Characterization of Geo-Hydro-Ecological Factors Affecting the Distribution of Endangered Species in Viiankiaapa Mire, a Mineral Exploration Site

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Abstract A prominent Cu-Ni-PGE sulphide discovery named Sakatti has been discovered below the Natura 2000 protected Viiankiaapa mire. A thermal infrared survey using an unmanned aerial vehicle was combined with field observations and hydrogeochemical analysis of pore water in the peatland to assess whether endangered species (especially Hamatocaulis vericosus) prefer areas influenced by groundwater or certain geochemical environments. Before planning of the intensive exploration and possible mining activities, it is important to understand the possible association of the mire vegetation with groundwater–surface water interactions, as well as the geochemical features of the local bedrock.

Key words mire, endangered species, hydrogeochemistry, thermal infrared, unmanned aerial vehicle

Introduction

A Cu-Ni-PGE sulphide mineralization has been discovered in Sodankylä, Northern Finland (Brownscombe et al. 2015), located beneath the Natura 2000 protected Viiankiaapa mire close to the River Kitinen (fig. 1). It is important to understand the hydrology of the aapa mire and the possible association of the mire vegetation with the groundwater–surface water interactions, as well as the geochemical features of the local bedrock (fig. 2).

Although it is widely known that the plant cover and water quality of bog waters are related to the surrounding groundwater flow systems, the whole geo-hydro-ecological system of aapa mires is usually inadequately understood. Fraser (2001) concluded that the mixing of meteoric water and deeper groundwater controls the geochemical profiles of pore water in peatlands, being important to their biogeochemical functioning. Laitinen et al. (2005) summarized that mire hydrology, and especially its relationship with groundwater recharge–discharge patterns, is crucial for mire vegetation, but has seldom been studied in Finland.

In Viiankiaapa mire, based on present understanding of the surface and groundwater flow patterns and hydrogeochemical features of the surface and groundwaters (Salonen et al. 2016), as well as the distribution of endangered species (fig. 1), we assume that the hydrological pattern can provide an explanation for the distribution of these special habitats. Because water is able to transfer essential nutrients and trace elements for the certain types of vegetation, it is important to understand the geo-hydro-ecological system of the mire complex and its surroundings.

In this study, a thermal infrared (TIR) survey using an unmanned aerial vehicle (UAV) was combined with field observations and hydrogeochemical analysis of pore water in the peatland to assess whether endangered species (especially *Hamatocaulis vermicosus,* fig. 1) prefer groundwater-influenced habitats or certain geochemical environments.

Material and methods

Groundwater discharge zones in the surface water bodies and wetlands of the study area were located by searching for anomalies in surface and surface water temperatures. Groundwater (temperature approximately +4 °C around the year) can be seen as a temperature anomaly in the warmer environment in summer. The temperature was observed *in situ* from the mire and surface water bodies and from groundwater monitoring wells. The spatial variation in surface temperatures was assessed by thermal infrared (TIR) remote sensing using an unmanned aerial vehicle (UAV). UAV-TIR (figs 2 and 3) was used in mire areas with and without *Hamatocaulis vermicosus* habitats, as well as at reference sites (fig. 2). Reference temperature measurements (n = 21) were simultaneously collected during the UAV-TIR survey to compare the kinetic water temperature measured 1 cm below the water surface with a YSI 600 XLM-V2-M multiparameter probe to the images recorded with a thermal sensor (FLIR TAU2 640) from the skin layer of surface water bodies. The first UAV-IR survey was performed in August 2016 and the second in October 2016. Water samples were taken in September to October 2016. The UAV-TIR (Fig. 3) consisted of a Matrice 100 platform (DJI) with a Xenmuse X3 gimbal and camera (DJI), and a FLIR TAU2 640 infrared camera (FLIR® Systems, pixel resolution of 640 x 512, spectral range 7.5–13.5 μm) integrated with a ThermalCapture module (TeAx Technology UG). The FLIR TAU2 640 is capable of detecting temperature differences of ±0.05 °C. The flight survey was acquired from 100 m above the ground surface (m a.g.s.), producing a ground resolution of 13 cm, and the ground speed was approximately 3.5 m s^{-1}. Thermal images were collected and recorded by the ThermalCapture module at a rate of 8 frames s^{-1}, which guaranteed 75% overlap. Altogether, the UAV-IR survey mainly covered the mire areas (figs 2 and 3) with and without *Hamatocaulis vermicosus* habitats, as well as the reference sites. The UAV-TIR system used in this study was acquired by the Department of Geosciences and Geography, University of Helsinki, in 2016.

Water samples were taken from surface waters (n = 45), peat pore waters (n = 48) and groundwater (n = 12). The sampling locations (fig. 2) were planned to cover varying bedrock types in and outside the area of the Sakatti deposits, both with and without *Hamatocaulis vermicosus* habitats.

Surface water samples were directly collected into sampling bottles. Groundwater samples from observation wells were taken with a sampler and peat pore water samples were collected with mini-piezometers. The mini-piezometers were hand driven into the peat at the sampling locations using the bolt method described by Lee and Cherry (1978) to sample the discharging peat pore water. The screens of the mini-piezometers were at depths ranging between 15 and 350 cm below the peat surface.

Specific conductivity, pH and temperature were measured *in situ* with a YSI6000XL probe. The samples were collected for analysis of the main ion composition, stable isotopes ($\delta^{18}O$, δD), dissolved silica (DSi), dissolved organic carbon (DOC) and trace elements. To observe the surface water–groundwater connections, 93 isotope and DSi samples from groundwater

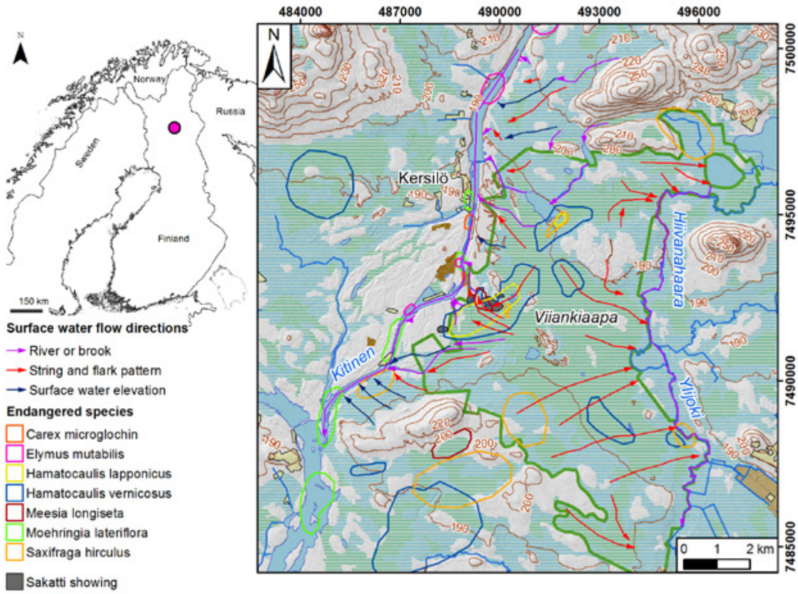

***Figure 1** Distribution of endangered species and surface water flow directions in Viiankiaapa mire. (General map Database © National Land Survey of Finland 2014).*

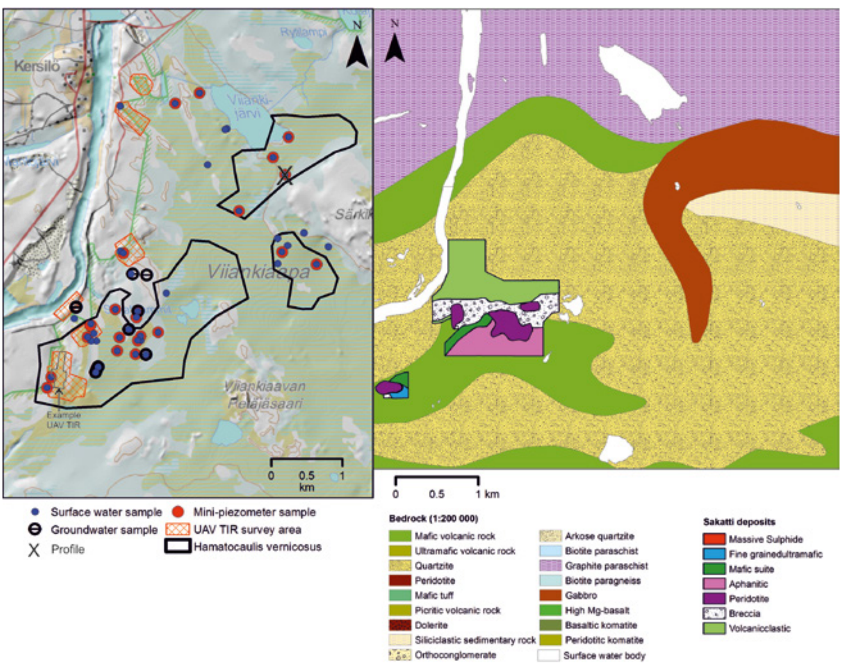

***Figure 2** Water sampling locations and the coverage of the 2016 UAV-TIR survey in Viiankiaapa mire on the left and the bedrock map of Finland (Brownscombe et al. 2015) on the right. (General map Database © National Land Survey of Finland 2014)*

and surface waters were collected and analysed with a Picarro L2120-i analyser and ICP-MS, respectively, at the Department of Geosciences and Geography, University of Helsinki. The isotope results are reported as δ values, representing the deviation in per mill (‰) from the isotopic composition of Vienna Standard Mean Ocean Water (VSMOW). To observe the chemical variation in pore water in separate peat layers with depth, 97 dissolved organic carbon (DOC), 105 trace element and 90 main ion samples from groundwater and surface waters were taken. DOC samples were analysed according to the SFS-EN 1484:1997/OUL standard at the laboratory of Ahma Environment Ltd in Oulu. Major ion and trace element samples were analysed at the Department of Geosciences and Geography, University of Helsinki

Geochemical data were graphically analysed and using statistical tests. The nonparametric Mann-Whitney U-test for independent samples was performed using IMB SPSS Statistics 24 in order to evaluate possible differences in water chemistry between sites with and without *Hamatocaulus* habitats.

Figure 3 *Viiankiaapa mire (on the left) and the UAV-TIR platform (Matrice 100) with TIR and RGB cameras (on the right).*

Results and discussion

At total of 45 000 thermal images were acquired during the UAV-IR survey in August and September 2016, and the survey covered approximately 70 hectares. Thermal images were post-processed with ThermoViewer 1.3.13beta and Pix4D software to acquire georeferenced orthomosaic and thermal orthomosaic images (fig. 4). There are thermal differences (including cold sites indicating groundwater discharge into the surface water body) between the surveyed mire areas, which enabled UAV-TIR to be used in groundwater-dependent ecosystem habitat mapping.

The stable isotope composition of $\delta^{18}O$ ranged from -8.63‰ to -14.79‰ and δD from -72.41‰ to -108.77‰. Isotopic fractionation differs according to the sources of water (groundwater, surface water), as is typical in Finland (Rautio and Korkka-Niemi 2015). The process of evaporation tends to remove lighter isotopes, enriching the heavier isotopes in the remaining water. The stable isotope composition of the collected surface water samples had more negative values than could be assumed (fig. 5). In some mini-piezometer samples, the stable isotopic composition was close to the composition of groundwater. In addition,

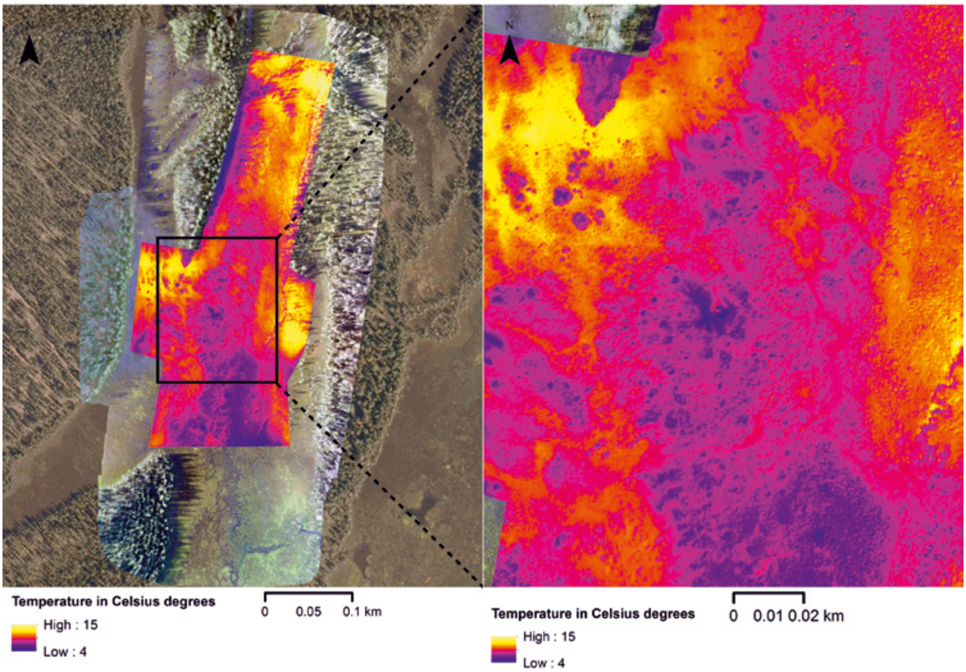

Figure 4 *The example of a thermal mosaic image.*
(Orthoimage Database © National Land Survey of Finland 2013). Colder locations indicate groundwater discharge into the mire system. Location is shown in figure 2.

the stable isotope composition of surface water samples varied considerably, suggesting a groundwater contribution to exist at some locations. In some vertical profiles, the influence of groundwater was clearly apparent, and values of $\delta^{18}O$ and δD decreased with depth, mainly reflecting the isotopic composition of groundwater (fig. 5).

DOC concentrations varied from 1.3 ppm to 65.6 ppm. Groundwater samples mainly had low DOC concentrations and variability in values (1.3–12.0 ppm) compared to surface water samples (highest concentration of 65.6 ppm). The highest DOC concentrations in depth profiles were generally in the middle of the profile or a few tens of centimetres below the mire surface (fig.5). Groundwater and mini-piezometer samples had the highest EC values, and these values increased with depth (Fig. 5). pH values varied considerably in surface water, being higher at sites having *Hamatocaulus* habitats (fig. 6).

According to the nonparametric Mann-Whitney U-test for independent samples, there was a statistically significant difference ($p < 0.05$) between the measured T, DOC, Na, K, Fe, Mn and some trace elements in surface water samples of the mire from sites containing *Hamatocaulus* habitats sites and those without *Hamatocaulus* habitats. In the samples representing *Hamatocaulus* habitats, temperature and DOC and all mentioned concentrations were generally lower than at the reference sites.

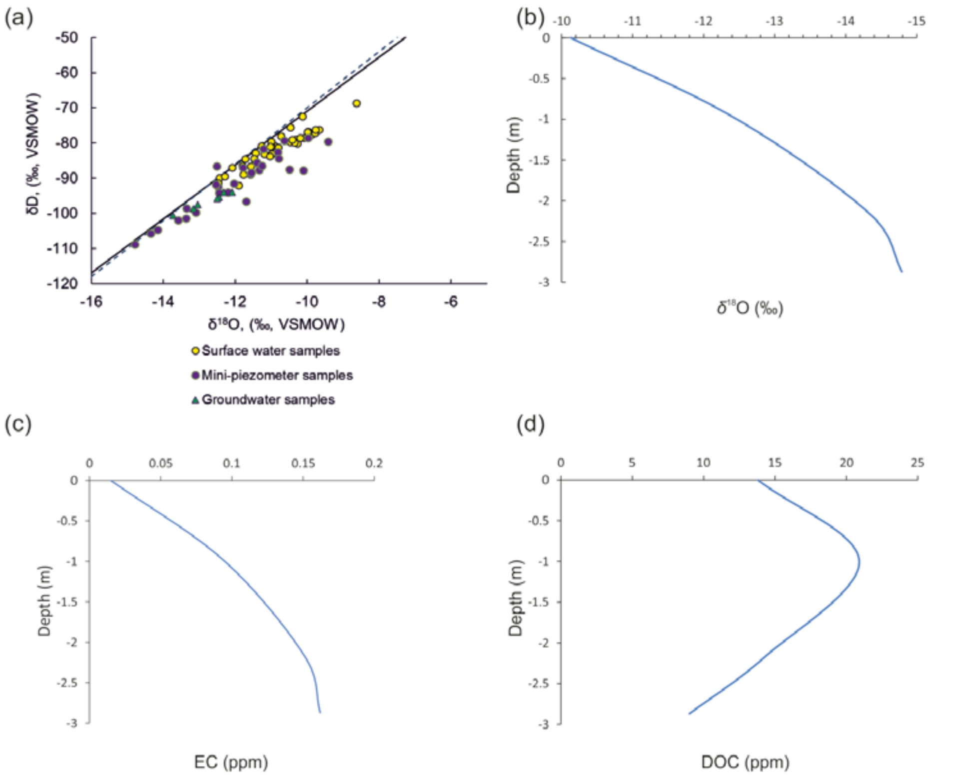

Figure 5 *The relationship of δD and $\delta^{18}O$ in groundwater and surface waters (a). The local meteoric water line (solid line) and global meteoric water line (dashed line) are shown for comparison. $\delta^{18}O$ (b), EC(c) and DOC(d) in depth profile (location in fig. 2).*

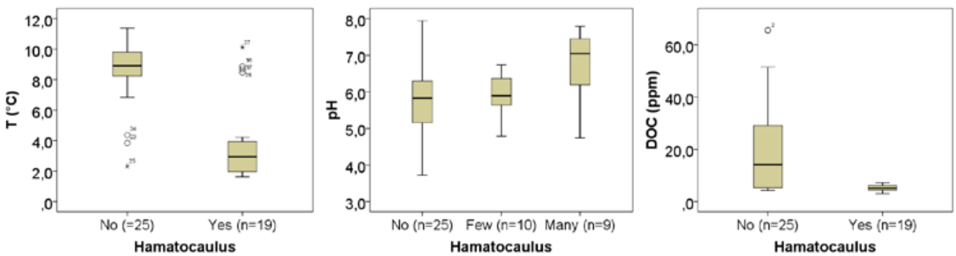

Figure 6 *Temperature, pH and dissolved carbon (DOC) in surface water samples from the Viiankiaapa mire in areas having Hamatocaulus habitats and at reference sites.*

Conclusions

Temperature anomalies were detected in the surveyed Viiankiaapa mire areas, indicating cold groundwater discharging into the soil surface at some locations. UAV-TIR appears to be an applicable method to map possible groundwater-dependent ecosystem habitats in the sensitive mineral exploration area. However, additional mapping is needed in summer during the more optimal TIR imagery conditions. The temperature, DOC, Na, K, Mn and Fe, as well as some trace element contents of surface water in the peatland were lower at locations having *Hamatocaulus* habitats than at reference sites. In some vertical profiles, the influence of groundwater was clearly evident, and values of $\delta^{18}O$, δD, DSi and DOC decreased with the depth, reflecting the composition of groundwater. Moreover, further analysis of vertical piezometric levels in the peat layers should be conducted in order to verify the groundwater flow patterns, especially at sites having *Hamatocaulus* habitats.

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