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The Use of Remote Sensing for Studying Environmental Changes in the Area of Palsa Mires (Northern Finland)

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Abstract

The aim of the presented work is to analyze changes in the environment covered by palsa peatlands located in Northern Finland in the years 1985–2024. The research includes analysis of changes in vegetation, water relations and humidity of the area (e.g. NDVI, NDWI, NDMI index) on Landsat satellite images, using GIS tools and techniques. Based on the obtained results, it was found that the use of remote sensing methods and calculation of multispectral indices based on Landsat satellite images is a useful tool in determining changes in the palsa region environment.

1. INTRODUCTION

Permafrost peatlands host some of the southernmost lowland periglacial features in the Northern Hemisphere, marked by the presence of palsas peatland mounds with an ice core formed through freeze-thaw cycles (Seppälä 2006). In northern Finland, where they form an essential part of the tundra landscape, palsas are especially vulnerable due to their location at the permafrost margins (Gisnås et al. 2017). Their development depends on local climate conditions such as temperature, precipitation, wind, vegetation, snow depth, and soil properties (Fewster et al. 2022). Even small increases in temperature (1 °C) or precipitation (10%) can substantially reduce areas favorable for their formation (Fronzek et al. 2006). Recent warming in northern Europe along with thicker snow cover and deepening of the active layer has accelerated palsa degradation (Verdonen et al. 2023). This poses a significant threat to the stability of permafrost-dependent ecosystems.

Given the rapid climatic changes in northern Finland, there is a growing need to monitor these shifts using modern technologies. Advances in satellite imaging and open-source geospatial tools have significantly expanded its use in the study of permafrost regions during recent decades (Philipp et al. 2021). RS enables researchers to track spatial patterns and temporal changes in palsa landscapes, offering essential insights into the pace and extent of environmental changes.

2. RESEARCH AREA

The study area is located in the northern part of Finland in the sporadic permafrost zone and covers an area of approximately 402,000 km^2 (Fig. 1A). The landscape of the study area is dominated by tundra vegetation, numerous thermokarst lakes and palsa peatland (Fig. 1B).

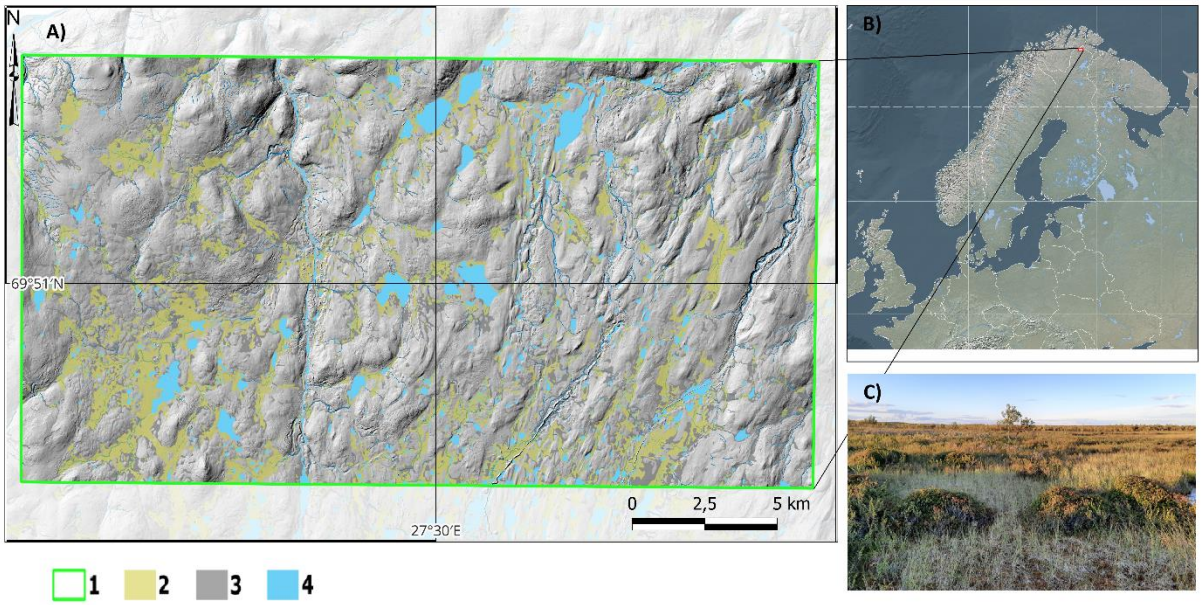

Fig. 1: A) The study area where palsa peatland occur: 1 – study area, 2 – peatlands, 3 – other wetlands, 4 – water areas; B) Location of the research area in Finland; C) View of the palsa peatland in the field (author: D. Szumińska).

3. MATERIALS AND METHODS

Satellite images from the Landsat 5/7/8/9 mission with a resolution of 30 m from 1985 to 2024, covering the vegetation period (May–September), were used. The images were made freely available by the USGS EarthExplorer (https://earthexplorer.usgs.gov/), which were then processed using QGIS 3.18.3 software. In order to identify changes in land cover and environmental conditions, selected spectral indices were calculated: NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) to assess vegetation changes, NDWI (Normalized Difference Water Index) and MNDWI (Modified NDWI) to analyze water surfaces, and NDMI (Normalized Difference Moisture Index) and SMI (Soil Moisture Index) to determine changes in vegetation and soil moisture. The analysis of the indicators allowed for the assessment of long-term environmental trends in the study area.

4. RESULTS

Analysis of Landsat satellite data from 1985 to 2024 for a selected area in northern Finland revealed a slight but consistent decline in vegetation index values (NDVI and EVI). This trend may indicate a gradual decrease in vegetation productivity or changes in vegetation structure,

potentially associated with the effects of climate change, natural succession, or local disturbances in forest and peatland ecosystems. During the same period, a significant increase was observed in moisture-related indices (NDMI and SMI), suggesting improved water availability in soil and vegetation. Water indices (NDWI and MNDWI) also showed a small but steady upward trend, which may reflect an increase in the surface area of small water bodies or enhanced detectability in satellite imagery due to seasonal or hydrological changes. These shifts may have important implications for local boreal ecosystems and for the ongoing natural processes in this climatically sensitive region.

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