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Plant succession and soil development on the foreland of the Morteratsch glacier (Pontresina, Switzerland): Straight forward or chaotic?

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ABSTRACT

As study area we selected the glacier foreland of Morteratsch (approx. 1900–2100 m a.s.l.) near Pontresina northwest of the Bernina pass, Upper Engadine, Grisons (Switzerland). The aim of this study is a multimethodological approach using floristic inventories, vegetation and soil mapping of the pro-glacial area in order to detect crucial parameters controlling plant resettlement in recently deglaciated areas as related to time, local microtopography and soil development.

The following methodological approaches were included in this study: (i) floristic relevees along a chronosequence covering 134 years (1857–1990); (ii) dendrochronological data on tree establishment, collected on a grid with a mesh width of 40 m in the area, which became ice-free between 1857 and 1980; (iii) vegetation mapping; (iv) soil analyses including physical and chemical properties of 11 typical profiles; (v) soil mapping and (vi) data evaluation using GIS.

Retreating glaciers successively expose mineral substrates that are colonised within a few years by vascular plants, mosses, lichens and soil biota. With increasing plant cover, also the abundance of soil organic matter increases. At first sight, the large-scale patterns of vegetation and soil seem to be driven by the time since deglaciation, whereas the small scale patterns may appear chaotic since they depend on local site conditions, which may change dramatically over short distances.

The large-scale pattern seems to develop as follows. About 7 years after deglaciation the first pioneer plants establish themselves and form after an additional 20 years period the Epilobietum fleischeri community, which today dominates the recently deglaciated areas, but may be found in patches more or less on the whole pro-glacial area. By contrast, the first elements of the short living Oxyrietum digynae community appear approximately 10 years after deglaciation and persist for only about 30 years. Dendrochronology showed that the first European larch and Swiss stone pine trees established themselves 15 and 31 years, respectively, after deglaciation. Surprisingly, on the study area, Swiss stone pine is about twice as frequent as the typical pioneer species European larch (88 stems per ha vs. 45 stems per ha), despite the fact that larch starts earlier and grows faster than Swiss stone pine (annual height increment: 21 cm vs. 8 cm). Up-to-now, however, nowhere in the 150-year-old glacier foreland a near-to-mature larch-Swiss stone pine forest can be found.

Besides large-scale factors such as time since deglaciation, topography and disturbance (floods, rockfalls, avalanches), also small-scale factors such as grain size and water content of the substrate, micro-relief and micro-climate seem to be crucial for the development of both vegetation and soil. Time since deglaciation and a straightforward single-pathway succession model are clearly not sufficient for understanding the small-scale patterns of succession. A non-linear succession model with different starting points and different pathways of potential primary successions for the different ecological niches is more promising for describing accurately the spatio-temporal vegetation dynamics of the pro-glacial area of Morteratsch.

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Introduction

Since approx. 1850 AD, most Alpine glaciers show phases of marked recessions, temporarily interrupted by smaller glacier advances (cf. e.g. Kinzl, 1932; Röthlisberger, 1986; Patzelt, 1985; Burga, 1987; Zumbühl and Holzhauser, 1988; Furrer, 1991; Maisch, 1992; Holzhauser and Zumbühl, 1996). Locally, large deglaciated surfaces arose where vegetation development, i.e. primary plant succession, may be investigated. Where accurate data of glacier movements are available, soil development and vegetation dynamics along time-gradients (chronosequences) and/or using permanent plots can be studied (e.g. Aletsch, Grindelwald, Rhone, Morteratsch, Roseg, Sesvenna glaciers). First investigations on this topic in Swiss and Austrian Alps have been published e.g. by Coaz (1887), Von Klebelsberg (1913), Lüdi (1921, 1934) and Oechslin (1935). Mainly Lüdi (1945, 1950, 1955, 1958) studied vegetation development of Swiss glacier forelands (Aletsch, Gries, Hüfi, Grindelwald, Rhone, Morteratsch, Roseg). Friedel (1938, 1956) made similar investigations in the Austrian Alps (Hintereisferner, Pasterze). Later studies of Alpine glacier forelands have been done by e.g. Jochimsen (1963), Richard (1973, 1987), Bäumler (1988), Schubiger (1988), Gafner and Hess (1994), Richter (1994), Gerber (1995), Burga (1999a,b), Fischer (1999), Münch (2001), Schwarz (2001), Caccianiga et al. (2001), Rehberger (2002), Treter et al. (2002), Wellstein et al. (2003), Bianchi (2005), Hangartner (2005), Walther et al. (2005), Raffl et al. (2006), Krüsi et al. (2007), Vittoz et al. (2007) and others.

Similar investigations of vegetation dynamics were also carried out in other European areas, e.g. Norway (e.g. Burrows, 1990; Matthews, 1992), and in North America, notably in Alaska (e.g. Cooper, 1923 and others, see references in Burrows, 1990, and Stuart et al., 1994), in other parts of the USA (e.g. Jones and Moral, 2005) and in Canada (e.g. Jones and Henry, 2003). In Glacier Bay (Alaska), Cooper (1923) established in 1916 the first permanent plots to monitor vegetation development following deglaciation.

Investigations (field experiments) on seed rain, soil seed bank, germination and establishment of seedlings of pioneer plants growing on Alpine glacier forelands have been carried out e.g. by Fossati (1980), Urbanska and Schütz (1986), Bäumler (1988), Stöcklin and Favre (1994), Stöcklin and Bäumler (1996), Erschbamer et al. (2001) and Marcante et al. (2009). There are also monitoring field experiments on glacier foreland vegetation related to global change (e.g. Erschbamer, 1997, 2007). Phytosociological approaches of primary plant colonisation of Swiss alpine glacier forelands have been used, e.g., by Richard (1973, 1987), Bäumler (1988) and Schubiger (1988).

Generally, two main approaches have been used for the study of primary plant succession on glacier forelands, viz. (i) permanent plots and (ii) chronosequences ('space-for-time-substitution'). Local site conditions are crucial for establishing first plant settlers. In most cases, grain size and moisture of the substrate are crucial parameters of plant establishment. A multi-methodological approach using vegetation data, soil data and a spatial analysis is, however, missing in most cases.

According to Landolt (2003) the glacier foreland Morteratsch lies within the Swiss supra-subalpine coniferous belt (European larch-Swiss stone pine forest). Its colonisation by larch (*Larix decidua*) and Swiss stone pine (*Pinus cembra*) is part of the primary plant succession processes. At this elevation in the Central Swiss Alps, larch is considered to be the typical pioneer on raw soils, whereas Swiss stone pine is generally believed to require more developed soils. Consequently, we expect larch to dominate the only recently deglaciated areas and stone pine the more advanced successional stages with more developed soils. Contrary to expectations, however, Bianchi (2005) and Elsener (2006) showed that the glacier foreland of Morteratsch is today dominated by Swiss stone pine due to a zoochorous spread by the bird *Nucifraga caryocatactes* (Mattes, 1982, 1988; Holtmeier, 1993; Kratochwil and Schwabe, 1994).

Using dendrochronology, also Bleuler (1986) investigated germination dates of larch trees on the glacier foreland Morteratsch in relation to the historical glacier extensions. He distinguished three sub-populations, which started their growth 10, 10–20 and 20–30 years, respectively, after deglaciation. On undisturbed and otherwise favourable micro-sites, larch can rapidly colonise recently deglaciated areas. Both Bianchi (2005) and Fischer (1999) compared the most advanced successional stages on the glacier foreland of Morteratsch with near-to-undisturbed forests in its immediate surroundings and concluded that 150 years are definitely not sufficient for the formation of mature larch-stone pine forest (Larici-Pinetum cembrae) with a well developed shrub and herb layer.

Plant succession is tightly bound to the underlying substrate and other site factors. Anderson et al. (2000) and Matthews and Whittaker (1987), for instance, showed that factor complexes like snow melt, exposure, moisture, terrain and time control vegetation succession. However, only few studies deal with substrate characteristics (parent material) in pro-glacial areas and little is known about the rates of physical and chemical changes of soils in such areas and their consequences for plant growth. Arn (2002), Egli et al. (2003) and Hosein et al. (2004) measured high rates of mineral formation, transformation and chemical denudation, especially on young surfaces, indicating rapid soil development in proglacial areas. In order to explain primary plant succession on glacier forelands many authors suggested therefore a micro-site approach, taking small-scale differences in microclimate, disturbance levels, water supply, grain size of the substrate, and soil development into account (e.g. Gafner and Hess, 1994; Burga, 1999a,b; Böhmer, 1999; Elsener, 2006; Ziefle, 2006; Wüthrich, 2008).

The present study aims at elucidating the crucial factors governing plant establishment on recently deglaciated areas, such as time since deglaciation, micro-relief or soil development, using a multi-method approach including (i) floristic relevees along a chronosequence covering 134 years (1857–1990); (ii) dendrochronological data on tree establishment collected using a sampling grid with a mesh width of 40 m in the area which became ice-free between 1857 and 1980; (iii) vegetation (iv) soil analyses; (v) soil mapping and (vi) spatial analyses using a GIS. Related to our main question "Straight forward or chaotic?" we try to establish a generalised model explaining the patterns of primary plant succession observed on the glacier foreland Morteratsch.

Study area

The investigation area consists of the glacier foreland Morteratsch (approx. 1900–2100 m a.s.l.) near Pontresina northwest of the Bernina pass, Upper Engadine, Grisons (Switzerland) (Fig. 1). The backwall of the glacier is formed by high mountain peaks of the South Raetian Alps, like Piz Bernina (4048.6 m a.s.l., the highest peak of the Grisons and the Eastern Alps) and Piz Palü (3901 m a.s.l.). The glacier foreland is easily accessible by a trail beginning at the railway station Morteratsch. The area between Pontresina and Morteratsch belongs to the Lower Austroalpine Bernina Nappe s.l. and comprises mainly various plutonic rock types, like granodiorites and alkali-granites, further syenites, diorites and gabbros (Staub, 1946; Rageth, 1984; Büchi, 1987, 1994; Spillmann, 1993).

Palaeo-glaciological and palaeo-ecological studies near the Bernina pass and in the Upper Engadine region have been done