Chrysomyxa rhododendri in Trentino: a First Analysis of Monitoring Data

FABIO ZOTTELE1, CRISTINA SALVADORI1, STEFANO CORRADINI1, DANIELE ANDREIS1, ALESSANDRO WOLNYSKF AND GIORGIO MARESI1
1 FEM-IASMA – Centre for Technology Transfer; Via E. Mach 1, 38010 San Michele all’Adige (TN), Italy
2 Forest and Wildlife Service, Autonomous Province of Trento, Italy


Abstract

Chrysomyxa rhododendri de Bary is a well-known pathogen that frequently produces massive and conspicuous attacks on Picea abies Karst. in the Alps. Although the cycle of this rust was described at the end of the 19th century, it is only recently that research has focussed on its real impact on spruce dynamics at the treeline. In Trentino, spruce needle rust is regularly reported through the Forest Tree Damage Monitoring (FTDM) programme, carried out by FEM-IASMA and the Forest and Fauna Service in the woodlands of the Autonomous Province of Trento (N.E. Italy). This set of geographically referred data was analysed and correlated with meteorological and ecological parameters in order to gain a better understanding of the environmental factors involved in attacks of this rust. Measures taken from representative meteorological stations and data from woodland management plans were also analysed.

Rust infections were reported during every year of the period studied, but with considerable variability in terms of both affected surface and spatial distribution, although no clear trend was observed over the whole period. This variability could be explained by variations in precipitation in May and June, which is known to be the period of basidiospore release; solar radiation and wind could concur in spreading the fungal attack. Other parameters played a less important role in explaining the spread of rust, which affected all kind of spruce woods, regardless of age and management. Local morphology seems to be a significant factor in spreading attacks.

FTDM data showed high potential for obtaining a better understanding of spruce rust behaviour.

Key words: Rust fungi, Picea abies, tree line ecology, Geographic Information System, basidiospore dispersal

Introduction

Chrysomyxa rhododendri De Bary is common in Alpine spruce woods, including those in Italy. Attacks have been reported since the end of the 19th century (Garovaglio and Cattaneo 1876) and continue to be regularly recorded by the forest health monitoring programmes carried out in different parts of Italy and the Alps (Salvadori and Maresi 2008). The spread of this rust fungus is facilitated by the abundance of its two hosts, Picea abies Karst and Rhododendron spp. (R. ferrugineum and R. hirsutum), which are the dominant vegetation components in the Alpine belt and at the treeline over most of the southern Alps. Rust host shift is presumed to occur at the beginning of summer, when basidiospores are produced on the affected leaves of rhododendron and migrate through the air onto the new flush of P. abies. Aecidia appear on spruce needles at the beginning of August, and large-scale infestation can have devastating effects (Figure 1), often giving rise to concerns about the healthy status of the trees, the external crowns of which appear almost completely yellowed. The affected needles fall in autumn, leaving large gaps in the foliage on the terminal shoots. The rust is mainly latent on Rhododendron spp. and becomes evident only in summer with the uredial stage, consisting of orange pustules on the lower surfaces of the leaves (Figure 2).
*Chrysomyxa rhododendri* is native and endemic to the Alpine and boreal areas of Europe. It has circumpolar distribution throughout the northern hemisphere, but is absent from southern Asia, Japan and Tibet (Crane 2001, 2005), although it has recently been reported in the latter country by Chen (2002).

The fungus is a Regulated Pest in the USA, and although some infections on *Rhododendron* spp have been ascribed to it in the past, despite the aecial stage not being observed, Crane (2001) has suggested that the native rust *Chrysomyxa reticulata* may be responsible for these attacks. *C. rhododendri* has been introduced into the UK, New Zealand and Australia, where it is now considered a pest (Bennell 1985).

Although the cycle of the fungus has been well-known since it was first described (De Bary 1879), the real impact of infection on spruce vitality and treeline ecology remains unclear. Recent research on this subject suggests that the fungus may either cause photosynthetic impairment to varying degrees on new and old needles (Mayr et al. 2001), or radial increment of young trees (Oberhuber et al. 1999), and that infection may also intensify winter water stress (Mayr et al. 2010). In this context, the lack of long-term records of attacks is a stumbling block to improving understanding of the effects of the rust (Mayr et al. 2001). Spruce needle rust is regularly reported by the Forest Tree Damage Monitoring (FTDM) programme, carried out by the Fondazione Edmund Mach – Istituto Agrario di San Michele all’Adige (FEM-IASMA) and the Forest and Fauna Service of the Autonomous Province of Trento (NE-Italy). In this work, we carried out exploratory analysis of 22 years of monitoring data to ascertain the relationship between the size of the areas affected by *C. rhododendri* and meteorological and morphological variables, in order to individuate the patterns and the environmental factors involved in the spread of the rust and to better understand its effects on the ecological environment.

**Materials and Methods**

**Data collection**

Data on the distribution of rust attacks in the province of Trento (Figure 3) have been recorded since 1990 through the FTDM; this monitoring programme was carried out by the Forest Services of the Autonomous Province of Trento in collaboration with FEM-IASMA (Salvadori and Maresi, 2008). Our methodology involved direct field survey by forest personnel, periodic compilation of paper forms, and the diagnosis of hitherto unidentified damage. New attacks were diagnosed by FEM-IASMA specialists in both the forest and the laboratory. All data refer to Woodland Management Plan compartments. In 2005 a new methodology based on a WebGIS/geodatabase system was adopted (Valentinotti et al., 2004): since then, affected areas have been recorded in the FTDM database as geographically-referred polygons in the Monte Mario/Italy zone 1 datum. For the present study, the entire dataset was converted to the WGS84/UTM zone 32N datum.

**Figure 2.** *Chrysomyxa rhododendri* uredial form on *Rhododendron* leaves

**Figure 3.** Map of Trentino. Darker shading indicates the Cavalese Forestry district. The black point indicates the position of the Paneveggio meteorological station used for the climatic analyses

**Phenological data**

Phenological records (bud burst) of *P. abies* have been collected since 2003 at the Lavazè site (11.49407E 46.35823N 1807 m a.s.l), part of the Italian and European Monitoring networks (ICP IM; CON.ECO.FOR).

**Spatial and temporal distribution of the disease**

Distribution of infection during the period studied was defined as the total hectares affected by the rust, as obtained from the dataset. To assess geomorpholog-
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We calculated overlapping polygons and occurrences of attacks over the period studied for the entire affected area. The map obtained was overlaid with the map showing the presence of Pinus cembra (75%, 50% and 25% of the composition of the woods) derived from data obtained from the Woodland Management Plan (PAT 2006).

Meteorological data

The Paneveggio meteorological station (11.74752E 46.30951N, 1542 m a.s.l.) is part of the FEM meteorological network and its position, altitude and lengthy time series of hourly-recorded meteorological parameters (covering the entire period from 1990 to 2012) make it representative of the climatic behaviour of the Alpine area of the Province of Trento. For this study we used daily records of rainfall, air relative humidity, air temperature, global incoming solar radiation (the latter three measured at 2 m from the ground) and mean wind speed (measured at 3 m from the ground).

We chose the period from 1st May to 30th June, which corresponds with the appearance of new flush in P. abies, according to phenological records. To obtain the precipitation data, we calculated total daily rainfall (from 00.00 h to 23.59 h) and total precipitation from sunset to sunrise for every day of the period studied. Similar calculations were carried out for temperature, relative humidity and wind speed. No measures of relative humidity were available for 1999. A rainy dawn was defined as precipitation greater than 1 mm during sunrise, from which we obtained the percentage of rainy sundays during the period studied.

Total annual precipitation and mean annual temperature were also included in the analysis.

To calculate global incoming solar radiation and mean wind speed at the Paneveggio meteorological station, we aggregated measures taken from the time of astronomical sunrise to the time of orographic sunrise (morning). Similarly, we used orographic and astronomical sunset times to obtain evening global radiation and mean wind speed. Wind speed and global radiation measures were available only from 1998 and 2002 onwards, respectively. Morning and evening wind speed measures were missing for 2003, 2006, 2007 and 2008. A summary chart of the meteorological records used throughout this work is shown in Table 1.

Statistical analysis

Parametric (Pearson) and non-parametric correlation coefficients (Kendall, Spearman) were tested in order to ascertain the relationship between the affected surface and the meteorological parameters. We used the base, Kendall (McLeod 2011), and spearman (Savicky 2009) packages of the R software.

Given that we used long-term monitoring data and hence there was no experimental design, we fixed the probability of rejecting the hypothesis of independence at 0.20 (one out of five) and accepted a higher probability to obtain ‘false positives’ to check whether the meteorological records are a reliable predictor of basidiospore diffusion, such as described in Van Arsdel et al. 2006.

<table>
<thead>
<tr>
<th>Table 1. Descriptive statistics of the meteorological variables collected by FEM at the Paneveggio meteorological station (1990–2012)</th>
</tr>
</thead>
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</tr>
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<td>relative humidity [%]</td>
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</tr>
</tbody>
</table>
Results

Phenological data
Phenological records for *P. abies* at the Lavazè site show bud burst to begin between 2nd May (2007) and 15th June (2004 and 2010) (mean bud burst onset 3rd June); bud burst completion was between 23rd June (2009) and 15th July (2008) (mean completion date 1st July). These data appeared to confirm the susceptible period for rust infection.

Spatial and temporal distribution of the disease
During the 22 years of FTDM, *C. rhododendri* was reported to be regularly present every year, but with large fluctuations in the affected surface area, ranging from about 13 ha in 2006 to 3077 ha in 2010 (Figure 4). It should be noted that there was a sharp reduction in the recorded affected surface area in the 2000s, and only after 2007 were the values comparable with those collected during the '90s. In any case, there was no clear trend discernible during the entire series of reported attacks.

The analyses carried out on the DTM showed a prevalence of attacks on middle slope morphologies (Figure 5), i.e. where the slope is > 5° and the standard deviation of the TPI falls in the [-0.5, 0.5] interval.

![Figure 4](image-url)
**Figure 4.** Hectares of woods affected by spruce needle rust recorded by FDTM between 1990 and 2012.

![Figure 5](image-url)
**Figure 5.** Hectares of woods affected by spruce needle rust by year from 2006 to 2012. Data were grouped according to the Terrain Position Index classification. The dotted lines represent data recorded in the Cavalese Forestry District.
(Jenness 2006). No differences were detected according to aspect, rust being present on all possible expositions. The rust attacked *P. abies* stands ranging from a minimum of 881 m. a.s.l. to a maximum of 2,209 m. a.s.l., mean elevation 1,730 m. a.s.l. *C. rhododendri* attacks had similar distributions in the whole of Trentino and in the district of Cavalese.

The areas where attacks recur are very small and localised: in the Cavalese district spruce needle rust recurred more than once only on 39 ha, with a maximum of 5 recurrences on 0.4 ha, out of a total affected area of 260 ha reported in the FDTM (Figure 6).

**Meteorological data and statistical analysis**

Descriptive statistics of the meteorological variables are reported in Table 1, while the results of the statistical analyses are reported in Table 2. At the level of significance adopted in this work, a positive relationship was found between the total surface of the affected stands and the total daily precipitation measured at the Paneveggio Station, while negative relationships were found with a) night-time temperatures, and b) mean daily temperatures. A strong negative correlation was found with morning global radiation, while the correlation was positive with evening glo-

![Figure 6. Spatial distribution and recurrence of Chrysomyxa rhododendri infestation from 2006 to 2012 in the Cavalese Forestry district. The different shades of violet indicate Pinus cembra at 25%, 50% and 75% of total vegetation](image-url)

Comparison of the minimum, mean and maximum elevations of the affected areas with the altitudinal distribution of the compartments where *Pinus cembra* is dominant (Figure 7) showed no significant overlapping of elevation distributions. The upper tail region of the *C. rhododendri* distribution overlapped slightly with the lower tail of *P. cembra*. In general, *P. cembra* stands grow at altitudes higher than the *picea* woods affected by rust attacks.

**Discussion and conclusion**

FTDM historical records have enormous potential for providing a clearer understanding of different
Table 2. Results of association and correlation analyses. Significant values ($p \leq 0.2$) are reported in bold.

<table>
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<tr>
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<td>whole day</td>
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<td>-0.20</td>
<td>0.48</td>
<td>-0.28</td>
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</table>

Figure 7. Comparison between the altitudinal distributions of reported attacks of Chrysomyxa rhododendri and the altitudinal distributions of Pinus Cembra stands derived from the Digital Elevation Model and The Woodland Management Plan.

Forest diseases. With respect to C. rhododendri, the data confirmed continuous but limited occurrence of the disease in the spruce woods of Trentino. The effects of the rust are evident mainly at high altitude, regardless of the aspect of the slope, and only occasionally cover large areas. Repeat attacks were highly localised and limited to small surface areas in a few valleys at higher altitudes, where micro-station conditions and local morphologies play a role which is not yet fully understood. This concentration of recurring
heavy infestations is indicative of the limited role played by the fungus as a constraining factor for spruce regeneration. It should, in any case, be pointed out that in over twenty years there have been no reports of spruce trees dying from rust attacks, even where the rust is frequently manifested. Repeated attacks of *C. rhododendri* seem only marginally related to the upward evolution of the treeline towards *Pinus cembra* stands, whose distribution overlaps only marginally with that of the recorded rust attacks.

Although *Chrysonyx rhododendri* has a limited impact on forest health, it may be worthwhile looking more closely at the effect of the disease on the development of infested plants and their photosynthetic activity. The detailed analyses reported by Oberhuber et al. (1999), Plattner et al. (1999), Bauer et al. (2000), and Mayr et al. (2010) show clear effects on the productivity and physiology of spruce in controlled conditions, and these need to be confirmed with more detailed, direct investigations in frequently affected stands. Moreover, monitoring data rely on visual observation of massive rust presence and do not provide quantitative evaluation of the intensity of attacks; direct measurement of the damage to individual trees would make it possible to accurately assess the eco-physiological effects of the rust.

Total daily precipitation and evening global radiation seem to be the main environmental factors driving the spread of rust over a large surface area, while morning temperature, global radiation and wind, and mean wind speed over the entire day apparently have a negative effect on the spread of *C. rhododendri*.

Unfortunately, there are no data on the survival of the fungus in secondary host during the winter. Anyway, it is to notice that until now there were no reported massive *Rhododendron* sp. dissection due to a reduction in snow cover, as observed by Piséta et al. (2012) on green alders.

It is well known that precipitation plays a role in basidiospore adherence to *P. abies* needles (De Bary 1879); the positive relationship with whole-day precipitation suggests that persistent wetting of the needles provides a favourable environment for the basidiospores to germinate on the shoots. This is consistent with the negative relationship found between rust spread and both night-time and whole-day temperatures: chillier days and nights prevent the needles’ surfaces drying out. Given that no observable correlation was found (at significance level = 0.05) between total precipitation measured during the day and both night-time and mean daily temperatures, these two parameters can be considered distinct meteorological drivers.

Radiative flux during the morning and evening hours seem to play a particular role in the spread of the rust. The negative correlation found with sunrise could be explained by the drying of the needles; the positive correlation found with evening global radiation could be related to local thermally driven winds originating in a complex morphology. The diurnal cycle of incoming solar radiation and outgoing long-wave radiation at night gives rise to cyclical heating and cooling of the air layers closest to the ground, causing airflows along sloping terrains, which affect air motion in the whole valley (Whiteman 1990, Vitti et al. 2005). Here it is important to remember that these wind circulations are triggered by standard atmospheric conditions in the absence of perturbations at a synoptic scale and with good weather conditions. After dawn, the *valley breeze* dies down and in order to maintain circulation air masses are pushed up from the centre of the valley then towards the higher reaches of the slopes before descending as *down-slope or katabatic* winds. Prantl (1942) and Defant (1949) give a more detailed description of these winds. Thermally driven winds have been widely investigated with respect to both anabatic (Ye et al. 1987, Petkovšek and Hočevar 1971) and katabatic flows (Grisogono and Oerlemans 2001, Yi 2009). Given that they play a major role in determining local weather and pollution distribution, they may well also play a role in *C. rhododendri* basidiospore dispersal, as suggested by de Bary (1879) and as observed and described in detail for pine blister rust spores (van Arsdale 1967).

Putting together the correlations with global radiation and with wind measures, we get a clearer picture of the association involved in the spread of the rust: in the morning the breeze and incoming radiation release the basidiospores and dry the needles; in the evening, calm slope wind circulation fosters the spread of the rust at lower elevations. When wind blows throughout the entire day the ideal conditions for breezes are probably not met, so the shoots dry fast and the spores cannot germinate.

Further information is needed in order to have a better understanding of the effect of terrain morphology and micro-meteorology on areas affected by *C. rhododendri* over time: the stability of the atmosphere in the period May–June needs to be taken into account as well as the influence of the canopy on heat transfer and the formation of slope winds.

*C. rhododendri* is a normal inhabitant of the spruce ecosystem at the treeline in Alpine regions. Its spread is associated with meteorological (and climatic) variability in the region, while its impact is limited and highly localised to spruce woods. Further investigations of the effects of spruce needle rust should focus on the eco-physiology, climate and morphology of these restricted zones.
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CHRYSOMYXA RHODODENDRI В ТРЕНТИНО: ПЕРВЫЙ АНАЛИЗ МОНИТОРИНГОВЫХ ДАННЫХ

Ф. Зоттеле, К. Сальвадори, С. Коррадини, Д. Андреис, А. Вольниски, Д. Марези

Резюме

Chrysomyxa rhododendri де Бари широко известный патоген, часто оказывающий массивные видимые поражения на Picea abies Karst, в альпах. Несмотря на то что жизненный цикл этих ржавчинных грибов был описан еще в конце девятнадцатого столетия, только сейчас исследования сфокусированы на реальном влиянии этих грибов на динамику развития еловых пород на границе лесов. В Трентино, ржавчина еловых игл регулярно фиксируется программой мониторинга поражения лесных деревьев (the Forest Tree Damage Monitoring (FTDM) programme), проводимой FEM-IACMA (FEM-IASMA) и службой флоры и фауны на лесных землях автономной провинции города Тренто (the Forest and Fauna Service in the woodlands of the Autonomous Province of Trento (N.E. Italy)). Этот набор географически обозначенных данных был проанализирован с учетом метеорологических и экологических параметров с целью лучше изучить природные факторы вовлеченные в процесс поражения деревьев плесенью. Измерения, взятые с представленных метеорологических станций и данных схем лесных служб также были проанализированы.

Ржавчинные инфекции были описаны в течение каждого года изучаемого периода, но с соответствующими вариантами условий для пораженной поверхности и пространственного распределения, однако одинназначных тенденций обнаружено не было за весь период исследования. Такое разнообразие может быть объяснено различиями в выпадении осадков в мае и июне месяцах, в которых происходит высвобождения базидиоспор; солнечная радиация и ветер могли способствовать распространению грибного поражения. Другие параметры имели меньшее значение для объяснения распространения ржавчины, которая поражала все разнообразие еловых деревьев в не зависимости от возраста и состояния. Местная морфология по-видимому является существенным фактором влияющим на распространение ржавчинных поражений.

ФДТМ данные показали высокий потенциал для развития нашего понимания о поведении ржавчинных грибов.

Ключевые слова: Ржавчинные грибы, Picea abies, экология границ лесов, Система Географической Информации, распространение базидиоспор