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Pollen in layers of seasonal snow in the South of Western Siberia

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Snow cover affects and regulates many ecological patterns and processes. Pollen has been actively used to indicate ecosystem, cryosphere, and climatic processes and states. However, the relationships between pollen deposition and snow layering have not yet been sufficiently studied. In this work, we focus on assessing the interrelations between the taxa composition of pollen in different layers of the seasonal snow cover in the western Siberian forest-steppe ecoregion. The snowpack had a composite profile consisting of crusts and layers of faceted crystals and deep hoar between them. The lower deep layer of the hoar represented the maximum diversity of pollen grains (*Pinus* sp., *Artemisia* sp., Chenopodiaceae). Pollen transfer likely occurred when the surrounding territories (potential sources of secondary pollen input) were still open from the snow. In addition, we revealed that ice and melt-freeze crusts could prevent redistribution of pollen grains in the snowpack during winter, thereby providing a high taxonomic diversity. The five recognized taxa (*Betula* sp., *Pinus* sp., *Artemisia* sp., Asteraceae, and Chenopodiaceae) were identified between two layers of crust.

Keywords: Seasonal snow, pollen, forest steppe, western siberia

Introduction

Snow cover regulates many ecological patterns and processes (Slatyer et al., 2021). Snow transmits and modifies interactions between microorganisms, plants, animals, nutrients, the atmosphere, and soil (Snow ecology, 2001). The duration and amount of snow cover affect tree growth (Wu et al., 2018), vegetation productivity during the early growing season (Wang et al., 2017), soil microbial activity (Gavazov et al., 2017), and species distribution (Niittynen & Luoto, 2018). Furthermore, many species use the space under the snow cover as habitats (subnivean habitats) (Soininen et al., 2015; Guiden, Orrock, 2020). However, climate change has significantly affected the duration of snow cover and other snow characteristics (Pulliainen et al., 2020). These changes determine many challenges for ecosystems, such as loss of biodiversity and changes in the length of the growing season (Huss et al., 2017; Niittynen et al., 2018).

Pollen is a valuable indicator of ecological, climatic, and cryospheric processes. Pollen emission (Pollen Index) was used to study the temporal dynamics of high-mountain Mediterranean grasslands (Algarra et al., 2019). Airborne pollen has long been applied to track air masses and climate change (Ghasemifard et al., 2020; Sarda Estève et al., 2018, Clot, 2003). Pollen has been successfully implemented to distinguish between seasonal and annual layers of firn and ice cores (Nakazawa et al., 2005; Festi et al., 2017). However, the interactions between pollen deposition and seasonal snow metamorphism have not been sufficiently investigated. As shown for seasonal snow cover in Japan, the peak pollen concentration peak was consistently observed at the snowpack's surface during the melting period (Nakazawa and Suzuki, 2008). In other words, the maximum pollen concentration was not redistributed to the lower layers due to percolation. However, the behavior of pollen grains in regions with other snow types (eg, primarily temperature gradient metamorphism) needs to be clarified.

The concentrations of light-absorbing particles, such as black carbon and dust, in the snow cover have received enormous attention in recent years (Shevchenko et al., 2010; Meinander et al., 2020; Zhang et al., 2018). The presence of such particles in the snow can darken the snow surface, affect the energy balance, and further accelerate snow and ice melting (Kang et al., 2020; Hadley & Kirchstetter, 2012). For example, the effect of black carbon and dust reduced the duration of snow cover duration by 3.1 ± 0.1 to 4.4 ± 0.2 days on the Tibetan Plateau, China (Zhang et al., 2018). In this regard, pollen as an important indicator can be used to trace the possible origin of contaminants (Hicks & Isaksson, 2006).

Understanding the interactions between pollen deposition and snow layering is essential when applying pollen as an indicator of ecological, climatic, and cryospheric processes. In this study, we explore pollen relationship between the composition of pollen in different layers of seasonal snow cover in the south of western Siberia.

Study area

Snow profiling and pollen sampling were carried out on the Ob plateau occupying the southernmost part of the western Siberian plain (Fig. 1). The study area belongs to the West Siberian Forest Steppe ecoregion (Olson et al., 2011). The long stripes of pine

forests (*Pinus sylvestris*) are a distinctive feature of the Ob plateau. The forests are located within an extended ancient flow depression (Rudaya et al., 2020). However, the dominant type of land cover is arable land. Therefore, the sampling site was located within an extensive area of arable land representative of the surrounding area.
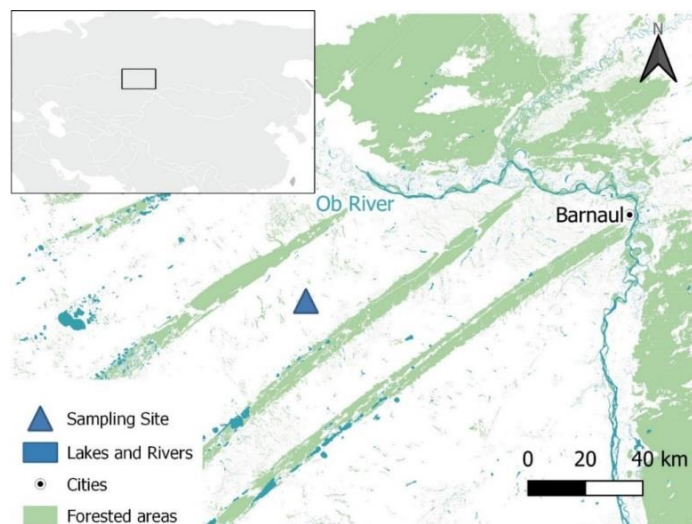
Fig. 1. Location of the study area and sample site.

Snow profiling and samples

Snow profiling was conducted during the peak snow accumulation (March 2020) according to the International Classification for Seasonal Snow on the Ground (ICSSG) (Fierz et al., 2009). We characterized standard snowpack parameters: total snow height, bulk density, layering, grain size, grain shape, hand hardness, and snow temperature. Field data was analyzed and plotted using NiViz software (https://niviz.org/). We used data from the Rebrikha weather station (RIHMI–WDC database) to estimate snow accumulation conditions during winter of 2019-2020. Meteorological and pollen data were processed and plotted using R (https://www.r-project.org/).

Snow samples for pollen analysis were taken layer by layer using a snow tube sampler. The sampling sites were located in open areas at a considerable distance from trees (to exclude secondary contamination). The layers of samples were placed in plastic bags, labeled, and transported to the laboratory.

Identification of pollen

During the preparation of the primary sample, the samples were melted in plastic bags at room temperature, then we poured water into containers of suitable volume and added 40% formalin to reduce the microflora. Next, according to hydrobiological methods (Manual..., 1992), the samples were placed in a dark, cool place for 7-10 days to settle the sediment, after which it was separated by decantation.

Pollen samples were mounted and counted at a magnification of x 400 with the aid of a Laboval 4 light microscope (Carl Zeiss, Germany). We used a 0.2 ml Nageotte Counting Chamber to estimate the concentration of particles. The resulting samples were installed in aluminum sample holders, dried, and sputered by gold-palladium mixture in a SC7620 Mini Sputter Coater (Quorum Technologies Ltd, UK) for further electron microcopy. The use of a scanning electron microscope (SEM S-3400N Hitachi ScienceSystems Ltd, Japan (magnification up to 300000 resolution up to 3.0 nm) made it possible to detect pollen grains visually. For each slide, regular latitudinal sweeps were read. Pollen grains were identified according to atlases (Kupriyanova & Aleshina, 1972, 1978; Dzyuba, 2005; Karpovich et al., 2015) and international databases (https://www.paldat.org/search/A, https://pollenatlas.net/homepage).

Results and Discussion

We identified pollen grains from trees (*Betula* sp., *Pinus* sp.) and grasses (*Artemisia* sp., Asteraceae, Chenopodiaceae) in snow samples (Fig. 2). Pollen grains had a presumably advective origin, that is, they were transported from surrounding regions free of snow. The predicted origin was very likely since we sampled snow during peak accumulation (March 2020). The study area was fully covered with snow in that period, limiting the secondary transfer of pollen from the ground surface. Different transfer ranges characterize identified pollen grains (Sofiev et al., 2013). Pollen from trees belonging to wind-pollinated (anemophilous) plants is transported over considerable distances compared to insect-pollinated (entomophilous) taxa (most often grasses). For example, due to the morphology of the pollen grains (presence of air sacs), pine pollen may be transported up to several thousand kilometers, while birch pollen travels not more than 1000 km (Giner et al., 2001).
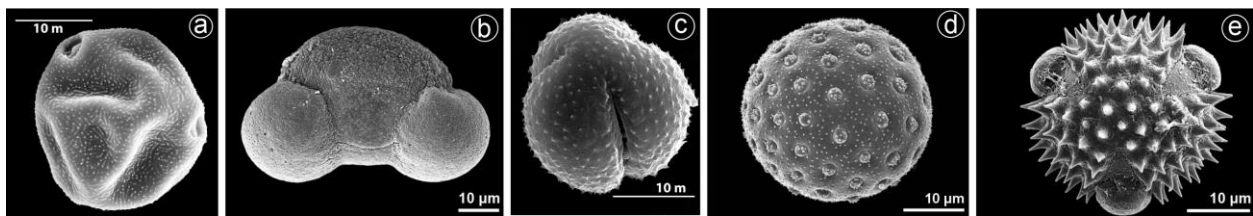
Fig. 2. Identified pollen grains: a) *Betula* sp.; b) *Pinus* sp.; c) *Artemisia* sp.; d) Chenopodiaceae; e) Asteraceae.

Likewise, grass pollen is distributed within the areal, but under the influence of convective air flows, it may rise to the upper borders of the atmosphere's boundary layer and be transported over considerable distances. In the pollen spectrum obtained, 64% of pollen grains belonged to trees, with pine dominance (Fig. 3). Birch pollen was twice less than the pine–42%. Grasses were represented in approximately equal amounts from 14 to 7%.
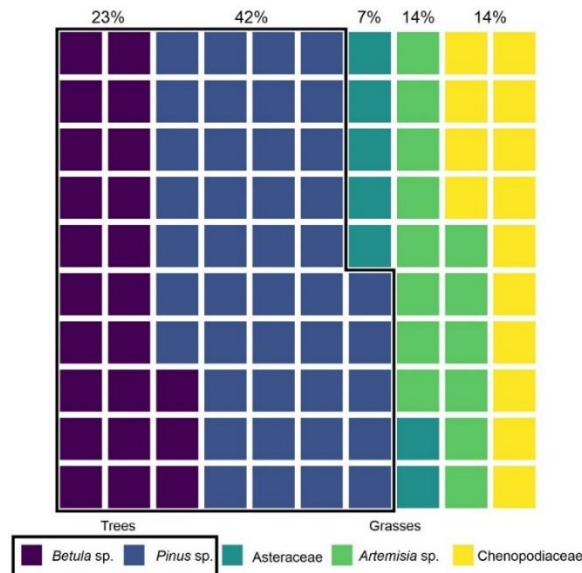

Fig. 3. Distribution of pollen taxa in snow cover. One panel corresponds to 1%.

Snowpack stratigraphy was typical for moderately cold grassland regions, despite snow depth being significantly above average for this territory (Fig. 4). The profile consisted of several crusts and wind slabs separating faceted crystals and deep hoar (Fig. 5), which are layers standard for temperature gradient metamorphism (Sturm et al., 1995). However, many crusts and ice layers reflected warm periods during winter and the active influence of wind transport.
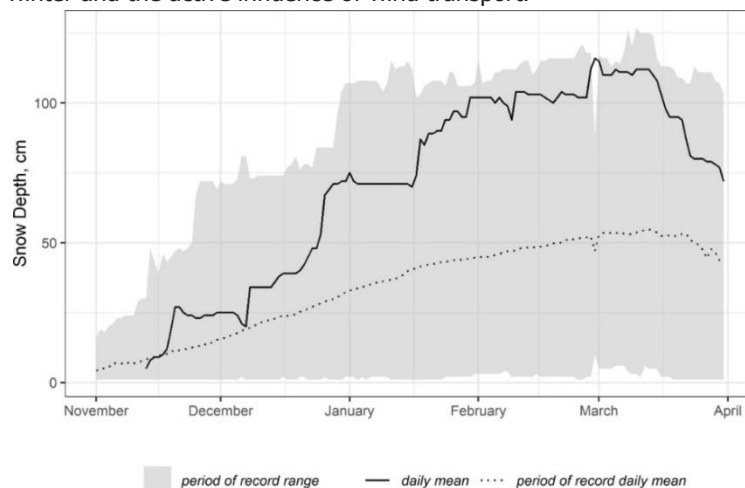
Fig. 4. Snow depth of the Rebrikha weather station for the winter 2019-2020, as well as the station period of record (1956-2020).

The highest taxonomic diversity (*Pinus* sp., *Artemisia* sp., Chenopodiaceae) in one layer was detected in the deep hoar (0–20 cm). This layer was formed at the beginning of the winter season when the surrounding southern regions were still free of snow cover. Secondarily, pollen grains could be transferred from these territories with air masses. *Artemisia* sp. and Chenopodiaceae identified in this layer are specific taxa of the steppes located in the southwest of the study area's southwest. The deep layer of hoar was overlain by an ice crust, which preserved pollen grains from wind redistribution.
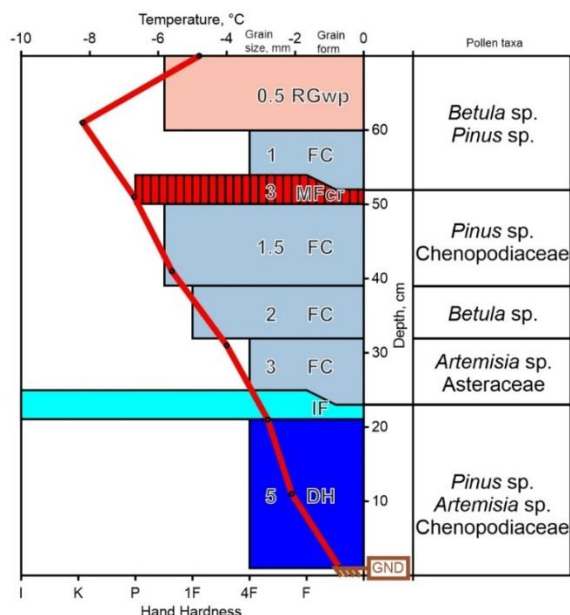
Fig. 5. Snowpack profile and pollen taxa distribution. Hand hardness: F–Fist, 4F–Four Fingers, 1F–1 Finger, P–Pencil, K–Knife, I–Ice; Grain Shape: RGwp, wind-packed rounded grains; FC, faceted crystals; MFcr–Melt-freeze crust; IF, ice forms; DH–Deep hoar.
In the faceted crystal layers located between the ice and melt-freeze crusts, all five recognized taxa were identified. Crusts appear to prevent the redistribution of pollen grains, that is, they contribute to pollen in the snowpack during winter. In the upper layer of wind that predominantly formed predominantly at the end of the winter period (end of February-March), the pollen of the trees was concentrated exclusively. It is more volatile compared to grass pollen and can remain in the atmosphere for a longer time.

Conclusion

The snowpack profile reflected the processes typical of cold steppe regions, the temperature gradient between the ground and the snow surface and the effect of wind transport. The influence of these processes formed a composite profile of crusts and layers of faceted crystals with deep hoar between them. In the snow pollen spectrum obtained, 64% of pollen grains belonged to trees, with pine dominance–42%. Grasses were represented in approximately equal amounts from 14 to 7%. The maximum diversity of pollen grains was represented in the lower layer of deep hoar, formed at the beginning of the winter season. This process probably occurred when the surrounding territories (potential sources of secondary pollen input) were still open from the snow. Furthermore, it was revealed that ice and melt-freeze crusts could prevent redistribution of pollen grains in the snow cover during the winter, thereby providing high taxonomic diversity: All five taxa were identified - trees (*Betula* sp., *Pinus* sp.) and grasses (*Artemisia* sp., Asteraceae, Chenopodiaceae).

Acknowledgements

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