Biogeomorphic interactions and patterns on Little Ice Age lateral moraines

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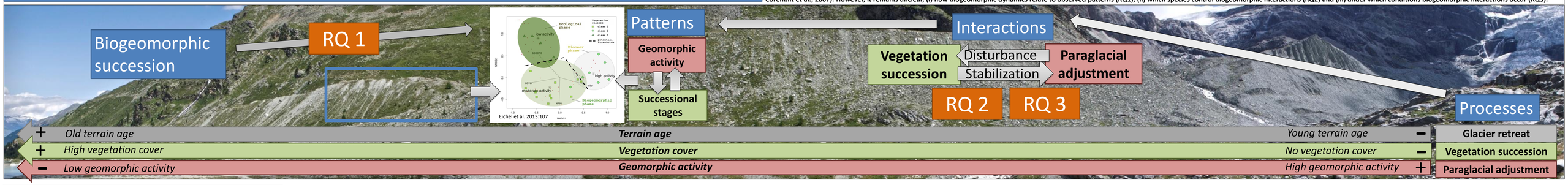
Geomorphology and ecology of glacier forefields and lateral moraines

Both ecology and geomorphology of glacier forefields and lateral moraines are strongly controlled by *glacier retreat*. In the geomorphic system, this results in *paraglacial adjustment* with an increased geomorphic activity (Ballantyne, 2002), while the ecosystem is characterized by *proceeding vegetation succession* (Matthews, 1992). In ecology, the frequent geomorphic processes of the paraglacial adjustment are seen as *disturbances* (Richter, 1994), while vegetation colonization is seen as a major factor for sediment stabilization (Matthwes, 1998). Interactions between these processes result in distinct patterns of related geomorphic activity and successional stages (Eichel et al., 2013). They can be interpreted as biogeomorphic succession phases (cf. Corenblit et al., 2007). However, it remains unclear, (i) how biogeomorphic dynamics relate to observed patterns (RQ1), (ii) which species control biogeomorphic interactions (RQ2) and (iii) under which conditions biogeomorphic interactions occur (RQ3).



Research goal

To understand the relationships between **biogeomorphic interactions, patterns and succession dynamics** on Little Ice Age lateral moraines **by applying and developing biogeomorphic concepts.**

Study area

Turtmann glacier forefield (Valais, Switzerland)

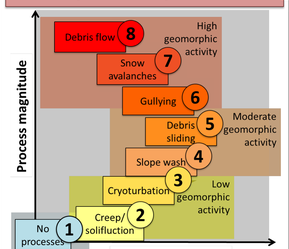
The Turtmann glacier forefield is located at the southern end of the Turtmann valley, which is a north-south oriented tributary to the Rhône valley. Its most important sediment storages are the Little Ice Age lateral moraines at the eastern valley side.

Biogeomorphic approach

Vegetation, geomorphic and soil paramaters were sampled in 50 permanent plots along the lateral moraines. Data was classified and statistically analysed to identify relationships between vegetation, geomorphic, soil and environmental properties.

Vegetation, geomorphic, soil and environmental survey in 50 permanent plots

Geomorphic activity classification



(Multivariate) Statistical analysis

Vegetation classification
→ ***Isopam*** *(Schmidtlein et al., 2009); based on species cover*

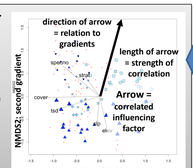
Biogeomorphic classification
→ ***Isopam****; based on species cover and occurence of geomorphic forms and processes*

Ordination
→ ***Non-metric multidimensional scaling (NMDS)****: calculates similarity of different objects with certain properties (e.g., species occurence or geomorphic properties)*

(Post-hoc) Correlations
→ *with potential influencing factors*

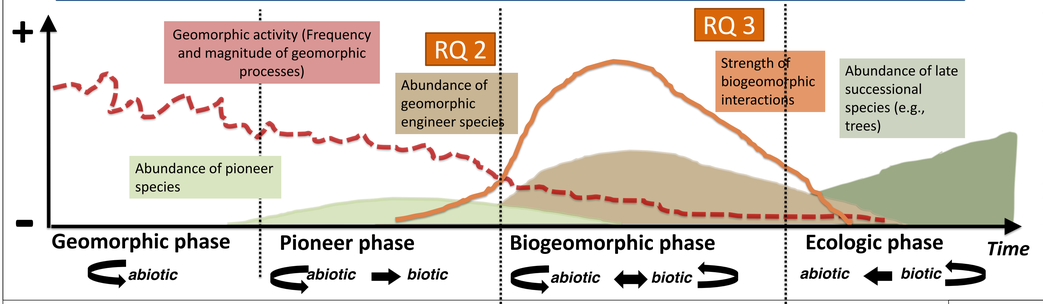
NMDS plot interpretation

Object, e.g., plot, position according to properties
→ proximity of plots = indicator for similarity of properties



RQ 1 How can biogeomorphic dynamics on lateral moraines be characterized and which patterns are produced?

Conceptual model of biogeomorphic succession dynamics on lateral moraines



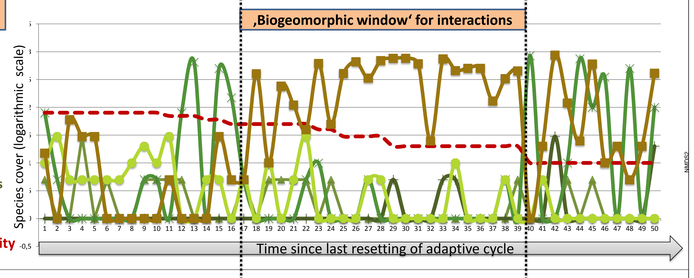
Conceptual model of biogeomorphic succession dynamics on Little Ice Age lateral moraines, based on the biogeomorphic succession concept by Corenblit et al., (2007, 2011). It shows the decreasing geomorphic activity and associated changing abundances of pioneer and late successional species during the biogeomorphic successional process. The changing strength of biogeomorphic interactions is believed to be strongly controlled by abundanace of geomorphic-engineer species (cf. Corenblit et al., 2010), which mediate these interactions.

Empirical evidence for the model is presented below.

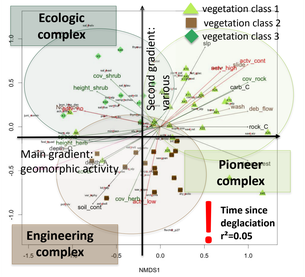
Empirical evidence

Biogeomorphic succesion dynamics on lateral moraines in the Turtmann glacier forefield based on cover of selected species. Plots are sorted according to decreasing geomorphic activity. Dynamics can be seen as an adaptive cycle which is reset by strong disturbances.

Pioneer species
Saxifraga aizoides
Linaria alpina
Geomorphic-engineer species
Dwarf shrubs
Mid to late successional species
Pinus cembra
Salix hastata
Geomorphic activity



Biogeomorphic relations

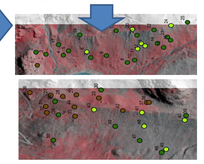


The NMDS result above shows relationships between the species composition and geomorphic, soil and environmental properties plots. The main gradient in species composition (NMDS1) can be attributed to geomorphic activity, while the second gradient is related to a variety of factors. Time since deglaciation is not related to gradients in species compositions. Showing patterns of species compositions and geomorphic and soil properties are interpreted as biogeomorphic complexes (see left side). ***Stress:=0.16.***

→ **Patch dynamics**

→ ‚Biogeomorphic patches'

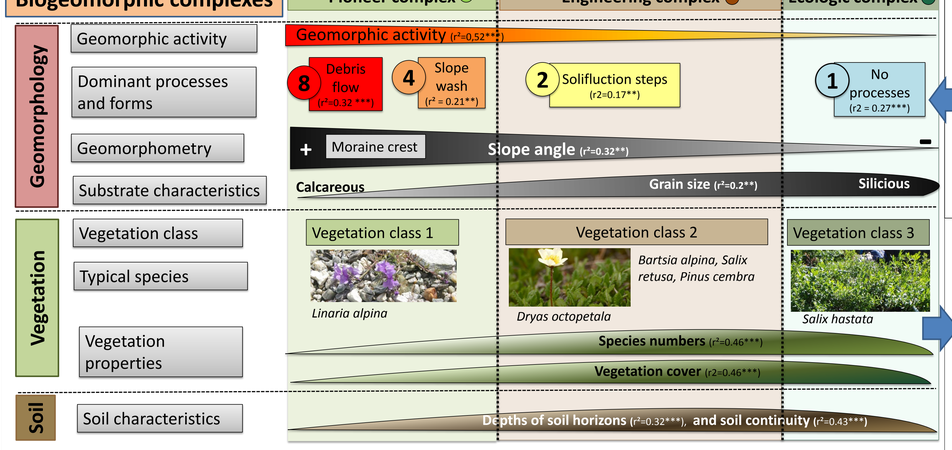
Patches as spatial representations of **biogeomorphic complexes** and **phases**?



Spatial distribution of biogeomorphic complexes (based on biogeomorphic classification) on lateral moraines in the Turtmann glacier forefield.

Pioneer complex | Engineering complex | Ecologic complex

Biogeomorphic complexes



Biogeomorphic complexes were derived from statistical analysis of permanent plot data (see above right) . They are characterized by specific geomorphic, vegetation and soil properties. They represent the biogeomorphic characteristics of the biogeomorphic successional phases. ***Significance of r²: *** = p value < 0.001, ** = p value < 0.01***

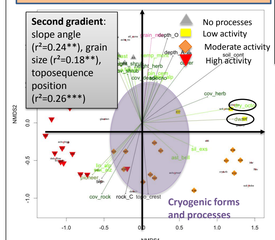
RQ 2 Which species on lateral moraines are geomorphic-engineer species?

Empirical evidence

Second gradient: slope angle (r^2=0.24**), grain size (r^2=0.18**), toposequence position (r^2=0.26***)

Strong correlation between degree of cover (*Dryas octopetala*) and geomorphic activity (r^2=0.41*)**

Main gradient: *Dryas octopetala* (r^2=0.47***) and vegetation class 2 (r^2=0.56***)
→ Strong correlation to cryogenic forms and processes



This NMDS plot shows the geomorphic similarity of the permanent plots, based on occurence of geomorphic forms and processes, and their relation to vegetation, geomorphometric and material properties. ***Stress = 0.05, Significance of r²: *** = p value < 0.001, ** = p value < 0.01***

→ Geomorphometric and material properties are not able to explain occurence of geomorphic forms and processes on lateral moraines
→ **Vegetation influence on geomorphic forms and processes (esp. cryogenic)**

***Dryas octopetala* as geomorphic-engineer species**

plant functional traits
Highly relevant for geomorphic engineering capacity

Whole plant traits
- Low-lying dwarf shrub
- Forms mats (0.5 – 1 m diameter)

Leaf traits
- High cover
- Humus formation
→ ‚nurse plants'

Engineering effects
→ **75 % less material loss during precipitation experiment** (Graf & Gerber 1997)
→ **No needle-ice creep below vegetation, deep and slow solifluction movements** (Matsuoka 2001)

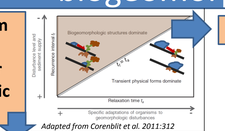
Stem and below-ground traits
- Symbiosis with mycorrhiza
- Finely branched lateral root system

Engineering effects
→ **5 times higher soil aggregate stability in rooted soil, higher angle of internal friction** (Graf et al., 2009)

Sources for traits: Elkington, 1971; Reisigl & Keller, 1994; Körner, 2003

RQ 3 Under which conditions can biogeomorphic interactions occur?

Transient form ratio: threshold for biogeomorphic interactions

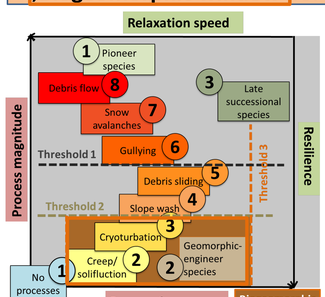


The ‚biogeomorphic window' describes the conditions under which biogeomorphic interactions can take place. It requires specific geomorphic and vegetation dimensions and is confined by thresholds (see below and right).

Geomorphic dimensions
magnitude and frequency of geomorphic processes
→ **geomorphic activity**

Vegetation dimensions
Relaxation speed + resilience
→ **regenerative traits + root traits and others**

‚Biogeomorphic window' for interactions



Threshold 1
Process magnitude and frequency low enough for engineer establishment
→ **Initial biogeomorphic interactions**

Threshold 2
Abundance of geomorphic-engineer species high enough to effect process frequency and magnitude
→ **Main biogeomorphic interactions (‚biogeomorphic window')**

Threshold 3
Low process magntiude and frequency → Late succesional species dominate competition, **engineer vanishs**

Conclusion

1) **Biogeomorphic succession dynamics** on lateral moraines are **patch dynamics.** Successional phases can be related to **biogeomorphic complexes**.
2) ***Dryas octopetala*** is a **geomorphic-engineer species,** which controls interactions and processes.
3) **Biogeomorphic interactions** depend on geomorphic and vegetation dimensions of a **‚biogeomorphic window'** , which is confined by **thresholds.**

For more information
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