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The potential timberline: Determination with dendrochronological methods

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Introduction

Polar and alpine timberlines have often been used as study sites for global change research (for references see Innes 1991, Holtmeier 1995, 2000). Special emphasis was given to climatically induced dynamics in the timberline ecotone (Szeicz & MacDonald 1995, Scott et al. 1997, Jacoby et al. 1998, MacDonald et al. 1998a, b; Eronen et al. 1999, Gervais & MacDonald 2000). Present-day timberlines are often not in balance with the modern climatic conditions because of human impact like reindeer herding at northern timberlines or alpine pasturing in the European Alps (Holtmeier 2000). Therefore, studies that refer to recent climate driven timberline dynamics have to contribute to the problem, that the potential climatic limit of the forest may be much higher than the actual timberline. Thus, this paper focuses on the determination of the timberline-altitude that is possible under present climatic conditions, called the 'potential timberline' (Holtmeier 2000).

Photo 1: View northward over the study site on the north-west facing slope of the Piz da Staz. Red line: Northeast facing border of the study site. October 1998

Study site

The methods for determining the potential timberline will be discussed on the basis of data from the Upper Engadine, Central Alps, Switzerland. The study site (photo 1) is located on the northwest facing slope of the Piz da Staz. The timberline was lowered to 2200 m a.s.l., mainly by alpine pasturing. Alpine pastures were used frequently up to the 1950s. Occasional use occurred until the 1970s. In the timberline ecotone between 2200 - 2400 m a.s.l., microclimatic conditions are influenced by the locally varying microtopography. Swiss stone pine (*Pinus cembra* L.) and European larch *(Larix decidua* Mill.), that dominate the subalpine forest (*Larici-Pinetum cembrae*) (Keller et al. 1998) also form the timberline.

Methods

For the determination of the potential timberline two central questions have to be answered:

1. Does a certain threshold of stem number per area of juvenile growth in a given altitude guarantee reforestation?
2. Does apical or terminal growth of the juvenile growth in a given altitude guarantee reforestation?

At the potential timberline, a sufficient stem number per area is required to ensure a minimum density of the stand to form a forest. If apical growth of the juvenile trees is insufficient, they will turn into stunted instead of erect growth forms. Thus, both criteria are relevant, so that stem density and apical growth rates have to be analysed.

Tree distribution was mapped for Swiss stone pine and larch for every tree higher than 2 m. For smaller trees (0,4 - 2 m high), stem density was mapped on the basis of a 10 x 10 m grid for a sample area of 150 x 400 m. Spatial interpolation (IDW - Inverse Distance Weighted) (Philip & Watson 1982, Watson & Philip 1985) was calculated using a geographic information system (Arc View). Dendrochronological samples were taken from 500 trees. Trees that were too small for the use of a conventional increment corer (5 mm diameter) were sampled with an increment puncher (Forster et al. 2000). In order to determine the exact age of the trees, the samples were taken as close as possible to the root collar. Ring width was measured with an accuracy of 0,01 mm with LINTAB and TSAP (Rinntech, Heidelberg). The growth curves were synchronized by the use of pointer years (Schweingruber 1996) and the so called "Datierungsindex" (Schmidt 1987). Frost ring analysis was done according to Glerum et al. (1966). Mean yearly apical growth was calculated as the ratio of tree height and tree age, mean yearly number of frost rings as the ratio of the total number of frost rings per tree and tree age.

Results

The distribution of larch and Swiss stone pine at timberline displays an altitudinal gradient, which is concealed by the strong influence of microrelief (Figs. 1 - 2). Stem density of both species generally declines with increasing altitude. Swiss stone pine and also larch are mainly found at exposed sites. Trees higher than 2 m are only found up to about 2300 m a.s.l., whereas smaller trees are also present at higher elevations up to 2400 m a.s.l..

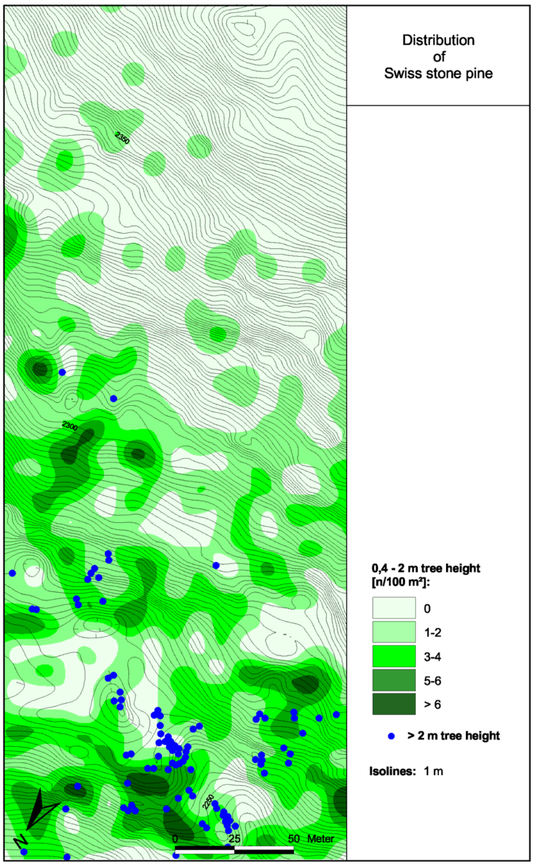

Figure 1: Distribution of Swiss stone pine on the study site (from Müterthies 2000, modified)

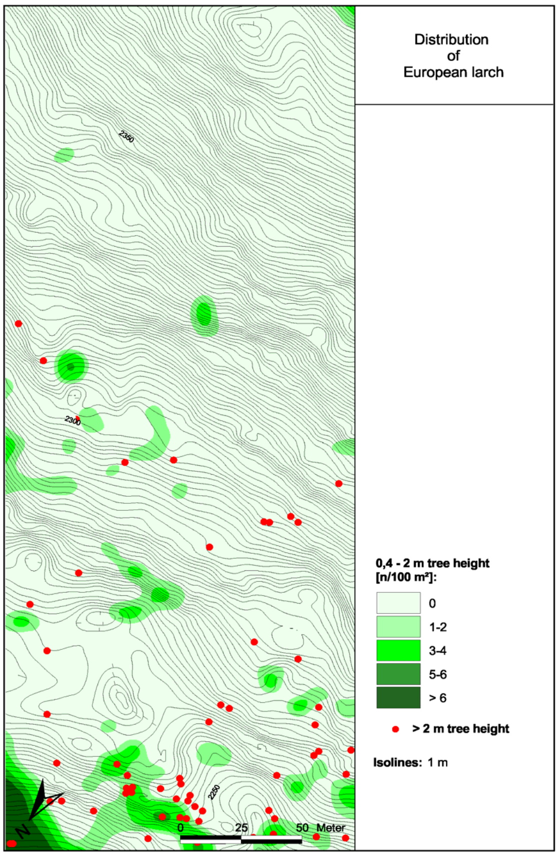

Figure 2: Distribution of European larch on the study site (from Müterthies 2000, modified)

The apical growth rates of Swiss stone pine and larch are increasing with age at elevations up to 2300 m a.s.l. (Fig. 3). Trees at higher elevations show a reduction of apical growth with increasing age from about 3 cm/a to less than 1 cm/a, which is contradictory to the normal age trend. Beside this altitudinal effect, a high variability of apical growth of trees of the same age can be observed for both tree species.

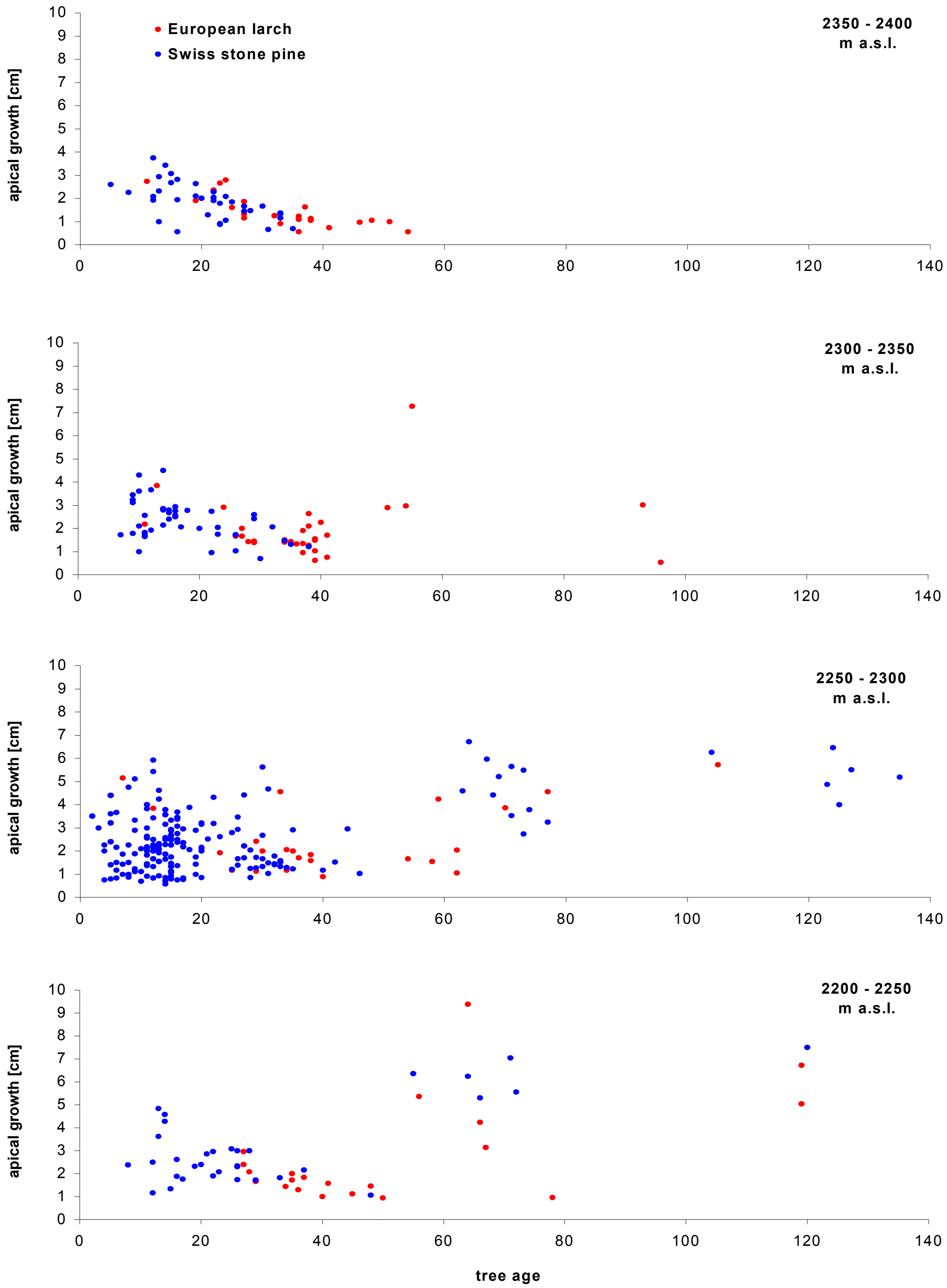

Figure 3: Mean yearly apical growth of Swiss stone pine and European larch in relation to tree age and altitude

An altitudinal differentiation can also be observed for the occurrence of frost rings in Swiss stone pine and larch (fig. 4). Both tree species are more frequently damaged by frost at higher elevations. The mean yearly number of frost rings of Swiss stone pine increases from 0,02 frost rings per year at 2250 m a.s.l. to 0,15 frost rings per year at 2400 m a.s.l.. A similar trend can be observed for larch. At 2250 m a.s.l., 0,02 frost rings per year can be found. This number increases to 0,13 frost rings per year at 2400 m a.s.l.. Beside this general trend it has to be mentioned that above 2350 m a.s.l. all Swiss stone pines and above 2300 m a.s.l. all larches, show frost damage, whereas at lower altitudes some trees show no frost rings at all.

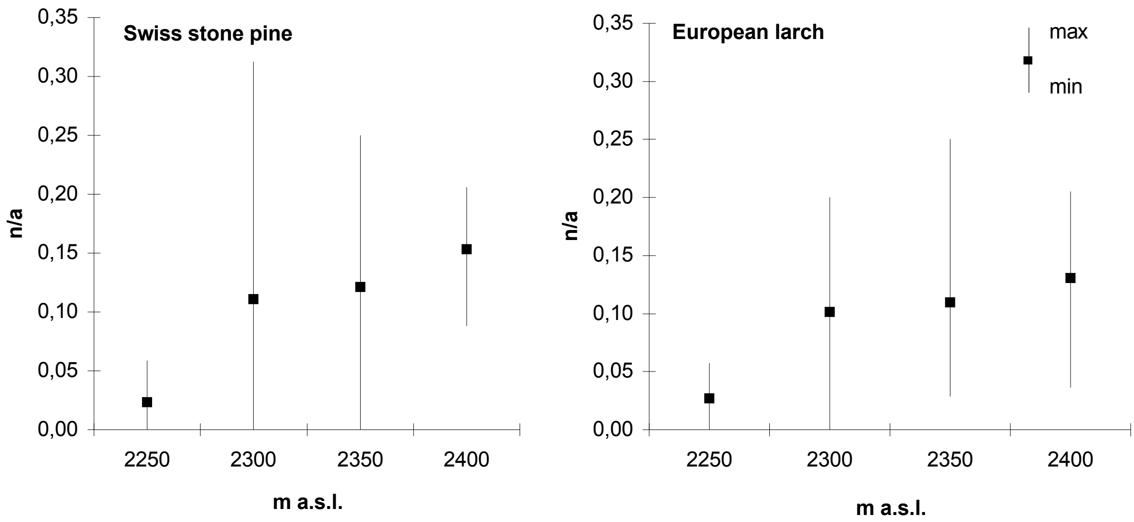

Fig. 4: Frost rings in Swiss stone pine and European larch in relation to altitude

Discussion

From the results of the frost ring analysis it can be concluded that frost damage of timberline trees (for references see Tranquillini 1979, Sakai et al 1987, Holtmeier 2000) increases with elevation. Consequently, the decreasing height growth of timberline trees (Tranquillini 1968, Schönenberger et al. 1995, Senn et al. 2001), might be attributed not only to lower temperatures in general, but also to a higher frequency of frost damage. While smaller trees, which enjoy warmer microclimate close to the ground and protection against frost damage by snow cover, grow well even at 2400 m a.s.l., mean yearly apical growth gradually declines as tree height increases, because the terminal shoot is exposed to the rough conditions of the free atmosphere (Holtmeier 2000, Müterthies 2002). Frequent frost damage at the terminal shoot leads to stunted growth forms like table trees, which are often found at the uppermost boundary of the timberline ecotone (Holtmeier 1974, Holtmeier 2000, Müterthies 2002).
Even though juvenile growth occurs up to 2400 m a.s.l., the results of the growth analysis clearly show that apical growth is insufficient for reforestation above 2300 m a.s.l. . Thus, the potential timberline can be expected at 2300 m a.s.l. (Müterthies 2002). The results of the growth analysis show, that the uppermost occurrence of regeneration at 2400 m a.s.l. is not identical with the potential timberline at 2300 m a.s.l. In conclusion, the position of the actual

potential climatic timberline can not be determined by simply mapping the highest occurrence of juvenile trees.

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