

Tree rings as a calibration tool for dynamic forest models

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Introduction

Most forest gap models have been calibrated so that trees perform well in the centre of their altitudinal or latitudinal distribution. Model curves for growth response to climatic factors, such as temperature, are therefore not always optimized to realistically simulate the effect of limiting resources (e.g. cold or drought extremes).

ForClim (Bugmann 1994) and its derived model TreeMig (Lischke *et al.* in prep.) use the traditional parabolic representation of growth response to degree-day sum. This curve has been improved for the warm boundary of species' ranges in more recent versions of ForClim (Bugmann & Solomon 2000), by replacing it with an asymptotic function. In this paper, the focus is on the other extreme, namely growth in alpine or boreal tree-line conditions, with a view to improving the growth response to degree-day sum at its lower limit in the TreeMig model. This is achieved by comparing measured tree-ring width with degree-day sum, calculated from daily minimum and maximum temperature measurements, at various locations and for different species in the Swiss Alps.

Material and methods

Ring-width measurements were collected from the literature for 3 tree-line species - *Picea abies* (Heiri 2002; Hitz 2003; Meyer 2000), *Pinus cembra* (Müterthies 2002; Niederer 2003) and *Larix decidua* (Müterthies 2002) - at various sites in the Swiss Alps (Fig. 1). Daily minimum and maximum temperature data from 12 nearby climate stations (2-3 per site) were used to calculate the daily minimum and maximum temperatures at each site by linear regression.

Degree-day sum

For each of the study sites, the degree-day sum was calculated using a slightly modified version of Allen's double sine wave method (Allen 1976), with a lower threshold set at 5.5°C and no upper threshold.

Measured growth curves

All ring-width values were assigned their corresponding yearly degree-day sum. For each study site and each species, the ring-widths were then rearranged by degree-day sum, rather than in chronological order, and grouped into 25 degree-day "windows". Within each window, the mean of the 5% largest ring-width values was calculated. Only the largest values were considered in order to minimise the influence of other factors, such as tree age, precipitation

insect attacks, etc. Thus, the measurements should reflect the maximum growth which can be attained when temperature is the only limiting factor.

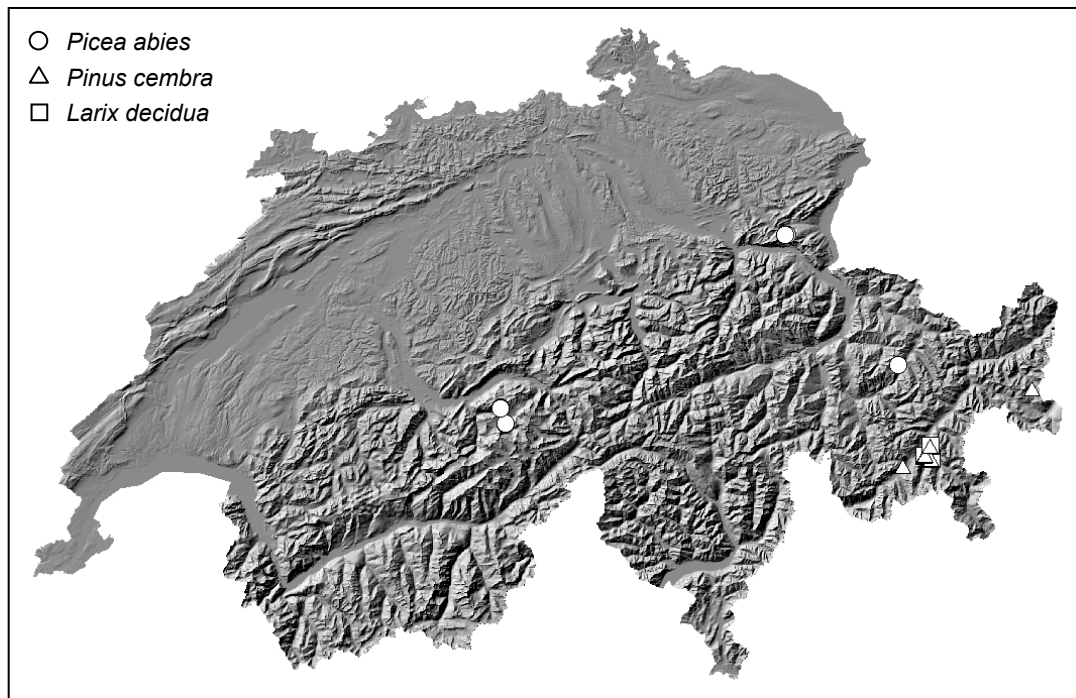


Figure 1: Location of the tree-ring width sample sites for 3 tree-line species: *Picea abies*, *Pinus cembra* and *Larix decidua*.

Theoretical growth curves

The measured growth curves were compared to two different theoretical curves: 1) the traditional parabolic curve used in many forest gap models, including early versions of ForClim (Bugmann 1994) and TreeMig (Lischke *et al.* in prep.); 2) the asymptotic curve used in ForClim 2.9 and later versions (Bugmann & Solomon 2000). The former is defined by the species-specific minimum and maximum degree-day sums, i.e. the temperature limits for growth, the maximum of the curve (where growth is maximal given the species' potential) being situated mid-way between the two. The second curve is defined by the species-specific minimum degree-day sum and tends towards the species' potential maximum growth. The shape of the asymptote is defined by a factor a , set so that growth is 75% of potential maximum when degree-day sum is equal to minimum degree-day sum + 1000 (Bugmann & Solomon 2000).

The asymptotic curve was then modified in order to improve its correspondence with the values of the measured ring-width data. The modifications concerned: 1) the minimum degree-day sum for each of the three species considered; 2) the shape of the asymptote, factor a being set so that growth is 75% of potential maximum when degree-day sum is equal to minimum degree-day sum + 250 (i.e. the slope of the curve is steeper).

Results and discussion

All three species showed growth at lower degree-day sums than the specific minimum in the original model curves (Fig. 2), which means the model would place the tree-line too low in altitude. The minimum degree-day sum for each species was therefore adjusted in the new curve, which better reflects the temperature limit for growth at tree-line.

Measured ring-widths increased rapidly with degree-day sum and the theoretical curves were all too flat, except for the parabolic curve for *Pinus cembra* (Fig. 2b). In the case of the asymptotic curve from ForClim V 2.9, this may be due to the fact that the slope was adjusted for the Pacific Northwest of the USA (Bugmann & Solomon 2000), where species' distributions seem to cover a broader range of degree-day sums. After adjustment of its parameters, the new asymptotic curve fits the shape of the maximum observed growth more closely.

In some locations, measured growth remains constantly low. This reflects the influence of other site factors, such as water availability, soil conditions, light, competition, etc. These factors are more likely to become the main cause for depressed growth as degree-day sums draw away from the lower limit.

For *Larix decidua* (Fig. 2c), the decrease in growth which appears when degree-day sum is further increased must be viewed with caution because of the smaller quantity of data used. Larch is subject to much growth fluctuation due to cyclic attacks by the Larch bud moth (*Zeiraphera diniana*). If the year with the highest degree-day sum also happens to be a "moth year", the effects of the two cannot be separated. The effects of other factors such as drought or tree age are also more difficult to separate if the dataset is small. Finally, the potential maximum growth of *Larix decidua* also seems to be underestimated, i.e. the value towards which the asymptote tends is too low.

Conclusions

This study has helped improve the theoretical growth curves used in the model, by adjusting their minimum values as well as their shape. This should enable the model to reflect reality better. Further investigation of age- and size-related growth is necessary to adjust potential maximum growth, particularly in the case of *Larix decidua*, for which more data must also be included. For all three species, this means extending the analysis of tree-ring growth beyond tree-line locations, thus including lower altitude sites, which have higher annual temperatures. Finally, the study will be extended to include other species, such as *Pinus sylvestris*, as the model is also to be used for the boreal tree-line.

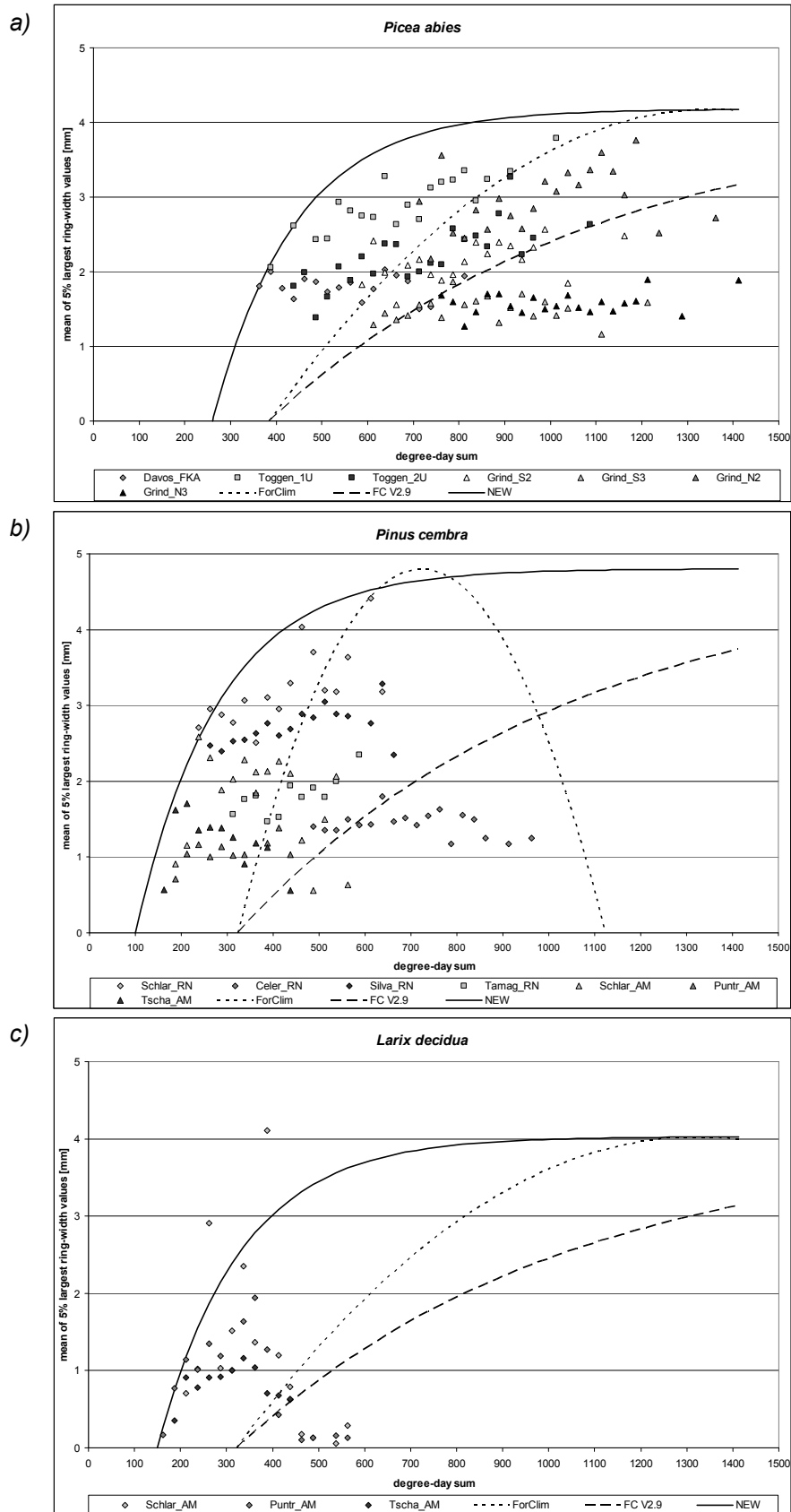


Figure 2: Means of maximum growth (ring-width) per site in each 25 degree-day window, for the 3 species: a) *P. abies*, b) *P. cembra* and c) *L. decidua*. The theoretical curves represented are ForClim/TreeMig (parabolic - dotted line), ForClim V 2.9 (asymptotic - dashed line) and modified asymptote (full line).

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