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EFFECTS OF FOG PRECIPITATION ON WATER RESOURCES AND DRINKING WATER TREATMENT IN THE JIZERA MOUNTAINS, THE CZECH REPUBLIC

Josef Křeček[1] and Ladislav Palán[2]

1. *Czech Technical University in Prague, Faculty of Civil Engineering, Department of Hydraulics and Hydrology, Thákurova 7, 166 29, Prague 6, Czech Republic;josef.krecek@fsv.cvut.cz*
2. *Czech Technical University in Prague, Faculty of Civil Engineering, Department of Hydraulics and Hydrology, Thákurova 7, 166 29, Prague 6, Czech Republic;ladislav.palan@fsv.cvut.cz*

ABSTRACT

Water yield from catchments with a high evidence of fog or low clouds could be increased by the canopy fog drip. However, in areas with the acid atmospheric deposition, this process can lead to the decline of water quality. The aim of this study is to analyze fog related processes in headwater catchments of the Jizera Mountains (the Czech Republic) with special attention to water quality and the drinking water treatment. In two years (2011-2012), the fog drip was observed by twelve passive fog collectors at transect of the Jizerka experimental catchment. Methods of space interpolation and extrapolation (ArcGis 10.2) were applied to approximate the areal atmospheric deposition of fog water, sulphur and nitrogen, in catchments of the drinking water reservoirs Josefův Důl and Souš. The mean annual fog drip from vegetation canopy was found between 88 and 106 mm (i.e. 7 to 9 percent of precipitation, and 11 to 13 percent of water yield, estimated by standard rain gauge monitoring). But, the mean annual load of sulphur and nitrogen by the fog drip was 1,975 and 1,080, kilograms per square kilometre, respectively (i.e. 55 and 48 percent of total deposition of sulphur and nitrogen, registered in the bulk. The acidification of surface waters leads to rising operational costs in the water treatment plants (liming, reduce of heavy metals, more frequent control of sand filters etc.). In a catchment scale, the additional precipitation, caused by the canopy fog drip, could be controlled by the effective watershed management (support of forests stands near the native composition with presence of deciduous trees: beech, mountain ash, or birch).

KEYWORDS

Mountain watersheds, spruce plantations, acid atmospheric deposition, fog drip, water quality, drinking water treatment.

INTRODUCTION

The introduction should present the scientific background of the study and state clearly its objectives. Access to safe water is a basic human right and a component of effective policy for health protection [1]. Generally, in areas of relatively high fog or low cloud evidence, water yield could be significantly increased by fog drip from the canopy [2],[3]. But, with air pollution and the acid atmospheric deposition, that process can lead to the decline of water quality [4], [5].

Therefore, the land use and watershed management practices can regulate the water resources recharge: quantity and quality [6].

The aim of this study is to analyze fog occurrence and potential fog drip upon the elevation and vegetation cover; and to assess impacts of fog precipitation on runoff genesis, water quality and drinking water treatment in headwater catchments of the Jizera Mountains (North Bohemia, the Czech Republic, Fig. 1).

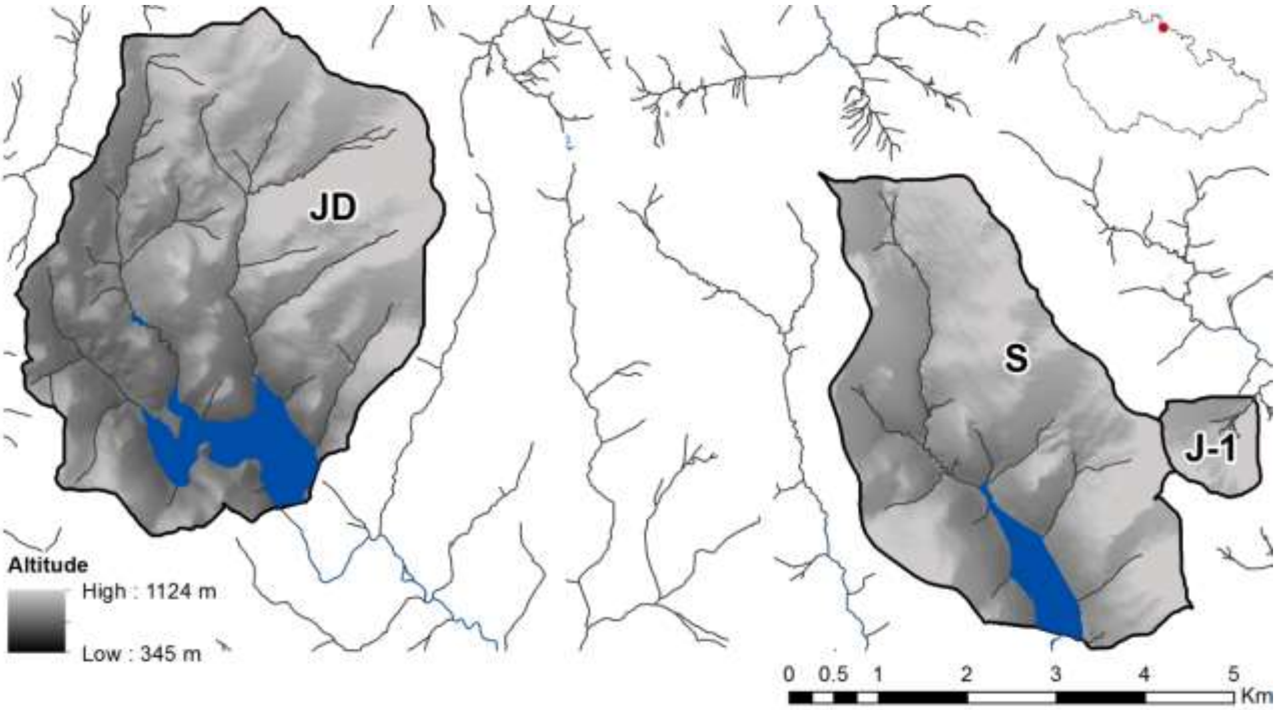

Fig. 1. Focused watersheds of the Jizera Mts.
(JD – Josefův Důl, S – Souš, J-1 – experimental catchment Jizerka)

EFFECTS OF THE ACID ATMOSPHERIC DEPOSITION ON WATER QUALITY AND ENVIRONMENTAL HEALTH

No health-based guideline value has been proposed for the pH of water. However, pH is one of the most important operational water quality parameters, and, national guidelines for drinking water quality often suggest that optimum pH is in the range 6.5 to 8.5 [1]. Low pH may also affect recreational users, with negative impacts on the skin and eyes [7]. Without air pollution and subsequent acid rain, most lakes and streams would have a pH level close to 6.5 [8]. The acid atmospheric deposition in the Jizera Mountains, however, caused water reservoirs and streams to have much lower pH levels, particularly, in the 1980s, around 4 to 5 [6]; associated with low hardness of water and increased concentrations of aluminium (1 to 2 mg per litre).

Hardness refers to concentrations of dissolved calcium and, to a lesser extent, magnesium in water. Soft water with less than about 100 mg per litre has a low buffering capacity and may be more corrosive to water pipes. Statistically significant inverse relationship between hardness of drinking water and cardiovascular disease was shown in several studies [1]. There is some indication that very soft water may have an adverse effect on human mineral balance.

The established limit of aluminium in drinking water is 0.1 mg per litre for large treatment facilities, and 0.2 mg per litre for small facilities [1]. Although aluminium is widespread in foods, drinking water and many antacid medications, there is some indication that when ingested orally in concentrations exceeding hygienic limits (i.e. 30 mg of aluminium per kilogram of fish meat, or 0.2 mg of aluminium per litre of drinking water) is toxic to humans. It has been hypothesized that aluminium exposure is a risk factor of acceleration of Alzheimer's disease. The elevated acidity, low hardness, and accelerated aluminium in surface waters, not only pose risks to human health, but are also deadly to aquatic wildlife [9].

In water treatment plants of the Jizera Mountains, increased acidity of raw water caused several additional investments [10] – annual liming of water reservoirs after the snowmelt, elimination of booms in acidophilous biota (rotifers, diatoms etc.), or reduction of heavy metals and aluminium. The additional deposition by a fog drip may escalate these problems there [8].

MATERIAL AND METHODS

During the period of two years (2011 – 2012), occurrence of fog precipitation was observed at transect of the Jizerka experimental catchment (evidence number: 1-10-78-000, area of 1 km^2, Fig. 2). Twelve passive fog collectors were installed in the elevation range from 862 to 994 m, and fog drip registered in monthly intervals. The storage of fog drip there was generated by 400 metres of teflon wire (diameter of 0.25 milimetres).

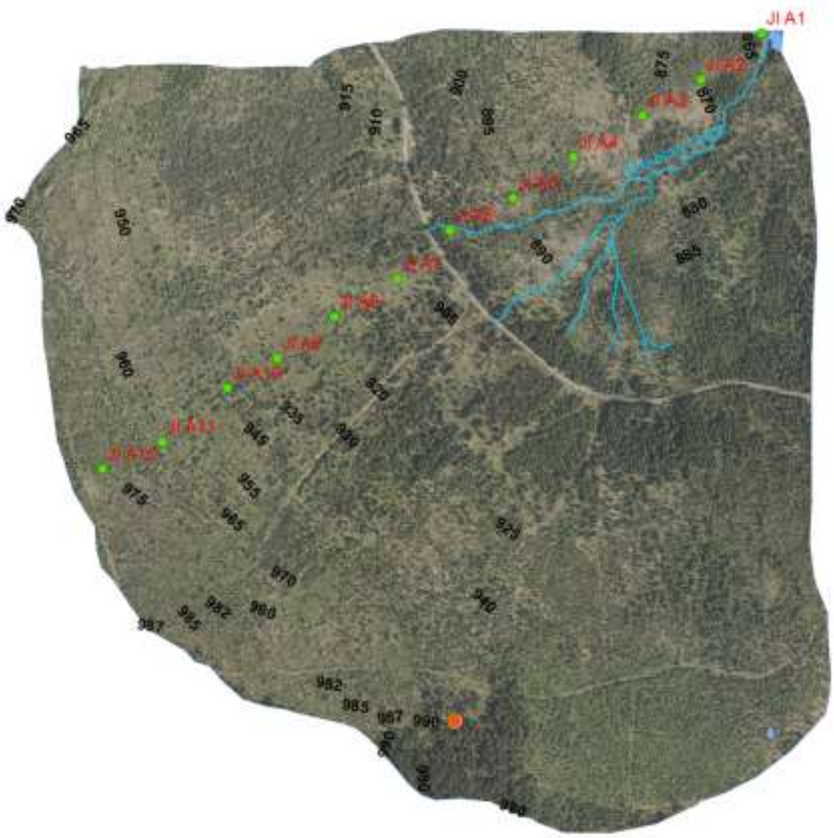

Fig. 2. Fog collectors in the investigated transect of the Jizerka experimental catchment.

Consequently, the additional precipitation of fog drip was observed under the canopy of two mature spruce stands (*Picea abies*) in elevations of 745 and 975 metres (ten standard rain gauges were randomly installed on the plots of 30 x 30 metres).

Samples of fog water were analysed in the Hydro-biological Laboratory Velký Pálenec of the Charles University in Prague, with special concern for pH, conductivity, and contents of $N\text{-}NO_3$, $N\text{-}NH_4$ and $S\text{-}SO_4$.

The method of space interpolation and extrapolation (ArcGis 10.2) was used to approximate the areal atmospheric deposition of fog drip, sulphur and nitrogen, in focused catchments of the drinking water reservoirs Josefův Důl and Souš. Beside the elevation, effects of the canopy density (tree species, age, height, canopy density, and leaf area index) were taken into account by calculating amounts of the fog deposition. Concerning extrapolation of the observed data, we hypothesised that in a mountain watershed, generally, the fog drip rises with elevation and canopy density.

RESULTS AND DISCUSSION

The annual deposition of fog drip in catchments of the drinking water reservoirs Josefův Důl and Souš in the Jizera Mountains (during the investigated period of 2011-2012) is given in Fig. 3.

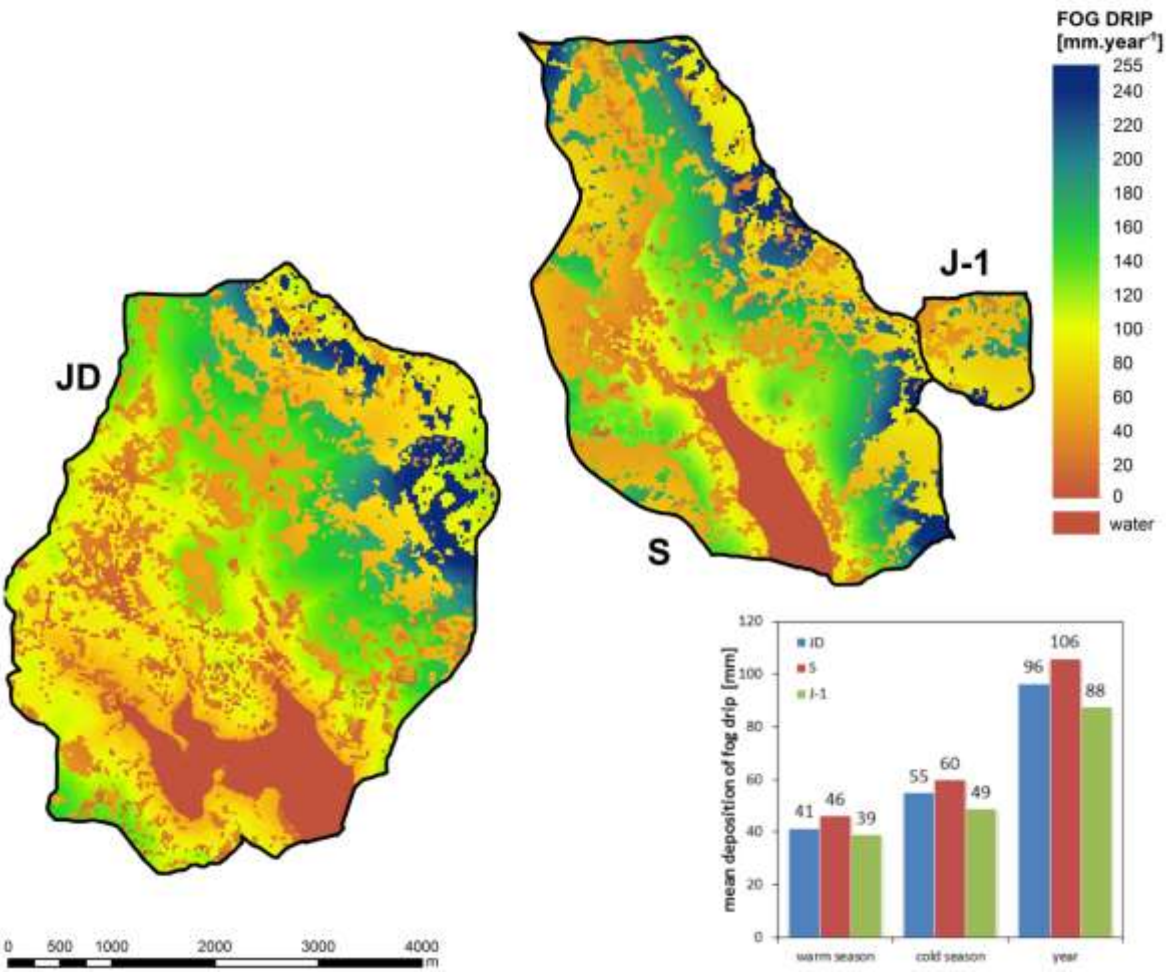

Fig. 3. Mean annual fog drip in focused catchments of the Jizera Mts. (2011-2012)

Fog consists of water droplets suspended in the atmosphere, diameters from about 1 to 40 micrometers and fall velocities from less than 1 to approximately 5 centimetres per second [11]. The fall speed of fog droplets is so low that the drops travel almost horizontally, and are not collected in standard rain gauge monitoring systems. Under the canopy of closed mature spruce stand, the annual fog drip was 14 % of bulk precipitation, measured in the open field. Thus, in the investigated catchments Josefův Důl and Souš, registered annual volumes of the fog drip varied from 7 to 9 percent of annual precipitation evaluated by standard methods. In the dormant season (XI-IV), fog drip sampled by passive collectors exceeds the summer amount by 20 %, as a result of more frequent fog evidence (229 hours compared to 78 registered in the warm period V-X). Significantly lower acidity observed in the fog precipitation relates to the genesis of fog droplets in the atmosphere, Fig. 4.

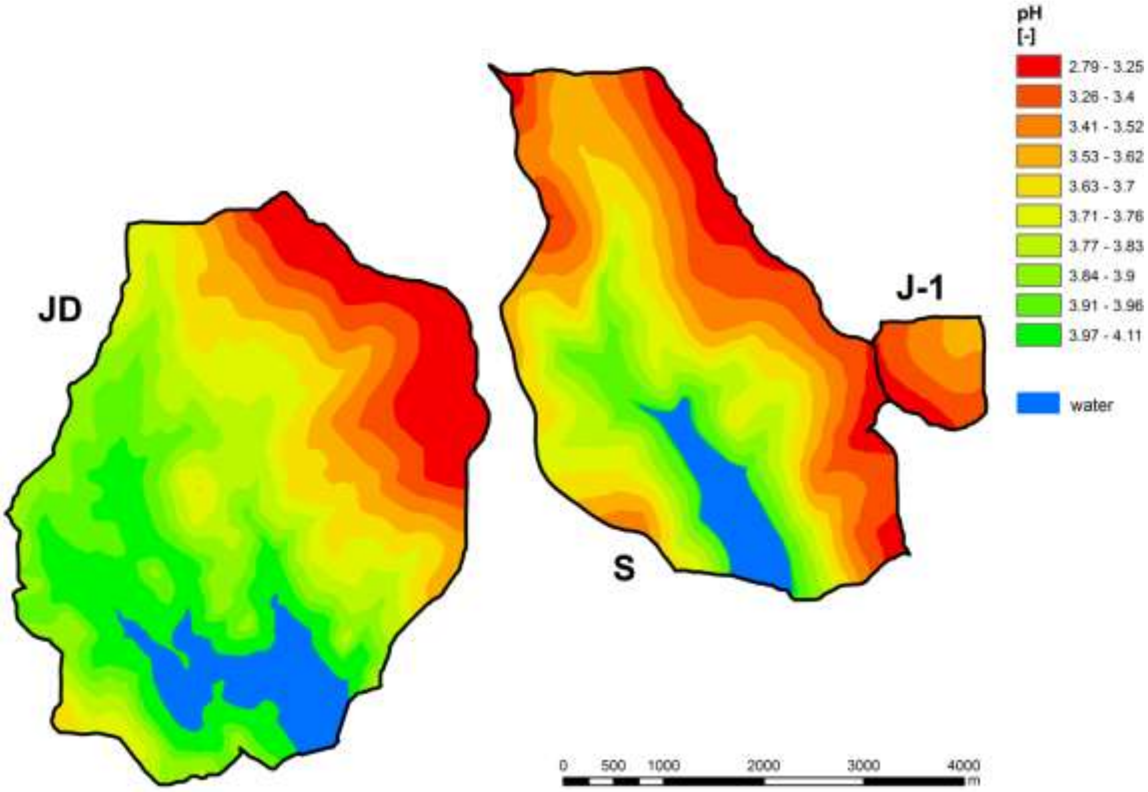

Fig. 4. Annual pH values of fog water distributed in focused catchments (2011-2012)

The percentage of acid deposition caused by the fog drip was 55 % by sulphur (1,975 kilograms per sq. kilometres and year) and 48 % by nitrogen (1,080 kilograms per sq. kilometre and year). The evidence of sampled fog-water and contents of sulphur and nitrogen is rising with elevation, cool seasons (37 % higher against summer), and the canopy density. Annual loads of nitrogen and sulphur by the fog drip in investigated catchments are given in Fig. 5 and 6.

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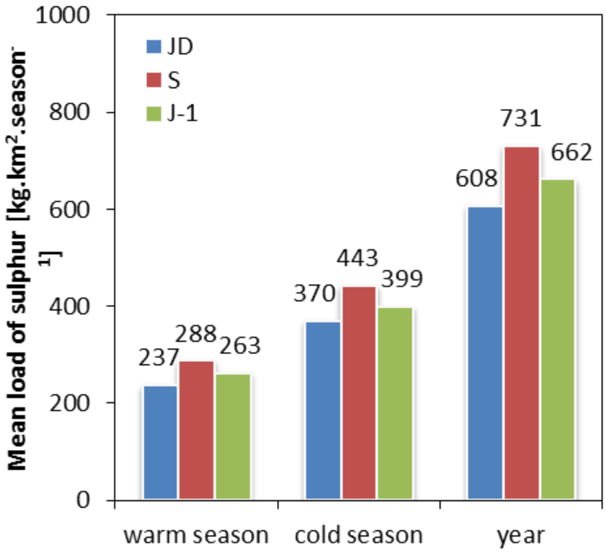

Fig. 5. Mean annual load of nitrogen in catchments of the Jizera Mts. (2011-2012)

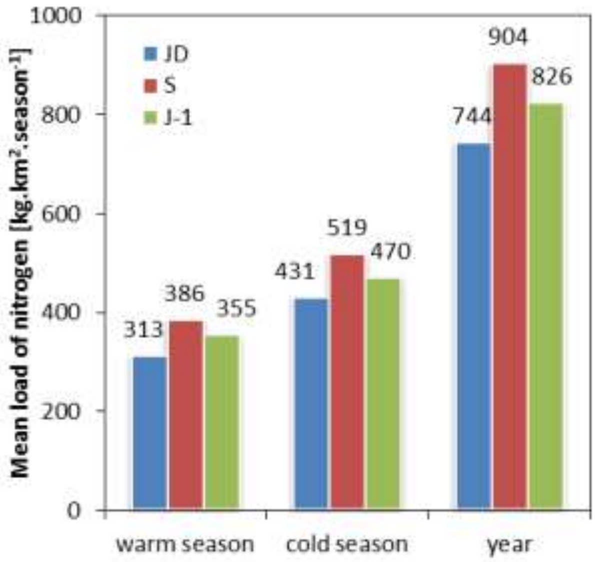

Fig. 6. Mean annual load of sulphur in catchments of the Jizera Mts. (2011-2012)

The investigated reservoirs are dimicted; with two mixing and two stratified periods in the annual cycle. Considering the summer stratification, epilimnion and metalimnion have been formed there up to the depth of 8 metres from June to September [12]. During the summer period, because of low water temperatures observed at inflows [9], catchment runoff affects mainly hypolimnion of reservoirs; while, in the spring, snow melt affects the whole volume of lakes by mixing periods. Concerning the acidity of reservoirs, critical situations are observed in May (after the snow melt). Anyway, in the summer stratification, water pH and concentrations of sulphur and nitrogen result, particularly, from the volume of hypolimnion, and transports of acid substances from the catchments. In the summer, volumes of water in hypolimnion are 11.5 and 1.1 million cub. metres at Josefův Důl and Souš, respectively. Therefore, the Souš reservoir might be more sensitive to the summer acidification.

Acidification of surface waters affects the treatment of drinking water by increasing operational costs (to increase water pH, reduce contents of aluminium and some heavy metals, and more frequent control of rapid sand filters (by acid related booms of diatoms or rotifers), Ambrožová [13]. Thus, also the recent reconstruction of the water treatment plant in Bedřichov (treatment of drinking water from the Josefův Důl reservoir) in amount of 120 million CZK [10] was mainly affected by the acid atmospheric deposition.

CONCLUSION

In headwater catchments of the Jizera Mountain, the mean annual fog drip from vegetation canopy was found between 88 and 106 mm (i.e. 7 to 9 percent of vertical precipitation observed by the standard rain gauge monitoring). Therefore, the additional precipitation by the fog drip might increase water yield of those catchments from 11 to 13 percent. However, negative role of fog precipitation is in increasing the acid atmospheric deposition. The mean annual load, found in the fog drip, was 1,975 and 1,080, kilograms per square kilometre, of sulphur and nitrogen, respectively. Those values represent 55 percent of total sulphur and 48 percent of total nitrogen, registered in the bulk by standard methods.

The “acid rain” related problems at the water treatment plants are in increasing operational costs by regulating water pH, contents of aluminium and heavy metals, and more frequent control of sand filters. Also, the last reconstruction of the Bedřichov treatment plant (120 million CZK) belongs among the acid related problems.

In a catchment scale, the additional precipitation, caused by the canopy fog drip, could be controlled by the effective watershed management. In the investigated catchments of the Jizera Mountains, the acid atmospheric deposition might be reduced by supporting the semi-native beech stands (reduced canopy namely in the winter period), and by forest stands near the native composition (with the traditional percentage of deciduous trees: beech, mountain ash, or birch).

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