METHODOLOGY

1. Biological Soil Crusts

Analysis of the biologically active soil cover

We use the term „biologically active soil cover" for soil covered either by BSCs or by vegetation. However, we acknowledge that stone-covered soils/skeletal soils might be inhabited by hypolithic microbial communities, which might, to some extent, contribute to organic matter and nutrient cycling in such soils (e.g., Mergelov et al., 2020). However, incorporating hypolithic communities was beyond the scope of this study.

In each study plot, we identified the main types of soil cover based on their gross morphology visible with the naked eye and under a magnifying glass (x20). Lichens were only tentatively identified to morphotypes (Brodo et al., 2001, Rosentreter et al., 2016, Smith et al., 2009), while no attempt was made to identify mosses. Species of vascular plants were identified according to Ikonnikov (1963). Species names were updated in accordance with The Plant List of The Royal Botanic Gardens, Kew (http://www.theplantlist.org/). To visually assess the percentage coverage of identified soil cover types, a 0.5 x 0.5 m metal grid with a mesh of 2.5 cm was used. The first grid was always placed in a representative location; other grids (between 3 and 9) were thrown randomly within a 20 m range from the first location. From each study plot, we collected samples of a loose soil layer with no indication of living organisms visible (bare soil), samples of biological soil crusts (biomass), samples of soils located immediately under the crusts (sub-crust soil), and samples of soils located immediately under vascular plants (namely a soil sample was taken from under each type of crust identified in each study plot, and from under the most common species of vascular plants in each study plot). To decrease potential within-site heterogeneity, obtain a proper amount of material and not destroy limited sites of crusts, subsamples of crust biomass and sub-crust soil were gathered within a 20 m range from the first location of a crust and combined into mixed samples. In total, ten samples of the loose soil layer, 13 samples of biological soil crusts, 13 samples of sub-crust soils, and 32 samples of the soil underneath vascular plants were collected from the Uisu Glacier foreland.

Analyses of C, N, P contents and potential accumulation in the studied soils and BSCs

In order to assess the potential accumulation of C, N and P in BSCs, sub-crust soils, soils under vascular plants and bare soils, contents of these elements were measured in oven-dried (at 50°C), grounded and sieved (1 mm mesh grade) samples of crusts and soils. Total nitrogen (TN) and total organic carbon (TOC, after carbonates removal with HCl) were measured with a CHNS elemental analyzer FLASH 2000. For total (nitric acid-digestible) phosphorus (TP) determination, soil samples were subjected to microwave-assisted digestion in concentrated nitric acid (ISO 16729:2013) using Berghof Speedwave, in temperatures reaching 230°C and subsequently analyzed with continuous flow analyzer SAN++

Skalar. Olsen's method was used to determine available phosphorus (Pav), which is recommended for calcareous soils (Bashour and Sayegh, 2007).

To assess the potential accumulation of C, N and P in different types of BSCs, we calculated ratios of TOC, TN, TP and Pav contents in crust biomass to their contents in sub-crust soil (e.g., $TOC_{BSC}/TOC_{sub\text{-}crust\ soil}$). To assess nutrient enrichment (C, N and P) in sub-crust soils in comparison to soils under vascular plants, we calculated ratios of TOC, TN, TP and Pav contents in sub-crust and sub-plant soils to their contents in bare soils taken from the same location (e.g., $TOC_{sub\text{-}crust\ soil}/TOC_{bare\ soil}$ and $TOC_{sub\text{-}plant\ soil}/TOC_{bare\ soil}$).

2. Cushion plants

Sampling design

Samples were collected in July 2018 along a transect in the Uisu Glacier foreland, starting at 12 m and ending at about 9,000 m from the glacier terminus. Up to 1,500 m from the glacier terminus, samples were collected at intervals of 250 m and from 1,500 to 9,000 m from the glacier terminus – at intervals of 500 m. The complete transect covered a denivelation of about 300 m - from 4,400 m a.s.l to 4,100 m a.s.l., where the cushion plants were no longer present. In every sampling plot, at least two of the selected species were present. For our studies, healthy-looking, one-species cushions surrounded by soil without any biologically active cover were selected. The height and the longest and the shortest diagonals of each cushion were measured, and samples of soil and litter were taken, always restricting potential damage to the cushion to as little as absolutely necessary. For each studied cushion, a set of three samples were collected: (1) litter accumulated inside or under the cushion (potential plant input to soil organic matter) and two layers of soil directly under the cushion - (2) topsoil layer between 0 and 5 cm (P0-5) and (3) soil layer between 5 and 10 cm (P5-10).

Additionally, reference soil samples were taken from the areas without biologically active soil cover (bare soil) around every studied cushion. They were mixed samples (three subsamples per cushion) taken from the depths of 0 to 5 cm (B0-5) and 5 to 10 cm (B5-10).

In total, litter and soil were collected from 58 cushions, including 22 from *A. hedinii*, 16 from *O. immersa*, 20 from *O. poncinsii*. Additionally, 58 mixed soil samples were taken from areas without biologically active soil cover surrounding every studied cushion.

The collected soil samples were sieved (1 mm grade) and weighed on site. After ten days of air drying, they were weighed again to assess soil moisture. In most samples, soil moisture was equal to or close to 0% (no soil water). In some cases, sample mass increased after drying, probably due to atmospheric moisture absorption. Thus, the results for soil moisture were not used in the statistical analyses. Nevertheless, they highlight the extreme dryness of soils in the Uisu Glacier foreland.

Measurements of soil temperature

To measure soil temperature under cushions, 20 iButton data loggers were placed under *A. hedinii* cushions along the transect, and 18 of them remained fully operational during the research period. The cushions selected for temperature measurements were not sampled to ensure undisturbed measurements. The soil temperature was recorded six times a day till the memory capacity of the loggers was fully used, resulting in the data covering the period from 19.07.2018 to 22.06.2019, with the exclusion of 27 measuring days from 22.06. to 18.07.2018 (full records for 338 measuring days in total). Mean Annual Soil Temperature (MAST), Mean Daily Soil Temperature (MDST) and absolute minimum and maximum soil temperature were calculated for each cushion separately.

Laboratory analyses

Litter and soil samples were prepared for analysis by drying at 50oC, grounding, and sieving through a 1 mm mesh. In the litter samples, the total nitrogen (TN) and the total carbon (TC) content were measured with a CHNS elemental analyzer FLASH 2000. In the soil samples, the following analyses were performed: (1) soil organic carbon (SOC), after carbonates removal with HCl, measured with a CHNS elemental analyzer FLASH 2000; (2) extractable phosphorous (P-PO43-, described henceforward as exP) by the Olsen's method, measured with a San++ Skalar continuous flow analyzer; (3) extractable N-NH4+ and N-NO3- in 1M KCl solution, measured with a San++ Skalar continuous flow analyzer and expressed together as the extractable Inorganic Nitrogen (exIN); (4) extractable cations (exK, exCa) in 1M NH4Cl solution with ContrAA 700 flame atomic absorption spectrometer.

All analyses were performed at the Laboratory of Biogeochemistry and Environmental Conservation at the Biological Chemical Research Centre of the University of Warsaw.