Chrysomyxa rhododendri in Trentino: a First Analysis of Monitoring Data

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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.

FDTM 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).

Figure 1. Heavy attack of *Chrysomyxa rhododendri* on *Picea abies* at Paneveggio (Tn). The detail highlights the terrible effect of rust colonization of young needles

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

C. 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 Asian, 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 state 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-terms 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.

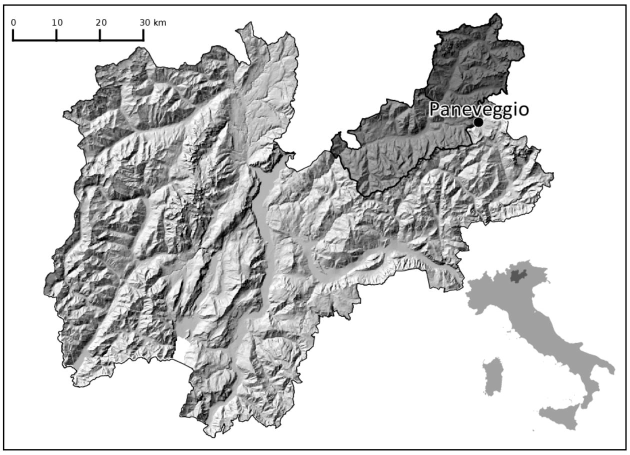

Figure 3. Map of Trentino. Darker shading indicates the Cavalese Forestry district. The black point indicates the position of the Paneveggio meteorological station used for the climatic analyses

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 geomorphological influence we examined the data recorded in the FDTM geodatabase (2006–2012), focusing on the Cavalese district (Fassa Valley) for the period from 2005 to 2012. Elevation, slope and aspect maps (minimum, maximum and mean) were calculated according to Horn (1981) and a reclassified (Jenness 2006) Topographic Position Index map (TPI) (Wilson 2007) of the affected area was derived from the Digital Terrain Model (DTM) of the Province of Trento (PAT 2007). The *raster* package (Hijmans and Etten 2013) of the R software (R Core Team, 2013) was used for all the spatial analyses.

We calculated overlapping polygons and recurrences 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 dawns 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 1. Descriptive statistics of the meteorological variables collected by FEM at the Paneveggio meteorological station (1990–2012)

variable		type	*Min.*	1st Qu	Median	Mean	3rd Qu	*Max*	St. Dev	*IQR*
rain	[mm]	night	13.00	39.37	51.00	55.89	72.47	104.80	23.55	33.10
rain	[mm]	whole day	109.60	191.73	223.30	238.51	275.93	435.40	84.36	84.20
rain	[mm]	whole year	626.40	871.30	1055.20	1095.16	1335.27	1734.50	290.48	463.97
rainy dawns	[%]	night	0.00	3.17	4.76	4.91	6.35	11.11	2.95	3.17
relative humidity	[%]	night	84.91	89.17	91.18	91.52	94.68	97.04	3.22	5.51
relative humidity	[%]	whole day	64.88	74.92	78.23	78.37	82.11	86.33	5.03	7.19
temperature	[°C]	night	2.41	4.75	5.09	5.34	6.15	8.01	1.27	1.41
temperature	[°C]	whole day	6.49	8.42	8.80	9.03	9.54	12.21	1.25	1.12
temperature	[°C]	whole year	2.05	3.11	3.69	3.64	4.09	5.03	0.79	0.98
global radiation	[MJ m^{-2}]	evening	0.52	0.56	0.61	0.66	0.78	0.84	0.12	0.23
global radiation	[MJ m^{-2}]	morning	0.13	0.16	0.21	0.22	0.27	0.38	0.08	0.11
wind speed	[m s^{-1}]	evening	0.53	0.62	0.66	0.67	0.71	0.80	0.08	0.10
wind speed	[m s^{-1}]	morning	0.42	0.47	0.48	0.51	0.57	0.61	0.06	0.10
wind speed	[m s^{-1}]	night	0.38	0.42	0.45	0.47	0.50	0.56	0.06	0.08
wind speed	[m s^{-1}]	whole day	0.76	0.86	0.94	0.94	1.00	1.06	0.08	0.14

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

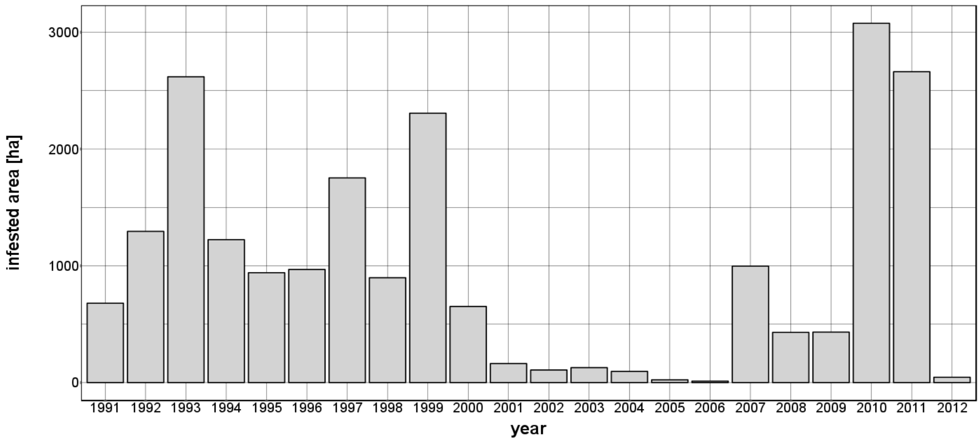

Figure 4. Hectares of woods affected by spruce needle rust recorded by FDTM between 1990 and 2012

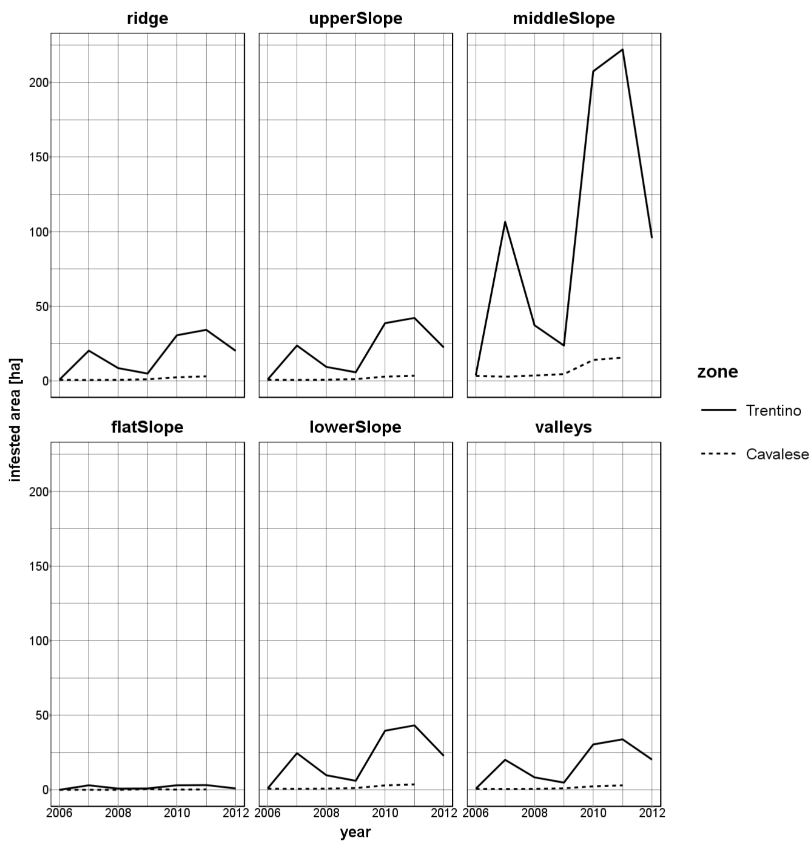

Figure 5. Hectares of woods affected by spruce needle rust by year from 2006 to 2012. Data were grouped according to the Terrain Position Index classification. The dotted lines represent data recorded in the Cavalese Forestry District

(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 localized: 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 global radiation. Analyses of wind measures showed a significant negative relationship only with mean wind speed measured in the morning hours and during the whole day.

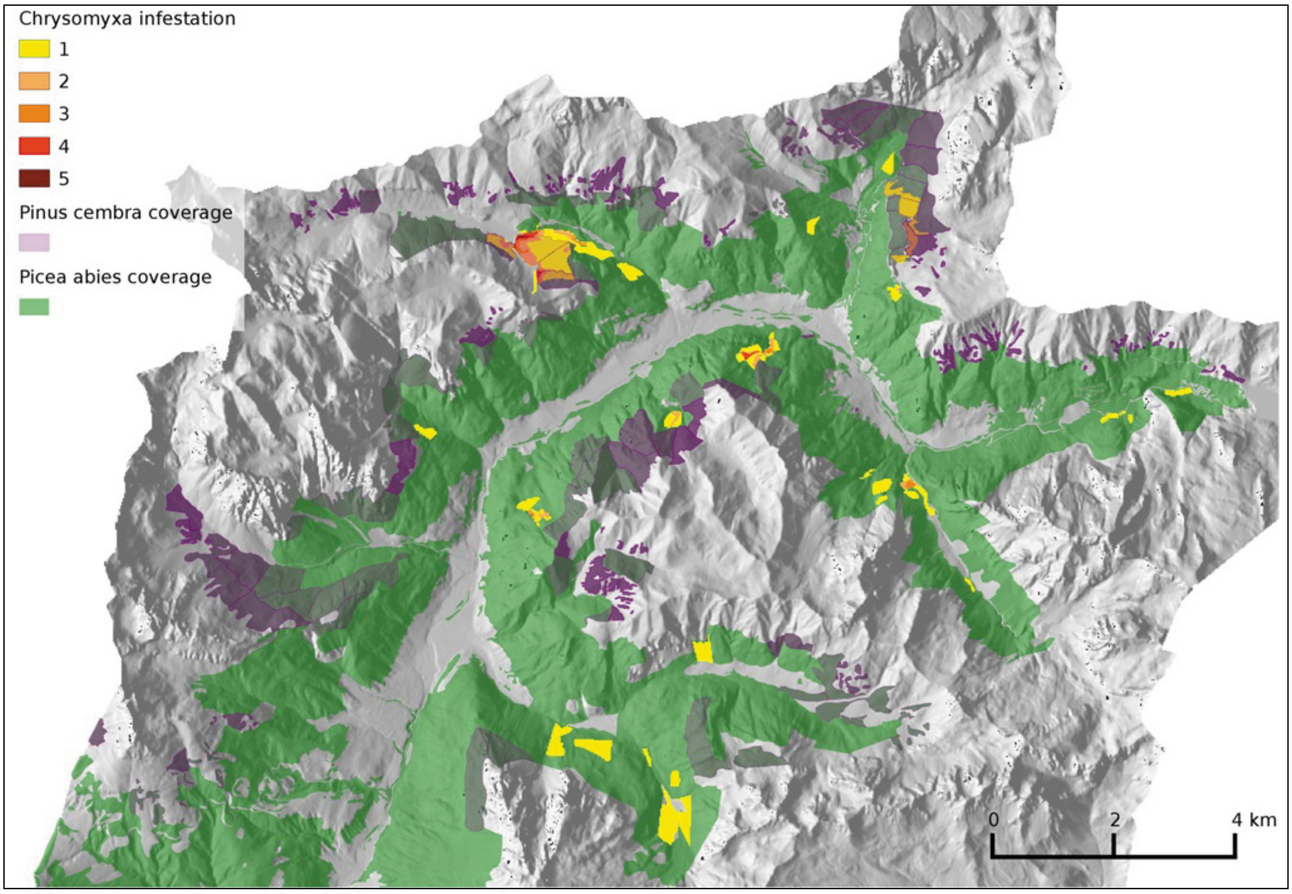

Figure 6. Spatial distribution and recurrence of *Chrysomyxa rhododendri* infestation from 2006 to 2012 in the Cavalese Forestry district. The different shades of violet indicate *Pinus cembra* at 25%, 50% and 75% of total vegetation

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. rhododentri* 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 ($p <= 0.2$) are reported in bold

variable		type	N	Pearson ρ	Pearson p-value	Kendall τ	Kendall p-value	Spearman ρ	Spearman p-value
rain	[mm]	night	23	0.11	0.63	0.16	0.29	0.16	0.47
rain	[mm]	whole day	23	0.17	0.44	0.25	**0.10**	0.30	**0.17**
rain	[mm]	whole year	23	0.06	0.77	0.10	0.53	0.13	0.54
rainy dawns	[%]	night	23	0.02	0.93	-0.04	0.81	-0.04	0.85
relative humidity	[%]	night	22	0.23	0.30	0.05	0.78	0.11	0.64
relative humidity	[%]	whole day	22	0.25	0.26	0.04	0.82	0.09	0.69
temperature	[°C]	night	23	-0.22	0.30	-0.23	**0.14**	-0.33	**0.12**
temperature	[°C]	whole day	23	-0.28	**0.19**	-0.20	**0.20**	-0.26	0.23
temperature	[°C]	whole year	23	-0.11	0.63	0.04	0.83	0.03	0.88
global radiation	[MJ m^{-2}]	evening	11	0.50	**0.11**	0.24	0.35	0.36	0.27
global radiation	[MJ m^{-2}]	morning	11	-0.62	**0.04**	-0.42	**0.09**	-0.57	**0.07**
wind speed	[m s^{-1}]	evening	11	-0.06	0.87	-0.13	0.64	-0.24	0.49
wind speed	[m s^{-1}]	morning	11	-0.34	0.31	-0.31	0.21	-0.43	**0.19**
wind speed	[m s^{-1}]	night	15	-0.10	0.72	-0.10	0.62	-0.21	0.45
wind speed	[m s^{-1}]	whole day	15	-0.20	0.48	-0.28	**0.17**	-0.38	**0.16**

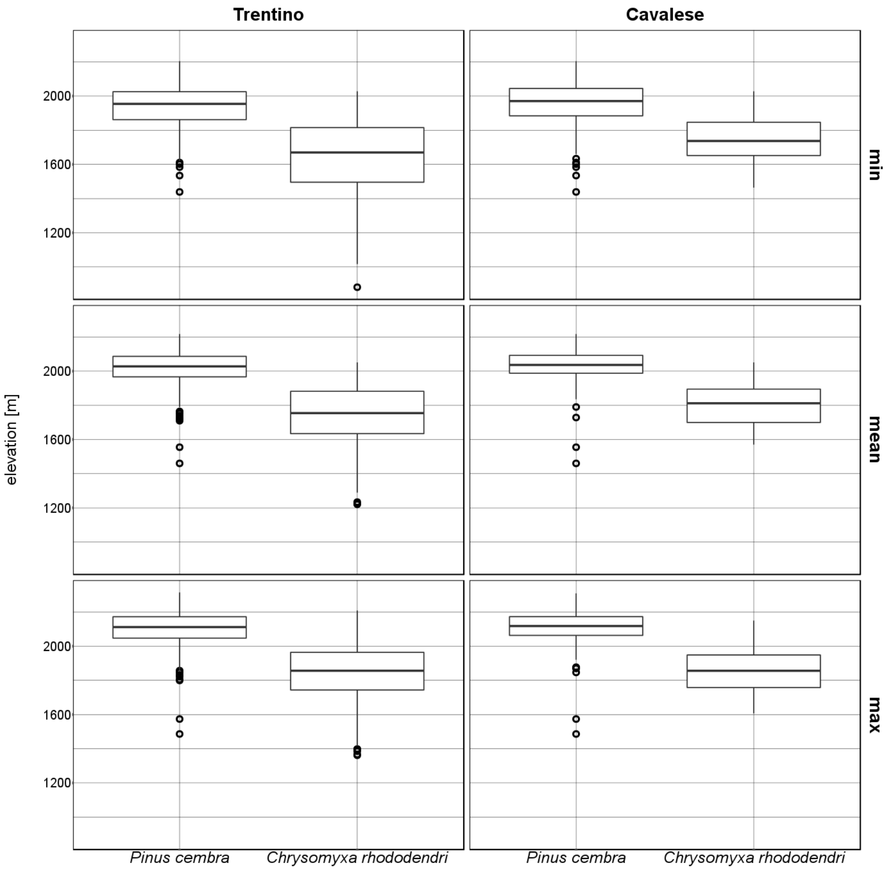

Figure 7. Comparison between the altitudinal distributions of reported attacks of *Chrysomyxa rhododendri* and the altitudinal distributions of *Pinus Cembra* stands derived from the Digital Elevation Model and The Woodland Management Plan

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 *Chrysomyxa 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. dissecation due to a reduction in snow cover, as observed by Pisetta 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 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 blist rust spores (van Arsdel 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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References

Bauer, H., Plattner, K. and Volgger, W. 2000. Photosynthesis in Norway spruce seedlings infected by the needle rust *Chrysomyxa rhododendri. Tree Physiology* 20: 211–216.

Bennell, A.P. 1985. Rhododendron rust - taxonomic and horticultural implications. *Notes from the Royal Botanic Garden, Edinburgh* 43: 25-52.

Chen, M.M. 2002. Forest fungi phytogeography: Forest fungi phytogeography of China, North America, and Siberia and international quarantine of tree pathogens. Sacramento, USA: Pacific Mushroom Research and Education Center, 469 pp.

Crane, P.E. 2001. Morphology, taxonomy, and nomenclature of the *Chrysomyxa ledi* complex and related rust fungi on spruce and *Ericaceae* in North America and Europe. *Canadian Journal of Botany* 79 (8): 957-982.

Crane, P.E. 2005. Rust fungi on rhododendrons in Asia: *Diaphanopellis forrestii* gen. et sp. nov., new species of *Caeoma*, and expanded descriptions of *Chrysomyxa dietelii* and *C. succinea*. *Mycologia* 97(2): 534-548.

De Bary, A. 1879. *Aecidium abietinum*. *Botanische Zeitung* 37: 761–847

Defant, F. 1949. Zur Theorie der Hangwinde, nebst Bemerkungen zur Theorie der Berg- und Thalwinde. *Archiv für Meteorologie, Geophysik und Bioklimatologie A* 1: 421-450.

Garovaglio, S. and Cattaneo, A. 1876. Sulla ruggine dell' Abete rosso: *Peridermium Abietinum. Rendiconti / Reale Istituto lombardo di scienze e lettere* Milano 1876 II-III: 61-67.

Grisogono, B. and Oerlemans, J. 2001. Katabatic Flow: Analystic Solution for Gradually Varying Eddy Diffuivities. *Journal of the Amospheric Sciences* 58: 3349-3354.

Hijmans, R. J. and van Etten, J. 2013. raster: raster: Geographic data analysis and modeling. R package version 2.1-25. http://CRAN.R-project.org/package=raster

Horn, B.K.P. 1981. Hill shading and the reflectance map. *Proceedings of the IEEE* 69(1): 14-47

Jenness, J. 2006. Topographic Position Index (tpi_jen.avx) extension for ArcView 3.x, v. 1.3a. Jenness Enterprises. Available at: http://www.jennessent.com/arcview/tpi.htm

Mayr, S., Schwienbacher, F., Beikircher, B. and Dämon, B. 2010. Damage in needle tissues after infection with *Chrysomyxa rhododendri* increases cuticular conductance of *Picea abies* in winter. *Protoplasma* 243: 137–143.

Mayr, S., Siller, C., Kriss, M., Oberhuber, W. and Bauer, H. 2001. Photosynthesis in rust infected adult Norway spruce in the field. *New Phytologist* 151: 683-689.

McLeod, A.I. 2011. Kendall: Kendall rank correlation and Mann-Kendall trend test. R package version 2.2. http://CRAN.R-project.org/package=Kendall

Oberhuber, W., Thomaser, G., Mayr, S. and Bauer, H. 1999. Radial growth of Norway spruce infected by *Chrysomyxa rhododendri*. *Phyton* 39: 147-154.

P.A.T. 2006: I dati della Pianificazione forestale aggiornati al 31/12/2006 [Forest and Woodland Management Plan]. Servizio foreste e fauna (unpubl.)

P.A.T. 2007. Modello Digitale del Terreno [Digital Terrain Model] Sistema Informativo Ambiente e Territorio (unpubl.).

Petkovšek, Z. and Hočevar, A. 1971. Night Drainage Winds. *Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie* 20: 353-360

Pisetta, M., Montecchio, L., Longa, C.M.O., Salvadori C., Zottele, F. and Maresi, G. 2012. Green alder decline in the Italian Alps. *Forest Ecology and Management* 281: 75-83

Plattner, K., Volgger, W., Oberhuber, W., Mayr, S. and Bauer, H. 1999. Dry mass production in seedlings of Norway spruce infected by the needle rust *Chrysomyxa rhododendri*. *European Journal of Forest Pathology* 29: 365–370.

Prandtl, L. 1942. Führer durch die Strömungslehre. Braunshweig, *Vieweg und Sohn*, 523 pp.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Salvadori, C. and Maresi, G. 2008: Forest health situation in Trentino, Italy. *Forstschutz Aktuell* 44: 21-22.

Savicky, P. (2009). pspearman: Spearman's rank correlation test. R package version 0.2-5. http://CRAN.R-project.org/package=pspearman

Valentinotti, R., Salvadori, C. and Ambrosi, P. 2004. Studio ed implementazione di un WebGIS per il monitoraggio delle foreste trentine [Design and development of a monitoring-oriented Web-GIS for Trentino□s forests]. In: Della Marta A., Orlandini S., (2004). Atti III giornate di studio "Metodi numerici, statistici e informatici nella difesa delle colture agrarie e delle foreste: ricerca e applicazioni". Edizioni Universitą Firenze: 212-215.

Van Arsdel, E. P.1967. The nocturnal diffusion and transport of spores. *Phytopathology* 57: 1221-1229.

Van Arsdel, E. P., Geils, B.W. and Zambino, P. J. 2006. Epidemiology for hazard rating of white pine blister rust. In: Guyon, J.C. comp. Proceedings of the 53rd Western International Forest Disease Work Conference; 2005 September 26-30; Jackson, WY. U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden UT: 49-61.

Vitti, A., Zatelli, P. and Zottele, F. 2005. 3D Vector Approach to Local Thermally Driven Slope Winds Modeling. *International Journal of Geoinformatics* 1(1): 79-86.

Whiteman, C.D. 1990. Observation of Thermally Developed Wind Systems in Mountain Terrain Atmospheric Processes over Complex Terrain. In: Atmospheric Processes over Complex Terrain, Ed: Blumen, W. Washington, D.C.., American Meteorological Society Monograph No. 23: 5-42.

Wilson, M.F.J., O'Connell, B., Brown, C., Guinan, J.C. and Grehan, A.J. 2007. Multiscale terrain analysis of multibeam bathymetry data for habitat mapping on the continental slope. *Marine Geodesy* 30: 3-35.

Ye, Z.J., Segal, M. and Pielke, R.A. 1987. Effects of Atmospheric Thermal Stability and Slope Steepness on the Development of Daytime Thermally Induced Upslope Flow. *Journal of the Atmospheric Sciences*. 44(22): 3341-3354

Yi, C. 2009. Instability Analysis of Terrain-Induced Canopy Flows. *Journal of the Atmospheric Sciences* 66: 2134–2142.

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CHRYSOMYXA RHODODENDRI В ТРЕНТИНО: ПЕРВЫЙ АНАЛИЗ МОНИТОРИНГОВЫХ ДАННЫХ

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Резюме

Chrysomyxa rhododendri de Bary широко известный патоген, часто оказывающий массивные видимые поражения на *Picea abies* Karst. в альпах. Несмотря на то что жизненный цикл этих ржавчиновых грибов был описан еще в конце девятнадцатого столетия, только сейчас исследования сфокусированны 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 ФЕМ-ИАСМА (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 проанализированны.

Ржавчиновые инфекции были описаны в течении каждого года изучаемого периода, но с соответствующими вариантами условий для пораженной поверхности и пространственного распределения, однако однозначных тенденций обнаружено не было за весь период исследования. Такое разнообразие может быть обьяснено 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 обьяснения 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 ржавчиновых поражений.

FDTM данные показали высокий потенциал для развития нашего понимания о поведении ржавчиновых грибов.

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