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Understanding alpine geosystem services from a geomorphological diversity perspective

Arie Christoffel Seijmonsbergen[1] and Matheus G.G. De Jong[2]
[1]University of Amsterdam, Institute for Biodiversity and Ecosystem Dynamics, Biogeography and Macroecology, Amsterdam, Netherlands (a.c.seijmonsbergen@uva.nl)
[2]Surface and Subsurface Resources, Haarlem, Netherlands (mdejong@susures.nl)

Mountains provide a wide variety of services for their inhabitants, such as drinking water, energy and mineral resources, dairy farming and tourism. At the same time, mountains are globally recognized as dynamic, vulnerable, high geodiversity environments that deserve protection. The high geodiversity is due to the variety of geomorphological processes and their resulting landforms across time and space, in dependency of the geological substratum and changing climate. The processes which are active at present day are usually readily recognisable, those of the past often not. In order to continue to profit from geosystem services (in general: the services provided by the abiotic subsurface) in a sustainable way, it is imperative to study the pathways that led to the geomorphological diversity as we see now.

To do so, we analyzed a multi-scale geomorphological ArcGIS Pro geodatabase and developed a recoding scheme to semi-automatically relabel the legend units of the existing geomorphological maps in terms of past processes and landforms. This enabled us to quantify the geomorphological diversity change since the Late Glacial Maximum (LGM) by means of spatial analyses and zonal statistics supported by regional expert data of the deglaciation history.

Our study area is the municipality of Nenzing in Vorarlberg (Austria). It includes the Meng river catchment, a high alpine valley network in the Rätikon Mountains with elevations between 450 and 2850m. It is characterized by a wide variety of geomorphological environments, process groups and morphogenetic domains in which human activities and land use are restricted to forestry, cattle grazing and small scale regulated summer tourism. The area's geomorphological diversity has documented scientific conservation value, such as pollen proxies and well-preserved ice-marginal landform sequences suitable for climate reconstructions, and also hosts geosites of outstanding educational and geoheritage value. Potential future developments in the area are the expansion of existing hydropower energy plants, the mining of ice-marginal gravel resources and the exploitation of groundwater aquifers, which all affect the geosystem services of the area itself and of adjacent areas.

The results of our analyses show that 1. geomorphological diversity has increased since the LGM, especially during and just after the Late Glacial period and likely due to the absence of a full vegetation cover; 2. landforms and deposits of the glacial environment have been degraded by or covered with deposits of the periglacial, fluvial, mass movement, organic and karst environments; and 3. human influence, notably in historic times, has added to and occasionally accelerated changes in geomorphological diversity by e.g. local mining activities, rerouting of waterways, deforestation leading to local landslides, construction of retaining walls and other natural hazard-reducing measures.

We conclude that knowledge of temporal geomorphological diversity change trajectories contributes to a better understanding and sustainable use of geosystem services. Furthermore, potential impacts from measures to unlock previously unused geosystem services can be interpreted in time and space.