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Weight loss of logwood piles stored under winter conditions in Poland

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Abstract

Our work focuses on the natural drying of woods in winter. It aimed to compare the natural drying process of three wood species: Scots pine as coniferous species, sessile oak as ring-porous species with a marked heartwood and silver birch as a sapwood species with a diffuse-porous structure. The research was carried out in central Poland. We collected logs from a 41-year-old stand destined for thinning. We stacked the logs randomly in one pile. The experiment took place between November 30, 2016 and April 4, 2017. All the samples were measured individually every two days throughout the experiment. We found logs lost weight during the experiment, especially pine (12% of total mass), less so oak and birch (7%). We recorded the biggest decrease during the last month (in spring). The wood moisture content decreased the most in pine and the least in oak heartwood. The stepwise regression model explains the impact of weather at 58%. Relative humidity was the most significant factor (0.58), followed by temperature and wind. We observed that weight loss and diameter are related to different degrees in the tested species, which probably depends on the sapwood area. Our observations show that natural wood drying in winter is a slow process that speeds up in the spring.

Keywords: natural drying, woodpiles, wood storage, moisture content

Introduction

Research on the natural drying of wood has a long history, and many researchers have developed drying methods in specific directions, based on the potential application of the wood. Most studies are focused on planning and transport costs (Stokes et al. 1993, Sims and Venturi 2004, Irdla et al. 2016, Sfeir et al. 2021); some works are focused on the energy value of biomass (Jirijis 1995, Petterson and Nordfjell 2007, Erber et al. 2012); others on economic benefits (Routa et al. 2018). Various methods of natural drying are taken into consideration, such as: transpirational drying, tested mainly on young trees (Stokes et al. 1987, Mithell et al. 1988, Cutshall et al. 2011, 2013, Filbakk et al. 2011a). Many wood storages have also been investigated (Kofman and Kent 2009, Röser et al. 2010, Routa et al. 2015). Logging residues have also been the subject of interest (Filbakk et al. 2011, Gautam et al. 2012, Kizha and Han 2017, Kizha et al. 2018). As proved by Greene et al. (2014), the harvesting method also affects the moisture of logs. Finally, we have observed the development of natural wood drying modelling. Models have been developed for different species and different drying methods (Erber et al. 2012, 2016, 2017, Kim and Murphy 2013, Raitila et al. 2015, Routa et al. 2015, 2016). Tests have been carried out at various time intervals, from short ones of several days, typical of transpirational drying (Wang et al. 2017, Tomczak et al. 2018), to weeks, months, one year and even longer (Patterson et al. 2010, Röser et al. 2010, Routa et al. 2015). This research has shown that models based on narrow intervals such as hours, give the best results; however, for the needs of forestry, models based on daily and monthly intervals are good enough (Erber et al. 2017). Most of the research indicates a significant decrease in moisture content or the mass of wood in the tested time intervals. Most often this is 20% or more for several months (Nurmi 1995, Nurmi and Hilderbrand 2007, Erber et al. 2012, Kizha et al. 2018). Among the factors having the greatest impact on the drying effect, the season of the year was mentioned most often (Röser et al. 2010). Some authors pointed to spring as providing optimal conditions for drying (Nurmi 1995, Nurmi and Hillebrand 2007). Moisture is lost fastest when drying starts in April; wood stored in December needs much more time to dry (Kofman and Kent 2009). The size of the wood also influences the drying process (Brand et al. 2014, Lee and Choi 2016, Tomczak et al. 2018). Existing works have examined various species, with an emphasis on wood for the local market. Typically, conifers predominate in central European or Scandinavian studies (Röser et al. 2010, Erber et al. 2014), birch is also often present (Nurmi and Hillebrand 2007, Röser et al. 2010); together with alder (Röser et al. 2010), beech (Erber et al. 2016, Tomczak et al. 2018), oak (Erber et al. 2017) or other species.

We aimed to compare the natural drying process of three different species with different wood structure. Scots pine was selected as a coniferous species, sessile oak as a ring-porous species with a clearly marked heartwood and silver birch as a sapwood species with a diffuse-porous structure. These species have an important economic value in timber harvesting in Poland.

As the country's dominant species, pine is the primary object of most research (Tomczak et al. 2016, Tomczak et al. 2020). Birch has also been carefully studied (Lachowicz et al. 2018, 2019, Jakubowski et al. 2020), while oak slightly less so (Szymański et al. 2013, Mirski et al. 2020). Research on weight loss and moisture content conducted in Poland is rare due to the specific nature of the industry and the dominance of the long wood harvesting system.

Our study aimed to understand the natural drying process of wood in winter and compare this process for three different wood species.

Materials and methods

The research was carried out in central Poland in the Piaski Forest District (51°53'N, 17°04'E). We selected wood of three species for the tests: sessile oak (*Quercus petraea* (Matt.) Liebl.), silver birch (*Betula pendula* Roth) and Scots pine (*Pinus sylvestris* L.). The study material was collected from a 41-year-old stand intended for thinning (51°51′N, 17°15′E). A total of 30 trees (10 trees for each species) were selected and felled with a petrol chainsaw. All operations were performed before the thinning took place. Three logs were selected from different parts of the stem of each tree (Table 1). The logs were selected so that the bark would not be damaged. Additionally, during the felling process, 2 cm-thick discs were taken to measure moisture content and wood density. The trees were felled on November 30, 2016, which was also the first day of mass measurements. The experiment was completed on April 4, 2017.

Moisture content and fresh wood density were determined on the first and last day of the experiment. The logs were stacked in a pile at random, according to the scheme shown in Figure 1. Each log was numbered and individually weighed before stacking. The pile was stored under a roof.

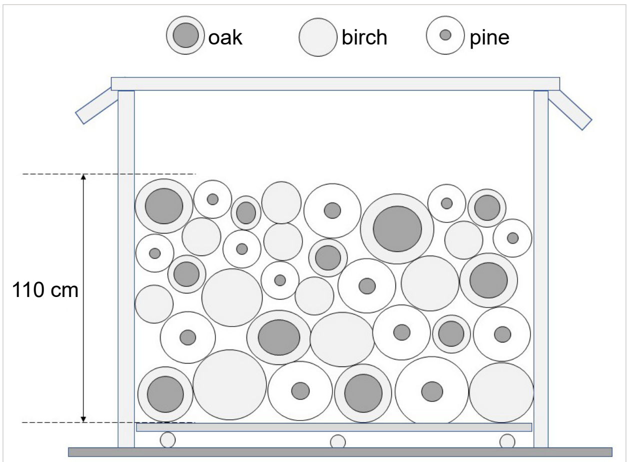

Figure 1. Scheme of the logwood pile and placement of the 3 species inside the pile

Moisture content measurements were carried out following the recommendations of the Polish standard PN-77/D-04100 (PKN 1977), using the following formulas:

$$MC_1 = \frac{M_1 - M_{0\%}}{M_{0\%}} \times 100\% ,$$

where:
MC_1 is the moisture content on the first day of the experiment,
M_1 is the mass of sample as fresh moisture content (refers to wood from a tree that has just fallen),
$M_{0\%}$ is the mass of dry sample at the first day.

$$MC_{125} = \frac{M_{125} - M_{0\%}}{M_{0\%}} \times 100\% ,$$

where:
MC_{125} is the moisture content on the last day of the experiment,
M_{125} is the mass of sample on the last day,
$M_{0\%}$ is the mass of dry sample on the last day.

Additionally, we calculated the relative moisture content (*RMC*) defined as:

$$RMC_1 = \frac{M_1 - M_{0\%}}{M_1} \times 100\% ,$$

where:
RMC_1 is the relative moisture content on the first day of the experiment,
M_1 is the mass of sample as fresh moisture content (refers to wood from a tree that has just fallen),
$M_{0\%}$ is the mass of dry sample at the first day.

The RMC_{125} was calculated in the similar way on the last day.

Wood density was calculated for every single log, including the bark, based on 2 cm-thick discs taken from

Table 1. Characteristics of the logs used in the experiment

Species	Length (m)	Diameter (cm)	Min (cm)	Max (cm)	Bark thickness (cm)	Min (cm)	Max (cm)	N
Pine	1	11.8	9.2	15.2	0.37	0.2	1.2	30
Birch	1	13.3	10.0	15.4	0.59	0.4	1.5	30
Oak	1	13.1	9.8	19.9	1.02	0.7	1.2	30

the outer part (first measurement: November 30) and the central part (second measurement: April 2) of each log. Measurements were taken on fresh wood at the moisture content of the wood at the moment of measurement. For the measurement of volume, we used the water displacement method (Olesen 1971).

The measurement of the log weight was repeated every two days; this involved taking apart and restacking the pile. The log placement was random after every measurement. Sometimes during the experiment, small amounts of bark fell off; they were collected, weighed and added to the weight of the logs. Therefore, all measurements were made on a canvas from which pieces of bark were later collected. Laboratory scales with an accuracy of 1 g were used for the tests. The weather conditions were recorded by a meteorological station about 400 meters apart from the pile of wood. The meteorological station was established by company "TRAX elektronik" for the Piaski Forest District. The station was included in programme "Meteorological Monitoring Woodland" in Poland. Standard meteorological parameters were used for the analyses, such as temperature, relative air humidity, precipitation, wind speed and solar radiation. Wood density was calculated on the last day of the experiment at a moisture content of fresh wood.

To calculate potential correlations between weight loss and the meteorological data, we built a correlation matrix based on the "psych" package (Revelle 2022), while for other calculations, we used the "tidyverse" package (Wickham et al. 2019), both within the *R* environment (R Core Team 2019). A stepwise regression procedure was conducted on the response and four predictors x1, x2, x3 and x4. The alpha to enter significance level was set at $\alpha = 0.05$ and the alpha to remove significance level was set at $\alpha = 0.05$. The regression model was built with the aid of STATISTICA software package.

Results

Initial moisture content differed significantly for each species. The highest value was found in pine sapwood (123%), which also lost the most moisture during the drying period. The lowest moisture content was in the heartwood of oaks (59%), which showed also the smallest decrease (48%) (Table 2).

All tested samples showed a clear, though slight, decrease in the wood weight. This decrease occurred throughout the period of natural wood drying (Figure 2).

Table 2. Moisture content (*MC*) of wood at the beginning and the end of the experiment

Species / type of wood	Nov. 30, 2016 MC_1 (%) ± SD / *RMC* (%)	April 2, 2017 MC_{125} (%) ± SD / *RMC* (%)	Δ*MC*
Pine / sapwood	123 ± 9.3 / 52.1	93 ± 5.7 / 44.7	30
Birch / sapwood	77 ± 9.4 / 43.5	64 ± 10.6 / 39.1	13
Oak / sapwood	80 ± 4.8 / 44.4	67 ± 4.9 / 40.0	13
Oak / heartwood	59 ± 2.5 / 37.3	48 ± 2.9 / 32.3	11

Notes: *RMC* – relative moisture content; *SD* – standard deviation.

The average pine log weighing 10.86 kg lost 1.3 kg of its weight in 125 days; birch and oak lost less, 0.91 and 0.97 kg respectively (Table 3). Considering the total weight of the tested pile (30 logs), the value is much higher. Individual species lost the following weight: pine – 39.3 kg (12.1%), birch – 27.2 kg (7%), and oak – 28.7 kg (7.2%). Ninety logs lost 95.2 kg of weight within 4 months. A clear weight loss was observed in each month regardless of the weather; however, the rate of decrease varied slightly from month to month. We observed the greatest weight loss in March for all species, for pine this was 45% of the total weight loss, while for oak it was 41% and for birch 36%. We recorded the smallest loss rate in February.

Temperature and humidity are mentioned as the main atmospheric factors that can affect the drying of wood. With temperature, we observed considerable variability. The average temperature within the tested period was only +1.3 degrees Celsius and ranged from –9 degrees to +16 degrees. The lowest average temperature was recorded in January (–2.8 degrees Celsius), while the warmest month was March (+6.3). During the entire observation

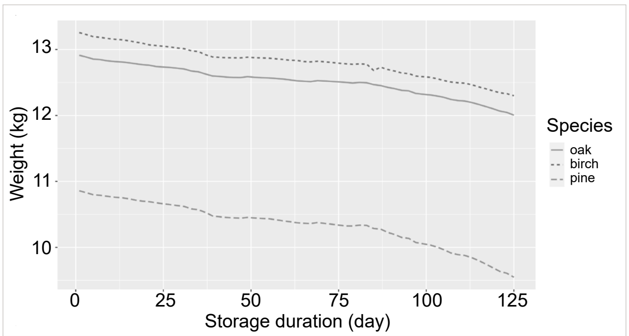

Figure 2. The average weight of the 3 wood species during storage time, from day 1 (November 30, 2016) to day 125 (April 4, 2017)

Table 3. Mass loss for the 3 species after 125 days of natural drying. Day 1 (30 November 2016), day 125 (3 April 2017)

Species	Term	Mean (kg)	*SD* (kg)	Sum (kg)	N	Min (kg)	Median (kg)	Max (kg)	Weight loss (kg)	(%)
Pine	Day 1	10.85	2.58	325.7	30	8.88	10.53	12.39	-	-
Pine	Day 125	9.54	2.83	286.4	30	7.37	8.96	11.35	39.3	12
Oak	Day 1	13.25	2.14	397.7	30	11.72	13.03	14.79	-	-
Oak	Day 125	12.29	2.04	369.0	30	10.77	12.14	13.78	28.7	7
Birch	Day 1	12.91	5.16	387.4	30	9.24	11.19	15.66	-	-
Birch	Day 125	12.00	4.87	360.1	30	8.60	10.36	14.67	27.5	7

period, no windstorms and downpours that could disturb the drying process were recorded. A slight wind with an average speed of 1.3 m/s prevailed, with the highest values recorded in December. Total precipitation during the observation period was very low and amounted to 73 mm; the highest value, as with wind, was recorded in December, while the lowest in January. However, precipitation is less important because the wood was stored under a roof. The average air humidity was typical for the winter months and amounted to 85%; it was the highest in December (92%) and the lowest in March (77%). An important parameter was also the amount of solar radiation. We noticed increased radiation towards the end of winter and the beginning of spring. Within the period from December to the end of February, the average monthly radiation was very low, from 44 W/m^2 to 97 W/m^2, while in March the value already exceeded 200 W/m^2. For comparison, the highest recorded value in December was 71 W/m^2, while in March it was 391 W/m^2.

The correlation matrix considers only continuous parameters; it does not consider periodically occurring phenomena such as precipitation. The weight losses of the three species fully correlate with each other (1.0); this shows that species lost mass to the same extent throughout the entire research period (Figure 3). Of all the weather parameters, solar radiation (0.81–0.84) shows the highest correlation with the wood mass increasing especially at the end of the measurement period, in March. Temperature also increased the most during this time, as mentioned earlier; however, the correlation with temperature in the entire period is lower and amounts to (0.54–0.58). Relative humidity shows a slightly greater correlation (0.62–0.63).

These three parameters seem to have the greatest impact on weight loss, with both temperature and relative humidity depending on the amount of incoming solar energy. Initial analysis of the correlation coefficients allowed to build regression models for the tested species. The models mostly explain the impact of weather at the level of 54%–59% depending on the species (Table 4). Precipitation was excluded as insignificant, while the loss of mass was explained mainly by relative humidity, which made the highest contribution (0.58), then by temperature and wind to a similar degree (Table 4). Wind made a significant contribution to the model despite the lack of linear Pearson correlation.

The initial wood density was the highest in pine (974 kg m^{-3}) and similar in oak (941 kg m^{-3}) and birch (927 kg m^{-3}). No significant differences were found be-

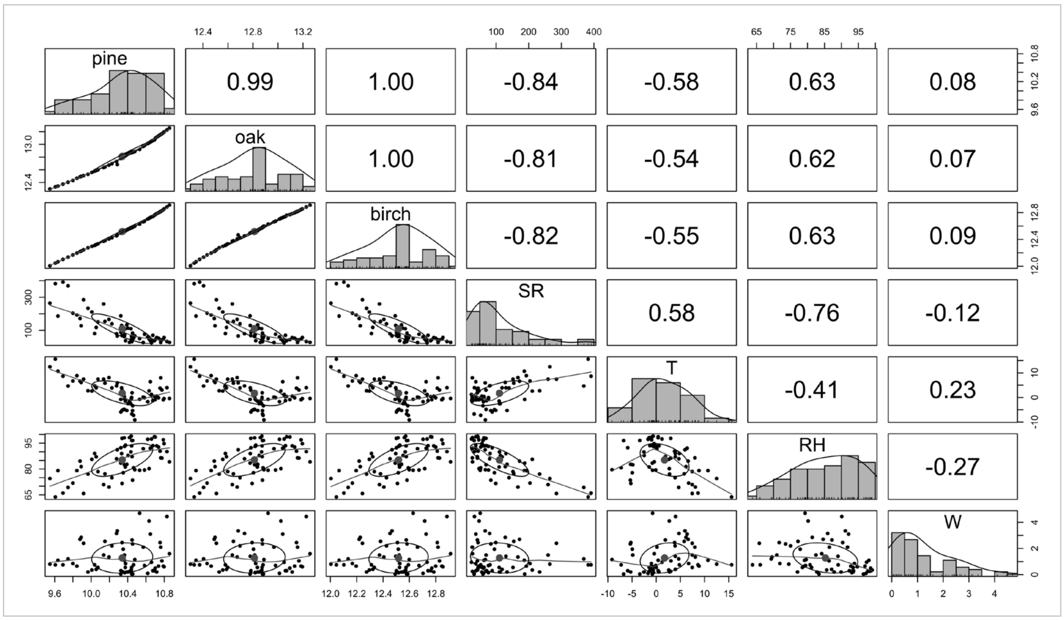

Figure 3. Correlation matrix based on Pearson

Designations: (pine, oak, birch) – wood mass, *SR* – solar radiation, *T* – temperature, *RH* – relative humidity, *W* – wind speed.

Table 4. Results of the forward stepwise regression models for pine, birch and oak

Species	R^2 (%)	R^2 adjusted (%)	*p*	Estimation std error	Variable	*B*	*B* std error	*p*
Pine	62.4	59.8	0.0000	0.6335	Relative humidity	0.5821	0.0996	0.0000
					Temperature	–0.4023	0.0934	0.0000
					Wind	0.3861	0.1090	0,0008
Oak	57	54.1	0.0000	0.6776	Relative humidity	0.5857	0.1065	0.0000
					Temperature	–0.3534	0.0999	0.0008
					Wind	–0.3695	0.1166	0.0024
Birch	59.4	56.6	0.0000	0.6588	Relative humidity	0.5858	0.1036	0.0000
					Temperature	–0.3722	0.0971	0.0003
					Wind	0.3856	0.1133	0.0012

tween oak and birch. At the end of the experiment, both species showed much lower but still similar densities (oak = 872 kg m^{-3}, birch = 860 kg m^{-3}). Pine density decreased the most (844 kg m^{-3}). However, the statistical differences between the three species at the end of the experiment were not significant ($\alpha = 0.05$). Pine wood density shows the greatest variability (8%). Oak (6%) and birch (3%) show more clustered populations because most of the logs show a similar density (Figure 4). The logs in the pile had different diameters, so the amount of weight loss was verified depending on the diameters. The clearest relationship occurs in birch wood, where the diameter of the log corresponds to the amount of weight loss and the correlation is clearly linear. In oak wood, this relationship is not so clear, but we can notice larger losses for logs with larger diameters. It should be noted that oak wood, despite its relatively small diameters, had a large heartwood with reaching up to 80% of the diameter. Pine logs do not show a clear correlation; the logs with the largest diameters lose little weight, while weight loss happens more often in the logs with small diameters (Figure 5a–c).

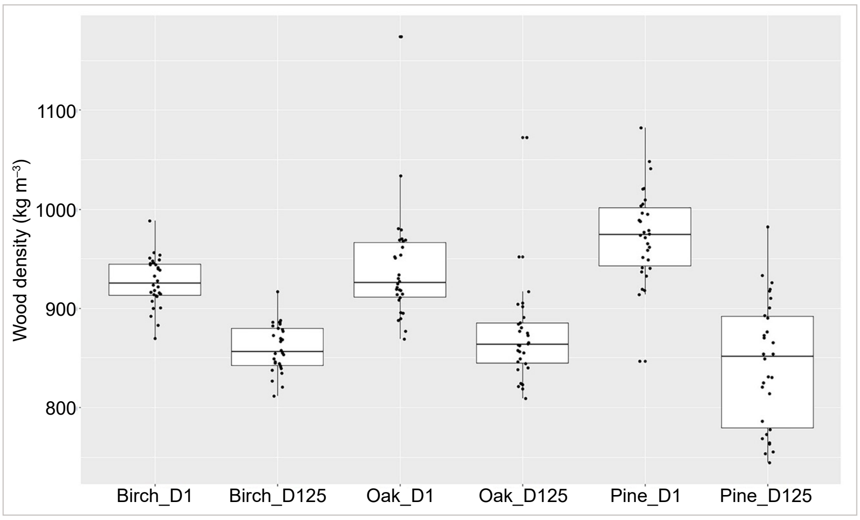

Figure 4. Fresh wood density at the beginning and the end of the experiment, D1 – day 1 (November 30, 2016), D125 – day 125 (April 2, 2017)

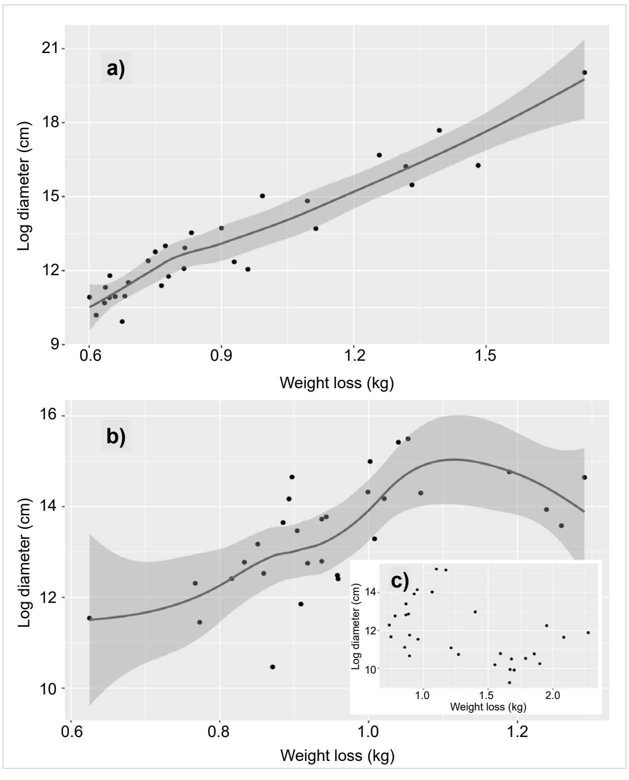

Figure 5. Relationship between diameter and weight loss in the 3 tree species: birch – a), oak – b) and pine – c)

Discussion

The impact of weather parameters is not the same throughout the period and increases only after reaching the threshold values. In particular, temperature exceeds 0 degrees Celsius and increases as more and more solar energy reaches the earth's surface (Figure 6). The key moment seems to be the constant increase in temperature with energy exceeding 100 W/m^2. The most important factor in speeding up the loss of mass, then appears to be the amount of solar energy, the weather parameters are only a consequence of this phenomenon. The initial stage of drying is not that fast despite the high moisture content of the wood, but it speeds up in spring when the weather changes. Nurmi (1995), Kofman and Kent (2009) and Röser et al. (2011) also found a high drying rate in spring. Winter drying is usually presented as very slow for both logs (Visser et al. 2014) and wood chips (Hofman et al. 2018). In summer, more deviations are often noticed in moisture content (Nurmi and Hillebrand 2007, Afzal et al. 2010, Erber et al. 2014); however, moisture content decreases to a specific level, which can be calculated based on weather parameters. Gigler et al. (2000) found that the drying process would stabilise after about 150 days. Long-term data analysed by Hultnäs et al. (2013) indicate strong seasonal fluctuations in the density of fresh wood, which may suggest that the initial humidity varies throughout the season and can affect the natural drying process. Similar relationships between wood mass and moisture content depending on the season of the year are presented by Trzciński et al. (2021).

In the regression model, relative humidity (0.58) shows the greatest impact on the three species, followed by temperature and wind (Table 2). Other authors also point to the role of relative humidity (Filbakk et al. 2011a, Erber et al. 2012, 2017, Visser et al. 2014). The influence of precipitation turned out to be insignificant, probably

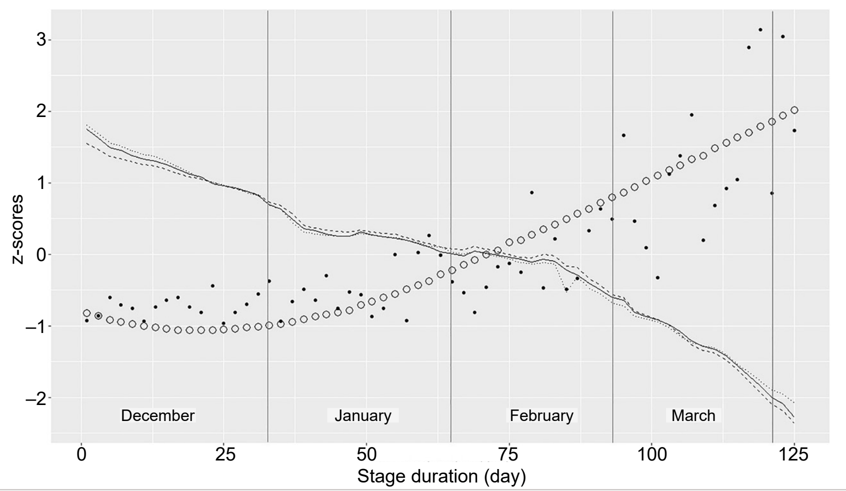

Figure 6. Visualisation of the trends for solar radiation (black dots), weight loss of the 3 species (oak – dotted line; birch – solid line; pine – dashed line) and the length of the day (circles). All data are presented as standardised variables (z-scores) to enable comparison of the effect. Day 1 (November 30, 2016), day 125 (April 4, 2017)

because of the low rainfall and the short duration of the experiment. Many studies demonstrate that cover significantly influences the results. Nurmi and Hillebrand (2007) suggest that spring may lead to increased moisture content. This may be caused by the melting of snow, so covering is proposed as a solution that may lower moisture content by as much as 3%–6% units. A similar effect of covering was reported by Kofman and Kent (2009); the weakest effect was found by Petterson and Nordfijell (2007). Röser et al. (2010) examined the covering of logwood in different parts of Europe (Scotland, Finland and Italy). Their results show different effects. The cover effect was positive in Finland and Scotland, where it achieves a lower moisture content in the end, while it makes no difference in Italy, especially for beech and spruce. Because we aimed to compare the drying of three wood species, we made efforts to ensure relatively stable conditions.

Solar radiation was not included in the regression models and needs to be discussed separately. The drying process began during short days, which after December 20 became gradually longer (Figure 6). Drying was carried out in parallel with increasingly longer days and increasing solar radiation. These processes showed a high correlation. If we include solar energy in the regression model, it will dominate and false the results for the other variables, which will be thrown out of the model. The other parameters are a consequence of the longer days and the increasing solar radiation reaching the Earth. In short, that the amount of energy reaching the ground may be the main seasonal predictor of the wood drying process. In the longer term, the length of the day and the amount of solar energy may become less important because of fluctuations in temperature, humidity and precipitation.

Birch belongs to the sapwood species and evaporation occurs evenly over the whole surface of the cross-section. Oak has a wide heartwood and all the logs significantly reduced evaporation; the effect of the diameter is also not clear. With pine, the heartwood was absent or minimal (2–4 annual rings), so it could have had only a small effect on drying. This is in line with the results of Patterson and Post (1980), who in a two-week experiment showed much more effective drying for birch wood than oak wood. This could be due to the large area of wet heartwood, which dries more slowly than the sapwood of birch. This effect was also shown by the rapid loss of moisture in sapwood during transpirational drying (Andoh et al. 2006). Thus, the size of the diameter and the proportion of heartwood may be related to the drying time. Due to the area of drying sapwood and heartwood, Lee and Choi (2016) found considerably more effective drying for smaller diameter wood (< 18 cm, *Larix* and *Pinus*) than for larger wood (< 30 cm). The differences were bigger between the species for large diameters, which may also be related to the area of heartwood. The relationship between diameter and weight loss was also found by Tomczak et al. (2018). Differences in log size may be important for these results, as pointed out by Erber et al. (2017), who noted that moisture content differs significantly between logs, while inside the log no differences were found (Erber et al. 2017).

Conclusion

Regarding total weight loss, there were no visible differences between birch and oak, which lost 7% of their weight during 125 days of observation. There was also an identical loss of moisture in the sapwood of birch and oak. Wood moisture content decreases from 77% to 64% in birch and from 80% to 67% in oak sapwood. Oak heartwood lost slightly less (11%). We found the greatest weight loss in pine (12%), which differs statistically from birch and oak. Weight loss occurred evenly for 3 months (December to February), then quickly increased in March, when it reached 45% of the total weight loss for pine, 41% for oak and 31% for birch. The stepwise regression model explains the impact of weather at 58%. Based on this model, relative humidity had the greatest influence (0.58), followed by temperature and wind. There was a distinct correlation between log diameter and weight loss in oak and birch while no clear correlation was found for the diameter of pine. Observations under our conditions confirm that natural wood drying in winter is slow and comparable to what research in other locations has found.

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