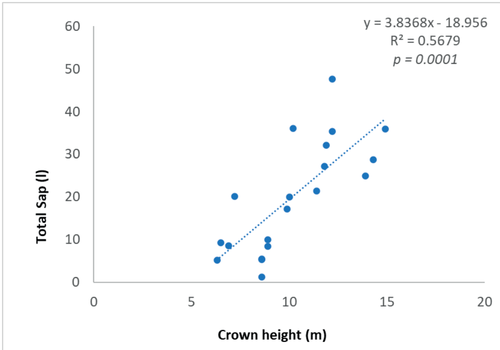

Figure 3. Strong correlation between total sap and crown height (significant at $p < 0.01$)

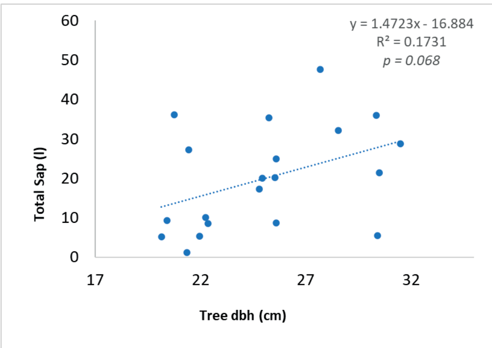

Figure 4. Relationship between total sap and diameter at breast height (dbh)

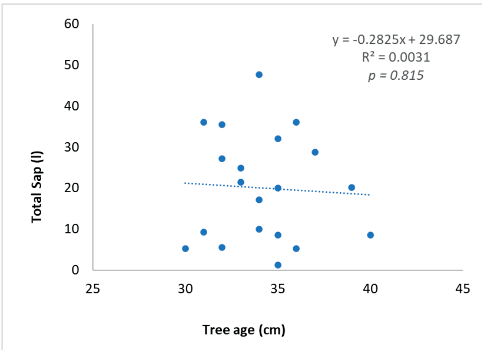

Figure 5. Relationship between total sap and tree age

Also, sap flow decreased when maximum temperatures exceeded 10ºC. The relationship between sap flow and air temperature was reported by other researchers (Harju and Huldén, 1990; Westhoff et al., 2008; Hölttä et al, 2018).
Low precipitation rate or drought do not seem to affect sap flow in birches (Gartner et al., 2009; Baumgarten et al., 2019; Sullivan et al., 2021). Still, silver birch trees (*Betula pendula*) are sensitive to prolonged drought (Beck et al., 2016; Dox et al., 2022).
The exudation period lasted 35 days in spring of 2020 and 43 days in 2021. Birch trees exude even longer, up to 47 days in northern Europe (Essiamah, 1980). This variation depends on temperature.
Although the sap flow lasted longer in the spring of 2021, the total quantity of sap was not greater than in 2020.
Total quantity of sap harvested from each silver birch was positively correlated (Figure 2) with tree height ($r = 0.5562$; $r^2 = 0.3094$; $p = 0.0108$). Thus, much more sap was collected from trees taller than 20 m. Moreover, sap quantity was strong positive correlated with crowns height (Figure 3).
The highest quantity of sap was harvested during spring of 2020, totalling 47.7 liters, from a tree of 21 m in height and with a crown height of 12 m. From the same tree was collected the highest quantity of sap as well in the following year.
For most of the investigated birches, the amount of harvested sap was lower in 2021. Thus, the total sap production in the spring of 2021 represented only 80% of that of 2020. A decrease in sap production of trees exploited in consecutive years has also been reported by Maher (2005).
No significant relationship was found between total sap harvested and dbh or tree age (Figures 4 and 5).
Some authors remarked a corelation between sap quantity and dbh (Shi et al., 2001; Maher, 2005; Mingaila et al., 2020) and other, did not (Ganns et al., 1982; van den Berg et al., 2013). Generally, dbh is one of the most used parameters that guide collectors to select trees for tapping, but sap yield proved to be more in relation with several other factors, such as birch species (Zyryanova et al., 2010), position of tree in the forest stand (Zajączkowska et al., 2019) or soil type (Mangaila et al., 2020). Anyway, the cardinal location of the boreholes in the tree trunk does not affect the sap quantity (Kopeć et al., 2020).
Sap harvesting in the spring of 2020 and 2021 had a negative impact on trees growth. Trees height were significant reduced comparative with untapped trees (Table 1) at the end of growing season.

Table 1. Comparative growth parameters at the end of 2020 and 2021 at untapped and tapped trees

Parameters	Untapped Trees		Tapped Trees		LSD
	2020	2021	2020	2021	
Average height differences (m)	0.61	0.43	0.39*	0.26*	*0.16*
Average dbh differences (cm)	0.38	0.60	0.33	0.39	*0.23*

LSD – Least Significant Difference
Asterix indicates a statistically significant difference ($P<0.05$, LSD test) from untapped trees.

Although the values of dbh were also smaller at tapped trees, these were not found statistically significant at $P<0.05$.
Springtime phenological events relies on xylem sap. In both years of studies, sap harvesting delayed the budburst. Moreover, drought restrict bud development and growth (Kukk et al., 2015). Consequently, although birches have indeterminate growth habit (Hara et al., 1991; Pothier & Margolis, 1991; Weih, 2000; Zarnovican, 2000), shoots extension period was shorter in tapped birch trees, and recorded lower heights in autumn. Our findings are confirmed by Rousi and Pusenius (2005), which concluded that the best predictor of silver birch growth is length of the growing period.

CONCLUSIONS

Climate warming changed the phenology of many tree species. In case of silver birch, our investigations in North-East of Romania revealed that sap exudation occurs at the same period every year, independent of weather conditions. Almost 65% from total quantity of sap was harvested between 25th of March and 5th of April, as in other European countries, including some northern and central ones. Sap yield was significantly correlated with tree height but not with dbh or age, parameters that usually sap collectors take as indicators of a higher harvest.

The tapping of silver birch trees in consecutive years, induced a significant loss of vigor that reduced productivity with 20%. Tapping trees must be done without compromising their growth and health over time. Therefore, it is essential to exploit the trees in the forest with responsibility, avoiding sap harvest in consecutive years and limiting the collection to one week.

REFERENCES

Ahas, R., Aasa, A., Menzel, A., Fedotova, V. G., Scheifinger, H. (2002). Changes in European spring phenology. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *22*(14), 1727-1738.

Anders, I., Stagl, J., Auer, I., Pavlik, D. (2014). Climate change in central and eastern Europe. In *Managing protected areas in Central and Eastern Europe under climate change*; Rannow, S., Neubert, M., Eds.; Springer: New York, NY, USA, 17–30.

Baumgarten, M., Hesse, B. D., Augustaitienė, I., Marozas, V., Mozgeris, G., Byčenkienė, S., Mordas, G., Pivoras, G., Juonyte, D., Ulevičius, V., Augustaitis, A., Matyssek, R. (2019). Responses of species-specific sap flux, transpiration and water use efficiency of pine, spruce and birch trees to temporarily moderate dry periods in mixed forests at a dry and wet forest site in the hemi-boreal zone. *Journal of Agricultural Meteorology*, *75*(1), 13-29.

Beck, P., Caudullo, G., de Rigo, D., Tinner, W. (2016). *Betula pendula*, *Betula pubescens* and other birches in Europe: distribution, habitat, usage and threats. In: San-Miguel-Ayanz, J.; de Rigo, D.; Caudullo, G.; Houston Durrant, T.; Mauri, A. (eds.) European Atlas of Forest Tree Species, Publication Office of the European Union, Luxembourg, 70-73.

Czúcz, B., Gálhidy, L., Mátyás, C. (2011). Present and forecasted xeric climatic limits of beech and sessile oak distribution at low altitudes in Central Europe. *Annals of Forest Science*, *68*(1), 99-108.

Dox, I., Skrøppa, T., Decoster, M., Prislan, P., Gascó, A., Gričar, J., Lange, H., Campioli, M. (2022). Severe drought can delay autumn senescence of silver birch in the current year but advance it in the next year. *Agricultural and Forest Meteorology*, *316*, 108879.

Emberlin, J., Detandt, M., Gehrig, R., Jaeger, S., Nolard, N., Rantio-Lehtimäki, A. (2002). Responses in the start of *Betula* (birch) pollen seasons to recent changes in spring temperatures across Europe. *International journal of biometeorology*, *46*, 159-170.

Essiamah, S. K. (1980). Spring sap of trees. *Berichte der deutschen botanischen Gesellschaft*, *93*(1), 257-267.

Ganns, R. A., Zasada, J. C., Phillips, C. (1982). Sap production of paper birch in the Tanana Valley, Alaska. *The Forestry Chronicle*, *58*(1), 19-22.

Gartner, K., Nadezhdina, N., Englisch, M., Čermak, J., Leitgeb, E. (2009). Sap flow of birch and Norway spruce during the European heat and drought in summer 2003. *Forest Ecology and Management*, *258*(5), 590-599.

Gloning, P., Estrella, N., Menzel, A. (2013). The impacts of climate change on the winter hardiness zones of woody plants in Europe. *Theoretical and applied climatology*, *113*, 683-695.

González-Muñoz, N., Linares, J. C., Castro-Díez, P., Sass-Klaassen, U. (2014). Predicting climate change impacts on native and invasive tree species using radial growth and twenty-first century climate scenarios. *European Journal of Forest Research*, *133*(6), 1073-1086.

Grabek-Lejko, D., Kasprzyk, I., Zaguła, G. Puchalski, C. (2017). The bioactive and mineral compounds in birch sap collected in different types of habitats. *Baltic Forestry*, *23*(2), 394-401.

Gurung, L. J., Miller, K. K., Venn, S., Bryan, B. A. (2021). Contributions of non-timber forest products to people in mountain ecosystems and impacts of recent climate change. *Ecosystems and People*, *17*(1), 447-463.

Hänninen, H., Tanino, K. (2011). Tree seasonality in a warming climate. *Trends in plant science*, *16*(8), 412-416.

Hara, T., Kimura, M., Kikuzawa, K. (1991). Growth patterns of tree height and stem diameter in populations of *Abies veitchii*, *A. mariesii* and *Betula ermanii*. *The Journal of Ecology*, 1085-1098.

Harju, L., Huldén, S. G. (1990). Birch sap as a tool for biogeochemical prospecting. *Journal of Geochemical Exploration*, *37*(3), 351-365.

Hawkins, C. D., Dhar, A. (2012). Spring bud phenology of 18 *Betula papyrifera* populations in British Columbia. *Scandinavian Journal of Forest Research*, *27*(6), 507-519.

Heuertz, M., Teufel, J., González-Martínez, S. C., Soto, A., Fady, B., Alia, R., Vendramin, G. G. (2010). Geography determines genetic relationships between species of mountain pine (*Pinus mugo* complex) in western Europe. *Journal of Biogeography*, *37*(3), 541-556.

Hölttä, T., Dominguez Carrasco, M. D. R., Salmon, Y., Aalto, J., Vanhatalo, A., Bäck, J., Lintunen, A. (2018). Water relations in silver birch during springtime: How is sap pressurised?. *Plant Biology*, *20*(5), 834-847.

Kirilenko, A.P., Sedjo, R.A. (2007). Climate change impacts on forestry. *Proceedings of the National Academy of Sciences of the U.S.A. 104*(50), 19697–19702.

Kleinbauer, I., Dullinger, S., Peterseil, J., Essl, F. (2010). Climate change might drive the invasive tree *Robinia pseudacacia* into nature reserves and endangered habitats. *Biological conservation*, *143*(2), 382-390.

Kopeć, S., Staniszewski, P., Giedrowicz, A., Misiurski, J., Szymańska, A., Bilek, M. (2020). Selected physical parameters and daily volume of silver birch sap collected from the cardinal directions of the tree trunk. *Environmental Sciences Proceedings*, *3*(1), 100.

Kūka, M., Čakste, I., Geršebeka, E. (2013). Determination of bioactive compounds and mineral substances in Latvian birch and maple saps. In *Proceedings of the Latvian Academy of Sciences. Section B. Natural, Exact, and Applied Sciences 67*(4-5), 437-441.

Kukk, M., Räim, O., Tulva, I., Sõber, J., Lõhmus, K., Sõber, A. (2015). Elevated air humidity modulates bud size and the frequency of bud break in fast-growing deciduous trees: silver birch (*Betula pendula* Roth.) and hybrid aspen (*Populus tremula* L.× *P. tremuloides* Michx.). *Trees*, *29*, 1381-1393.

Liu, X., He, B., Guo, L., Huang, L., Chen, D. (2020). Similarities and differences in the mechanisms causing the European summer heatwaves in 2003, 2010, and 2018. *Earth's Future*, *8*(4), e2019EF001386.

Loupian, E. A., Bartalev, S. A., Krasheninnikova Yu, S., Plotnikov, D. E., Tolpin, V. A. (2017). Abnormal development of spring crops in European Russia in 2017. *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa*, *14*(3), 324-329.

Maher, K. A. C. (2005). Production and quality of spring sap from Alaskan birch (*Betula neoalaskana* Sargent) in interior Alaska. *Master of Science thesis, University of Alaska, Fairbanks*, 76 p.

Martínez-Vilalta, J., Lloret, F., Breshears, D. D. (2012). Drought-induced forest decline: causes, scope and implications. *Biology Letters,* 8, 689–691.

Matías, L., Jump, A. S. (2014). Impacts of predicted climate change on recruitment at the geographical limits of Scots pine. *Journal of Experimental Botany*, *65*(1), 299-310.

Mingaila, J., Čiuldienė, D., Viškelis, P., Bartkevičius, E., Vilimas, V., Armolaitis, K. (2020). The quantity and biochemical composition of sap collected from silver birch (*Betula pendula* Roth) trees growing in different soils. *Forests*, *11*(4), 365.

Minin, A.A., Ran'kova, E.Y., Rybina, E.G., Buivolov, Y.A., Sapel'nikova, I.I., Filatova, T.D. (2016). Phenoindication of climate changes for the period 1976–2015 in the central part of European Russia: white birch (*Betula verrucosa* Ehrh. (*B. pendula* Roth).), *Problems of ecological monitoring and ecosystem modeling 27*(2), 17–28.

Morin, X., Fahse, L., Jactel, H., Scherer-Lorenzen, M., García-Valdés, R., Bugmann, H. (2018). Long-term response of forest productivity to climate change is mostly driven by change in tree species composition. *Scientific Reports*, *8*(1), 1-12.

Murphy, B. L., Chretien, A. R., Brown, L. J. (2012). Non-timber forest products, maple syrup and climate change. *Journal of Rural and Community Development*, *7*(3), 42-64.

Olsson, C., Jönsson, A. M. (2014). Process-based models not always better than empirical models for simulating budburst of Norway spruce and birch in Europe. *Global Change Biology*, *20*(11), 3492-3507.

Papp, N., Czégényi, D., Hegedus, A., Morschhauser, T., Quave, C. L., Cianfaglione, K., Pieroni, A. (2014). The uses of *Betula pendula* Roth among Hungarian Csángós and Székelys in Transylvania, Romania. *Acta Societatis Botanicorum Poloniae*, *83*(2), 113-122.

Possen, B. J., Rousi, M., Keski-Saari, S., Silfver, T., Kontunen-Soppela, S., Oksanen, E., Mikola, J. (2021). New evidence for the importance of soil nitrogen on the survival and adaptation of silver birch to climate warming. *Ecosphere*, *12*(5), e03520.

Pothier, D., Margolis, A. (1991). Analysis of growth and light interception of balsam fir and white birch saplings following precommercial thinning. In *Annales des sciences forestières 48*(2), 123-132.

Rousi, M., Pusenius, J. (2005). Variations in phenology and growth of European white birch (*Betula pendula*) clones. *Tree Physiology*, *25*(2), 201-210.

Rousi, M., Possen, B. J., Hagqvist, R., Thomas, B. R. (2012). From the arctic circle to the Canadian prairies-a case study of silver birch acclimation capacity. *Silva Fennica*, *46*, 355-364.

Ruiz-Labourdette, D., Schmitz, M. F., Pineda, F. D. (2013). Changes in tree species composition in Mediterranean mountains under climate change: Indicators for conservation planning. *Ecological Indicators*, *24*, 310-323.

Sancho, A. I., Birk, T., Gregersen, J. M., Rønne, T., Hornslet, S. E., Madsen, A. M., Bøgh, K. L. (2022). Microbial safety and protein composition of birch sap. *Journal of Food Composition and Analysis*, *107*, 104347.

Shi, F., Li, J., Koike, T., Nie, S. (2001). Resources of the white birch (*Betula platyphylla*) for sap production and its ecological characteristics in Northeast China. *Eurasian Journal of Forest Research*, *2*, 31-38.

Silva, D. E., Mazzella, P. R., Legay, M., Corcket, E., Dupouey, J. L. (2012). Does natural regeneration determine the limit of European beech distribution under climatic stress?. *Forest Ecology and Management*, *266*, 263-272.

Staniszewski, P., Bilek, M., Szwerc, W., Tomusiak, R., Osiak, P., Kocjan, R., Moskalik, T. (2020). The effect of tree age, daily sap volume and date of sap collection on the content of minerals and heavy metals in silver birch (*Betula pendula* Roth) tree sap. *Plos one*, *15*(12), e0244435.

Sukopp, H., Wurzel, A. (2003). The effects of climate change on the vegetation of central European cities. *Urban habitats*, *1*(1), 66-86.

Sullivan, P. F., Brownlee, A. H., Ellison, S. B., Cahoon, S. M. (2021). Comparative drought sensitivity of co-occurring white spruce and paper birch in interior Alaska. *Journal of Ecology*, *109*(6), 2448-2460.

Svanberg, I., Sõukand, R., Luczaj, L., Kalle, R., Zyryanova, O., Dénes, A., Papp, N., Nedelcheva, A., Šeškauskaitė, D., Kołodziejska-Degórska, I., Kolosova, V. (2012). Uses of tree saps in northern and eastern parts of Europe. *Acta Societatis Botanicorum Poloniae*, *81*(4), 343-357.

Vacek, Z., Cukor, J., Vacek, S., Linda, R., Prokůpková, A., Podrázský, V., Gallo, J., Vacek, O., Šimůnek, V., Drábek, O., Hájek, V., Spasić, M., Brichta, J. (2021). Production potential, biodiversity and soil properties of forest reclamations: Opportunities or risk of introduced coniferous tree species under climate change?. *European Journal of Forest Research*, *140*(5), 1243-1266.

van den Berg, A., Rogers, G., Perkins, T., Wilmot, T., Hopkins, K. (2013). Birch syrup production to increase the economic sustainability of maple syrup production in the Northern Forest. University of *Vermont extension maple conferences, Vermont, USA*. *Retrieved 2023 February 10 from https://nsrcforest.org/sites/default/files/uploads/vandenBerg11full.pdf*

Van Heerwaarden, C. C., Mol, W. B., Veerman, M. A., Benedict, I., Heusinkveld, B. G., Knap, W. H., Kazadzis, S., Kouremeti, N., Fiedler, S. (2021). Record high solar irradiance in Western Europe during first COVID-19 lockdown largely due to unusual weather. *Communications Earth & Environment*, *2*(1), 37.

Vieira, J., Carvalho, A., Campelo, F. (2020). Tree growth under climate change: evidence from xylogenesis timings and kinetics. *Frontiers in plant science*, *11*, 90.

Weih, M. (2000). Delayed growth response of Mountain Birch seedlings to a decrease in fertilization and temperature. *Functional Ecology*, *14*(5), 566-572.

Westhoff, M., Schneider, H., Zimmermann, D., Mimietz, S., Stinzing, A., Wegner, L. H., Kaiser, W., Krohne, G., Shirley, S., Jakob, P., Bamberg, E., Bentrup, F. W., Zimmermann, U. (2008). The mechanisms of refilling of xylem conduits and bleeding of tall birch during spring. *Plant Biology*, *10*(5), 604-623.

Zajączkowska, U., Kaczmarczyk, K., Liana, J. (2019). Birch sap exudation: influence of tree position in a forest stand on birch sap production, trunk wood anatomy and radial bending strength. *Silva Fennica*, *53*(2).

Zarnovican, R. (2000). Climate and volume growth of young yellow birch (*Betula alleghaniensis* Britton) at three sites in the sugar maple–yellow birch forest region of Québec. *Ecoscience*, *7*(2), 222-227.

Zhirnova, D. F., Belokopytova, L. V., Meko, D. M., Babushkina, E. A., Vaganov, E. A. (2021). Climate change and tree growth in the Khakass-Minusinsk Depression (South Siberia) impacted by large water reservoirs. *Scientific reports*, *11*(1), 1-13.

Zyryanova, O. A., Terazawa, M., Koike, T., Zyryanov, V. I. (2010). White birch trees as resource species of Russia: their distribution, ecophysiological features, multiple utilizations. *Eurasian Journal of Forest Research*, *13*(1), 25-40.