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## Radial Growth of Norway Spruce Infected by *Chrysomyxa rhododendri*

By

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**Key words:** *Chrysomyxa rhododendri*, dendroecology, defoliation, *Picea abies*, needle rust, tree ring.

### Summary

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*Chrysomyxa rhododendri* (D.C.) de Bary is a pathogen causing substantial needle loss in Norway spruce (*Picea abies* (L.) Karst.) at the timberline, where the main host (*Rhododendron* sp.) is widespread. Dendrochronological techniques were used in this study to detect the impact on radial tree growth (total ring width) of a heavily infected stand.

Increment cores were taken from infected trees (n = 43) of different age classes along an altitudinal transect. Disease severity was assessed visually throughout eight years (1989-1996) and trees were assigned to damage categories by the percentage of needle loss. To determine the influence of climatic events on tree growth, increment cores were taken also from Swiss stone pine (*Pinus cembra* L.) throughout the experimental stand as well as from a non-infected subalpine Norway spruce stand.

Though ring width variability is dominated by climatic factors at all stands, a significant age dependent relationship between intensity of rust infection and current year radial tree growth was found. Results are supported by significant growth reductions in ring widths found in artificially infected 3 to 4 year old potted trees.

It is suggested that at the timberline, where *Rhododendron* sp. is widespread and moist environmental conditions prevail, repeated heavy infestation of Norway spruce by *Chrysomyxa rhododendri* not only causes a substantial decrease in radial growth, but also impairs successful seedling establishment.

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## Introduction

*Chrysomyxa rhododendri* (D.C.) de Bary, is a common heteroecious needle rust of Norway spruce (*Picea abies* (L.) Karst.). It affects Norway spruce in areas where the alternate host (*Rhododendron* sp.) is widespread, i.e. the high-montane and subalpine zone of the alpine region, and leads to pre-mature shedding of current year needles in mid-summer. Symptoms on heavily infected trees can be quite dramatic as trees appear golden yellow (aeciospores) from a distance. The pathogen is considered to cause occasionally significant but rarely lethal defoliation, especially when moist environmental conditions prevail (DE BARY 1879, SCHMIDT-VOGT 1989).

In this study we use dendrochronological techniques (for a review see COOK & KAIRIUKSTIS 1990) to investigate radial growth of a Norway spruce stand, heavily infected by *Chrysomyxa rhododendri*. Our hypotheses were that (i) infected Norway spruce shows reduced radial growth, (ii) an age dependent relationship between disease severity and growth loss exists and (iii) infected trees are more susceptible to climatic extremes.

## Materials and Methods

### Study sites

The infected Norway spruce stand is situated at the timberline (Tuxer-Alpen, Zillertal, Bigneid-Alm), having humid climate character with annual rainfall reaching 1500 mm a year and mean monthly temperature of about 2°C. Investigated trees belong to different age classes (cambium age at breast height ranged from 18 to 123 yr) and are arranged along an altitudinal transect ranging from the high-montane to the subalpine zone (1650 m to 1830 m a.s.l.). Swiss stone pine (*Pinus cembra* L.), which is not a host of *Chrysomyxa rhododendri*, was sampled at this site too. The non-infected Norway spruce stand is situated at the timberline also (Stubai Alpen, Oberberg, 1850 m a.s.l.), in a linear distance of about 40 km from the other stands. *Chrysomyxa* infection is not apparent in this stand, since the alternate host is missing.

### Field collection and standard dendrochronological methods

Two core samples were extracted with an incremental borer at breast height (1.4 m above ground) from opposite sides of each tree, mounted on a holder and the surface prepared with fine sandpaper up to 800 grit. Ring-widths were measured to the nearest 0.01 mm using a linear table connected to a PC and the tree-ring program TSAP. Site chronologies were constructed according to standard dendrochronological methods (COOK & KAIRIUKSTIS 1990) and absolute dating was checked by synchronization with existing Norway spruce chronologies from Tyrol as well as program COFECHA (HOLMES 1994). This program identifies all locations within each ring series that may have erroneous cross-dating or measurement errors.

### Chronology development

Standardization is a method for removing low-frequency variability in individual tree-ring series. Furthermore, differences in the general growth rate or vitality of individual trees are removed. Detrending was done by fitting a negative exponential curve or a straight line to raw-measurement series (ring-width). Dimensionless indices were formed by dividing the observed ring-width value by the predicted ring-width value. Mean chronologies at each site were calculated by averaging detrended tree-ring series (COOK & KAIRIUKSTIS 1990).

#### Assessment of disease severity

Between 1989-1992 intensity of infection by *Chrysomyxa rhododendri* was assessed visually in mid-summer at the time when symptoms i.e. distinctive yellow-orange aeciospores, appear (KREHAN 1991, DONAUBAUER & al. 1995). Rust induced needle loss between 1993-1996 was estimated by tracing back needle foliage of annual lateral shoots. In both assessments, the percentage of current year needle loss of the whole tree was used as a basis to assign trees to damage categories. Healthy (0), lightly (1), moderately (2), and severely (3) infected trees showed <10, 11-33, 34-66, and more than 67 % of current year needle loss, respectively.

#### Artificially infected Norway spruce

3 to 4 year old trees were potted, artificially infected using telia-spores bearing leaves of the alternate host (*Rhododendron* sp.) and subsequently exposed to environmental conditions at the timberline. Ring-widths (average of two radii) of all trees (n = 60) were measured after two growing seasons on cross-sections made at the base of the stem.

## Results

Table 1 shows statistical parameters of all tree-ring series investigated. Due to the age-trend in tree-ring series and differences in local site factors (especially wind exposure, soil depth and soil moisture) and stand dynamics, values of mean ring-width are not evaluated. Mean sensitivities are generally low and not significantly different between stands. Autocorrelation predicts that current growth of infected Norway spruce is influenced to a higher degree by growth of the previous year, than radial growth of non-infected stands.

Table 1. Chronology-statistics of tree-ring series (AC=Autocorrelation, MS=Mean sensitivity, TRW=total ring width, mean±SD). Mean sensitivity is a measure of the mean relative change between adjacent ring widths. The first-order autocorrelation assesses relationship with prior growth (cf. FRITTS 1976).

Stand	n <sup>a</sup> trees	Chronology length	Age <sup>b</sup> (years)	TRW (mm)	MS <sup>c</sup> (%)	AC <sup>c</sup>
<i>Picea abies</i> - infected	43 (53)	1874-1996	51±25	1.81±0.77	13	0.580
<i>Picea abies</i> - non-infected	14 (23)	1917-1997	52±23	1.71±0.71	15	0.343
<i>Pinus cembra</i> - non-infected	15 (20)	1897-1996	54±20	2.76±0.54	11	0.302

<sup>a</sup> Number of trees used for chronology development. The total number of cored trees is given in parentheses. Each tree with two radii taken from opposite sides and parallel to the contourline.

<sup>b</sup> Cambial age at breast height, mean±SD.

<sup>c</sup> Calculated on the basis of detrended (indexed) chronologies for the common interval 1939-1996 (n trees ≥8).

Standardized chronologies are depicted in Fig. 1. Synchronous year-to-year changes in growth increment among chronologies indicate that the same climate factors have a limiting influence on tree growth at all stands. Norway spruce stands from the distant sites selected show a higher agreement in response to year-to-year climate variation (percentage of sign agreement W or 'Gleichläufigkeit' = 71 %,

$p < 0.001$ ; ECKSTEIN & BAUCH 1969) than the infected Norway spruce and non-infected Swiss stone pine stand growing at the same site ( $W = 65\%$ ,  $p < 0.01$ ).

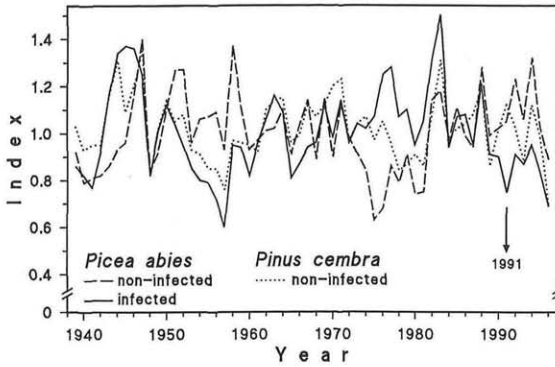


Fig. 1. Detrended (indexed) ring-width chronologies of each stand for the common interval 1939-1996 ( $n$  trees  $\geq 8$ ).

All stands show an abrupt decrease in radial growth in 1989 (Fig. 1), indicating a region-wide environmental influence on tree growth caused by adverse climate conditions. Though the non-infected Norway spruce as well as Swiss stone pine stand recover in following years, infected trees continuously show reduced ring-widths.

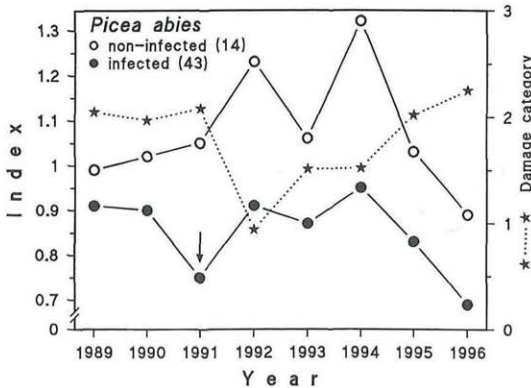


Fig. 2. Tree-ring series of infected and non-infected Norway spruce stands and mean defoliation during the period 1989-1996. Sample depth is given in parentheses. Damage categories correspond to needle loss of  $< 10$  (0), 11-33 (1), 34-66 (2) and  $> 67\%$  (3), respectively. Intermediate damage categories are caused by calculation of the mean of all trees in each year.

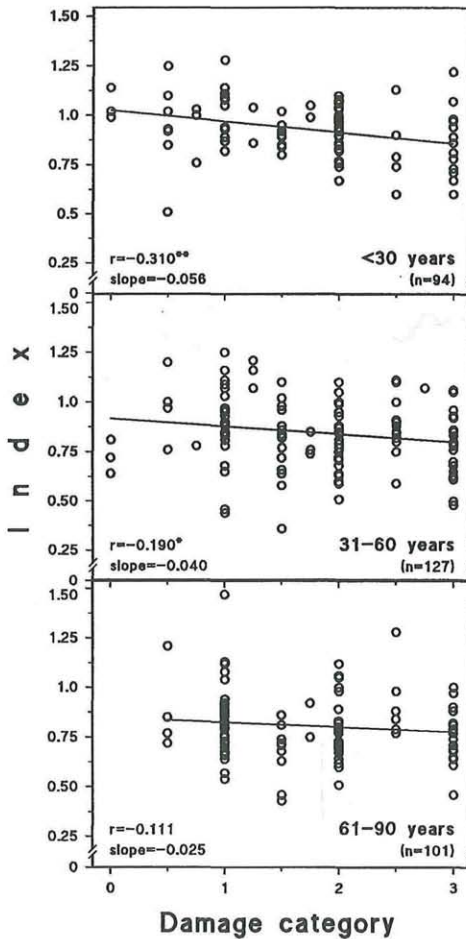


Fig. 3. Age dependent relationship between radial growth (indexed total ring width) and needle loss caused by *Chrysomyxa*-infection during the period 1989-1996. Damage categories as in Fig. 2. Asterisks indicate significance level (\*\*  $p < 0.01$ , \*  $p < 0.05$ , respectively).

Since inter-species differences in response to climate are found, indexed ring-width changes in years, where disease severity was assessed, are depicted in Fig. 2 for the infected and non-infected Norway spruce stand. Corresponding changes in annual growth are evident, except in 1991, where a strong decrease in ring-width of infected trees is seen after three successive years of heavy *Chrysomyxa* infection. It has to be noted that in 1991, Swiss stone pine shows an increase in radial growth too (see Fig. 1).

Growth increments (indexed values) versus intensity of current year defoliation for each tree, separated by age classes, are plotted in Fig. 3. Linear



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regression was performed on these scatter plots, which indicates that there is a higher correlation in younger trees. Scattering of data points may in part be attributed to inexact determination of needle loss caused by rust infestation. The Pearson correlation-coefficient ( $r$ ) of growth versus disease severity of all trees ( $n=322$ ) is  $-0.194$  ( $p<0.001$ ). An influence of the previous year infection on current year growth can only be detected in the  $<30$  yr age class ( $r=-0.318$ ,  $p=0.004$ ,  $n=82$ ) and in potted, 3 to 4 yr old trees (Fig. 4, hatched bar in 1997).

Artificially infection of 3 to 4 yr old potted Norway spruce by *Chrysomyxa rhododendri* (current year needle loss  $>67\%$ ) resulted in a 36 % decrease in ring-width compared to non-infected controls (Fig. 4; year 1996). Trees that were infected in two successive years had radial-growth decreased by 54 % (solid bar in 1997). A lag effect of previous year infection can be deduced from missing growth release in 1997 of just once infected trees.

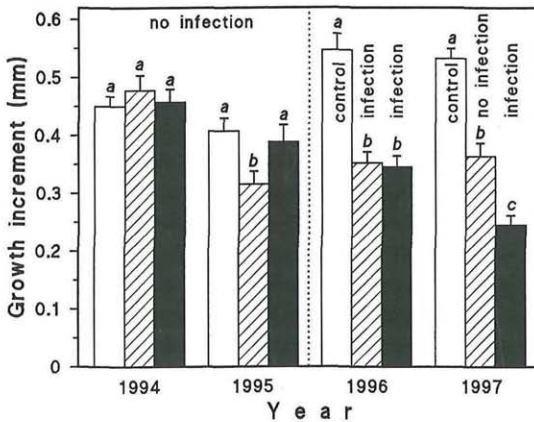


Fig. 4. Radial growth decrease  $\pm$  standard error of 3 to 4 year old, artificially infected potted Norway spruce trees. Bars indicate controls (open), samples once infected in 1996 (hatched) and samples twice infected in 1996 and 1997 (solid), respectively ( $n=20$  in each group). Means with different letters ( $a$ ,  $b$ ,  $c$ ) in one year are significantly different at  $p<0.001$ , except in 1995 where  $p<0.01$ , applying  $t$ -tests.

## Discussion

The synchronicity in variations in ring-width patterns among all investigated stands (Fig. 1) indicates a strong regional signal that reflects climate forcing. Therefore, the influence of *Chrysomyxa* infection on tree growth might be masked in some years not only by lag-effects but also by climate variation. Nevertheless, a strong decrease in radial growth in a natural Norway spruce stand in 1991 is suggested to be caused by at least three successive years of heavy infestation by *Chrysomyxa rhododendri* (Fig. 2). Since old needle foliage can compensate to some extent for the reduced carbon gain due to defoliation

(unpublished data) and infected foliage is not shed before mid-summer, cumulative effects are necessary before significantly reduced radial tree growth can be detected. This is consistent with forest decline studies, where a distinct reduction in increment is evident only after needle loss exceeds about 40 % of crown volume (SCHMIDT-VOGT 1989, KONTIC & al. 1992). However, a comparison is somewhat ambiguous since pollution effects cause predominantly shedding of older needles.

Age-dependent responses shown in Fig. 3 may reflect physiological changes related to ageing. The relationship between radial growth and reduced photosynthetic capacity could be affected by changes in carbon allocation pattern to root, shoot and cambial growth, the ratio of photosynthetic to non-photosynthetic tissues, changes in needle density and the availability and translocation of metabolites (KOZLOWSKI & al. 1991). Although the negative but gentle slope suggests that needle loss due to defoliation by *Chrysomyxa rhododendri* causes only minor growth reductions, after several years of heavy infection striking increment losses are to be expected (Fig. 2).

The separation of growth patterns between infected and non-infected stands after 1989 might indicate either an autocorrelation effect that keeps growth rates of infected trees lower or a persistent loss of tree-vigor. However, values of mean sensitivity are not significantly different (Table 1), indicating that a higher susceptibility of infected trees to extreme climatic events could not be detected.

Though increment loss at breast height does not reflect a decrease in annual volume increment of the whole stem, FRANZ 1983 and ECKSTEIN & al. 1989 found that impairment of the tree canopy primarily affects radial growth at the lower part of the stem. LEBLANC 1996 reports that for trees <100 yr old, growth decline analyses based on ring width at breast height cause overestimation of increment loss in forest decline studies. According to these findings, radial growth at breast height is considered to be a sensitive as well as appropriate parameter to detect less limiting disturbance effects like the one investigated in this study.

## C o n c l u s i o n

Preliminary results presented in this study suggest that an age dependent relationship between radial increment loss of Norway spruce and severity of infection by *Chrysomyxa rhododendri* exists. Repeated heavy infections not only retard growth, but can even be fatal to young Norway spruce trees (age <5 yr). Hence, successful seedling establishment might be hampered at timberline locations, where *Rhododendron* sp. is widespread and moist environmental conditions prevail, possibly resulting in reduced competitiveness of Norway spruce at these sites as proposed by GAMS 1970.

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