

Glacial Retreat and Global Warming in Relation to Vegetation Succession in Mt. Kenya and the Bolivia Andes

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1. Glacial retreat and vegetation succession in relation to recent global warming in Mt. Kenya

Although the Tyndall Glacier retreated at an average rate of ca. 2.9 m year⁻¹ from 1958 to 1997, the rate increased to 9.8 m year⁻¹ from 1997 to 2002, 14.8 m year⁻¹ from 2002 to 2006, 8.2 m year⁻¹ from 2006 to 2011, and 11.0 m year⁻¹ from 2011 to 2016. The pioneer species such as *Senecio keniophytum* and *Arabis alpina* to establish after glacial retreat, advanced at a rate similar to that of glacial retreat. The distributions of lichens, mosses, and *Agrostis trachyphylla* also advanced. Since 1997, these species advanced at a faster rate than years past as the glacier retreated.

Both the number of plant clumps and the proportion of vegetation cover in the permanent plot (80m x 20m), established in 1996 near the edge of the glacier, increased significantly between 1996 and 2011. The values of both were also higher at a distance of 16–18 m from the glacier edge than at 0–14 m away in 1996. This indicates that the distance from the glacier edge affects both the number of plant clumps and the proportion of vegetation cover in areas of recent deglaciation. Many seedlings of *Senecio keniophytum* were likely produced 5–6 years after deglaciation, as the rate of glacial retreat from 1984 to 1996 was 2.9 m year⁻¹. However, this effect of distance from the glacier edge was not verified in areas where deglaciation exceeded 15 years.

Monthly mean minimum and maximum temperature increased by >2°C during the 48-year from 1958 to 2011. In contrast, precipitation did not significantly decline during the 55-yr period starting in 1956, although annual fluctuations did occur. The rate of retreat of Tyndall Glacier could be explained by the increases in monthly mean minimum temperature at 4500 m a.s.l. around the study area. The movement of *Senecio keniophytum*, as well as that of *Arabis alpina* to some degree, could be explained by the rate of glacial retreat.

Although *Helichrysum citrispinum* had not grown at altitudes higher than the Tyndall Tarn (4470 m) prior to 2006, 32 clumps of this species were identified on lateral moraines above 4470 m in 2009. I postulate that their range expansions may not be directly related to glacial retreat; rather, their advance to upper slopes may be linked to increases in air temperature. The expansion of *Helichrysum citrispinum* was likely favored by the increment of about 1°C during the growing season from March to September of 2009.

2. Environmental conditions affecting the vegetation around Tyndall Glacier

Movement of the leading edges of *Senecio keniodendron* and *Lobelia telekii*, common large woody rosette plants, appeared to be unrelated to glacial retreat until 1997; since then, however, these species have advanced upslope. The succession of these species does not appear to be directly related to glacial retreat but may instead be linked to soil development brought by the advancing pioneer species, stability of land surface, and increasing temperature.

3. Glacial recession and vegetation succession in Cerro Charquini of Bolivia Andes

The moraines and their vegetation were surveyed in the West Cirque of Cerro Charquini, Bolivia Andes (Cordillera Real) in 2012–14. The moraines in the West Cirque of Cerro Charquini are classified in Moraine 1 to 10 by Rabatel (2005). The five permanent plots (10 m x 10 m) were established at Moraine 2 (1700±12), Moraine 3 (1739±12), Moraine 6 (1791±10), and Moraine 9 (1873±9) dated by Rabatel (2005), and Moraine 11 without date. The vegetation distribution and the size distribution of debris covering land surface were investigated at each plot (2 m x 2 m) in the permanent plot. The vegetation close to the glacial edge was also surveyed. The date of Moraine 11 was estimated to 1970' s.

The newer the moraine, the size of debris covering land surface become larger, and the number of plant species and the proportion of vegetation cover in the plot become lower. The altitude of present end of glacier is 4990 m. The species growing near the margin of glacier are limited to *Perezia* sp. (*Perezia multiflora* ?), *Deyeuxia chrysantha*, and *Senecio rufescens*. They grow by the large rocks and their vegetation coverage is very low.

Keywords: global warming, glacial retreat, vegetaion succession, tropical high mountain