CROWN TRANSPARENCY AND 'BUTT ROT' IN SILVER FIR (*ABIES ALBA* MILL.) IN MIDDLE ITALY

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Crown transparency is known as one of the main indicators of stress/suffering of forest trees. In silver fir (*Abies alba* Mill.) 'butt rot' is a severe disease complex that affects the tree by causing progressive internal decay from the roots to the trunk. However, little research is available on the diffusion and spreading of 'butt rot' in silver fir forests, and the relationships between crown transparency and 'butt rot', at least in Italy. If we assume that high crown transparency indicates weakness and/or stress of trees, which may also be reflected in tree growth, 'butt rot' may be related in that it takes advantage of tree weakness. On the other hand, if 'butt rot' is a primary cause of tree weakness and/or suffering it could lead to crown transparency instead. However, in both assumptions some kind of association is expected to emerge if the two phenomena are related. Thus, we tested whether any relationships occurs between crown transparency and 'butt rot' in two silver fir forests in the Tuscan Apennine Alps (Middle Italy). Preliminary results show that 'butt rot' is highly spread in silver fir stands (up to 70% of trees), but appears little associated with crown transparency and relative humidity within the stem; some correlation may be present between fir size and crown transparency. Thus early results suggest that crown transparency may not be an appropriate indicator for diffusion and gravity of 'butt rot' in a context where this severe disease strongly affects silver fir. Further research and monitoring of the spreading of 'butt rot' and its relationship with climatic/environmental stressors on silver fir forests is necessary under the evidence of the high incidence of the disease, and appropriate indicators for monitoring.

Keywords: silver fir, crown transparency, butt rot, forest management.
Parole chiave: abete bianco, trasparenza della chioma, "cuore bagnato", gestione forestale.

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1. Introduction

Climate analysis conducted on trends and changes in temperature and rainfall during the 20th century in the Tuscan Apennine Alps (Middle Italy) (D'Aprile *et al.*, 2010; D'Aprile *et al.*, 2012) has highlighted the possibility that those changes may impact on the growth and/or health conditions of silver fir (*Abies alba* Mill.).
In this scenario, identifying appropriate indicators to investigate relationships between stress symptoms, which are frequently caused by climate adverse conditions, and phytopathological conditions, is a necessary step that contributes to the understanding of climatic-environmental impacts on forests.
The presence of the 'butt rot' pathology - a severe complex disease that develops within the trunk - in silver fir has been known for some time. Nonetheless, little research on the potential effects of a changing climate on the diffusion and intensity of 'butt rot' is available. Actually, research quantifying spreading, incidence, and especially the relationships between 'butt rot' and climatic variability is largely absent, although climatic alterations may have an impact on the intensity and/or spreading of this serious disease complex. Therefore, it is of great importance to investigate the relationships between changing climate conditions and the diffusion and incidence of 'butt rot' in silver fir forests for the conservation and management of the species and associated biodiversity.
To test occurrence of 'butt rot' directly against climate and environmental variables is very difficult, therefore, we used crown transparency as a proxy for tree growth and viability, where climate variability is assumed to be one of the main drivers of silver fir growth and stress. Actually, crown transparency is expected to be associated to tree growth, and healthier trees are expected to grow faster. In other words, denser crowns would correspond to faster growing and/or healthier trees and indicate better climatic-environmental conditions, and vice versa. If so, crown transparency might be an indicator of 'butt rot' spread and incidence. Our research shows that this may not necessarily be so.

2. Materials and methods

2.1 Stress indicators and tree diseases

In recent decades, crown transparency has been considered one of the main symptoms of stress or damage in

silver fir. It has been frequently used as an indicator to monitor suffering or stress of forest species from the local to the European level.
One of the most important ecophysiological features related to stress conditions of forest trees is viability. In this research we assume that crown transparency and tree growth may be related, in the aim of understanding whether there are relationships between silver fir growth, crown transparency, and a severe pathological condition. One of the advantages of crown transparency as an indicator is that symptoms develop through years. So, they can show adverse conditions that persist from the medium to the long term. It can also be noted that crown transparency is different from crown defoliation or loss of needles/leaves, which are frequently caused by episodic or short-term events.
From a phytopathological point of view, the presence of 'butt rot', a severe alteration within the stem, is known to affect silver fir over a period of time. In advanced stages of wood alteration, the degraded tissues form a humid inner column in the stem that can develop into a liquid phase with leaking (Figure 1). 'Butt rot' is a complex disease or a symptomatology of various factors such as the fungi *Armillaria* spp. and *Heterobasidion annosum*. *Heterobasidion annosum* (Fries.) Bref. is known to be an agent of wood degradation that starts from the roots; the genus *Armillaria* has been reported as a factor that can influence the dynamics of many types of mountain forest in Europe.

2.2 Measurements
In 2010, eight transects were established in the forests of Camaldoli (Arezzo, Tuscany) and Vallombrosa (Florence, Tuscany) in the Tuscan Apennine Alps (Middle Italy). These forests are managed respectively by the Italian Forestry Corps - UTBs (Regional Offices for Biodiversity of Pratovecchio (Arezzo) and Vallombrosa (Florence), respectively); measurements were carried out in June in four transects in each forest. Variability of exposure among transects was limited as much as possible; the southern exposure dominates at Camaldoli (CAM) and the northern at Vallombrosa (VAL). The UTM coordinates, upper and lower elevation, prevailing exposure and maximum slope of each transect were each determined. The respective values are shown in Table 1.
Measurements of Leaf Area Index (LAI) were made using a Li-Cor LAI2000. More accurate values were obtained by a viewing cone opening as narrow as 7°, which focuses on the upper part of the crown.
A Protimeter Timbermaster (Sheen Instruments) was used to measure the *relative humidity of timber* (RH) under bark (5 vertical measurements taken through the point of coring on two sides of the tree and perpendicular to the maximum slope).
In addition, the following were measured:
-Height (H), diameter (D) to 1.30m, social position and cross sectional characteristic of each stem. The cross section of the stem was divided into three subsections from the centre (S_c), where S_1 is the section from the centre up to 1/3 of the radius, S_2 is between 1/3 and 2/3 from the centre, S_3 is the outer third, and S_m is the average of the sections;
- Class of wood degradation with intermediate values of 0.5;
- Ray in centimetres. Ray instead of diameter was used, since the development of *butt rot* (BR) in the cross-section of the stem is frequently asymmetrical and there could be differences in the relationships between extension of *butt rot* and length of ray on the two sides of the stem;
- Regarding BR, we did not find any research that has developed an experimental classification suitable for the aims of this research. Thus, we experimented with a field classification of the internal rot of the stem:
1: a) Presence of mechanical alteration in spring wood rings;
2: a) + b) Easy, partial detachment or cleavage of rings without breakage of the sample;
3: a) + b) + c) Easy breakage and detachment of the core sections examined;
4: a) + b) + c) + d) Swelling and torsion of series of rings; rings only partially recognizable;
5: a) + b) + c) + d) + e) Fragmentation, high fragility, crumbling.
The respective frequency distribution was identified in classes 1, 2…, *n* and the prevailing characteristics were summarized as classes of wood degradation.
Once the different frequency distributions were identified, the dominant characteristics were summarized in classes of timber degradation (BR) (Tab. 2).

2.3 Methods
The relationships between LAI, RH, and BR in the cross section of the stem at the level of both the class of distance from the stem centre (S_x) and their average along the ray, were tested by statistical analysis.
These parameters were also tested against height (H), diameter (D), and social position (SP). The statistics used were:
- Pearson's linear correlation and correlation matrices;
- Simple and multiple linear regression;
- Non-parametric regression;
- Polynomial regressions of the 2nd and 4th grade.
In linear regressions, BR was calculated as a quantitative and a qualitative variable.

3. Preliminary results

3.1 Incidence of butt rot in the sampled forests
Results show the poor health condition of silver fir at all the study sites (Tab. 3). Despite a high range of variability among sites, the average high-medium level of damage shown by BR is 40.3% at Camaldoli (CAM) and 30.5% at Vallombrosa (VAL). The low-medium level of damage - including just the presence of BR - shows an average 70.0% at CAM and 48.7% at VAL.

3.2 Transparency of the canopy
The density of foliage is 25%-30% higher at CAM compared to VAL (Tab. 4). LAI variability between transects within each forest appears moderate. The comparison of the mean LAI of transects with the mean LAI estimated by averaging the LAI of individual trees in the transect appears to be lower on average by 15% at VAL and 20% at CAM.

3.3 Crown transparency and butt rot

LAI is not correlated with BR for any transect (Tab. 5) except for CAM204, where correlation between LAI and BR is inversely proportional in S_2 (r = -0.65) and S_3 (r = -0.49), and VAL317 where LAI shows inverse correlation (r = -0.47) with respect to BR in S_1. Thus, LAI appears negatively correlated with the mean value of BR in some subsections of tree cross-section in three out of eight transects. This would suggest that the increase in intensity of the internal decay of the stem might correspond to a reduction in crown transparency (CT). However, in the other five transects the observed absence of correlation would indicate that CT is somehow not representative of the presence and/or level of BR. For example, the presence of correlation between LAI and BR appears doubtful in VAL521 where no significant correlation is shown at the level of cross-subsections (S_x) However in transect VAL317, the presence of an inverse correlation between BR and LAI occurs only in S_1; as this datum is not corroborated by other data, it does not appear sufficiently reliable to provide definitive indications. A possible actual relationship between LAI and BR may exist in S_2 and S_3 at CAM204. However, this is a single case and therefore it unlikely represents the general condition.

Thus, the hypothesis a relationship between mean values of BR and CT appears to be inconsistent although denser crowns may sometimes be associated to lower levels of BR.

3.4 Crown transparency and relative humidity of the stem

Results show that the correlation between LAI and RH is not significant except for a few transects (Tab. 6). These include CAM42, where LAI shows a correlation coefficient with RH of about -0.55 in S_c and S_1, and CAM291 where the coefficient is -0.38 in S_3. However, in general significant correlation between LAI and RH is not shown, even for CAM291. In CAM42, some inverse relationships between LAI and RH seem to occur in S_c and S_1. Therefore the main indication is that some 'random' causes appear only in two sampling areas out of a total of eight (only 3 cases out of a total of 32 by using S_x). Thus the data would indicate that LAI and RH are not associated, at least in the sampled areas.

3.5 Crown transparency and size of fir

3.5.1 Tree height

LAI appears moderately and inversely associated with tree height (H) in transects at CAM (Table 6), except for CAM180, which shows a positive correlation between LAI and H. No correlation is found at VAL except at VAL317 where the correlation is high, negative (r = -0.79), and significant (p-value <0.0001). Thus, a trend of higher transparency of crown with increase of H appears at CAM. In general, results would suggest that various causes may contribute: a) greater rate of longitudinal growth such as in the best site classes; b) differential density of fir stands and variable intraspecific competition; c) greater CT for taller trees, which have crowns more exposed to direct radiation, winds, adverse meteorological conditions, and pollutants.

3.5.2 Tree diameter

LAI tends to be moderately and negatively correlated with diameter (D) in about 60% of transects (Table 6); among them, CAM180 stands out because the correlation is positive. Presence and absence of correlation in transects appear to be equally distributed between CAM and VAL. In other words, it appears that when association between CT and D occurs, higher diameters tend to have higher transparency of crown in both sites.

3.6 Butt rot and relative humidity

The relationship between RH and BR does not show significant correlation in the sub-sections (S_x) of the stem except for two cases. Correlation is positive in S_3 at CAM204 and negative at VAL472, where BR at the centre of the stem increases with decreasing RH in S_3. However, these cases seem to be odd and unlikely to influence the prevalent result. A moderate correlation between BR and RH appears in VAL317 instead, with the level of RH in S_1 and S_2 moderately and positively associated with BR in S_c, S_1, and S_2. On average, no significant correlation (Pearson's r) between RH and BR is observed in most transects (6 out of 8), except for CAM291 (r = 0.66, p-value <0.0001) and VAL317 (r = 0.48; p-value 0.003), that are transects at lower elevation in the respective forests. Moreover, this correlation is also absent at CAM291. Thus, at this stage preliminary results would indicate absence of correlation between intensity of BR and RH with respect to the corresponding S_x.

3.7 Butt rot and size of fir

3.7.1 Tree height

On average, BR and H do not show correlation, with the exception of a moderate correlation at VAL615 (coefficient r is 0.37; p-value is 0.028). Some positive correlations that vary from moderate to low-moderate seem to emerge between H and BR in S_x.

3.7.2 Tree diameter

No association between BR and D occurs in transects, with the exception of few cases, where some correlation appears in individual subsections (S_x). Although larger diameters in silver fir stands tend to correspond to higher growth rates, this result would suggest that silver fir size and rate of growth may be of little importance in the development and/or severity of *BR*.

4. Summary of results

Crown transparency

CT does not appear associated with RH within the stem. It is moderately and positively correlated to diameter in about half of transects and moderately and positively related to the height of fir trees at CAM but not at VAL. The BR average in cross-section of the stem is not associated with the RH average of the stem and even with the diameter. In some cases, a weak positive correlation between BR and tree height occurs in some subsections of the stem. Average RH is not associated with tree height. In some cases, a weak positive correlation with tree height is observed in some subsections of the stem. Association of average RH with diameter is limited except under bark, where it shows very high levels in all the silver fir trees.

5. Unexpected relationships

In the study area, BR shows concerning incidence and frequency (Table 5). Variability of LAI within forests (Table 4) would confirm the LAI as an indicator of stress or viability. Absence or weakness of statistical relationships between CT, BR, and size (Tables 5 and 6) of silver fir prevails in the sampled areas. This feature may indicate significant and important aspects for management and conservation of silver fir forests, especially under increasing climatic-environmental pressure. The poor correlation between CT and BR suggest that CT would be a poor indicator to monitor, estimate, or show the distribution, incidence, and progression of BR in silver fir forests. However, further research is needed to confirm these results, and it may also be necessary to find more indicators to investigate the relationships between CT and BR. The low significance of association between BR and size of silver fir would suggest investigating to a deeper level the possible types of correlation with forest management factors. Another aspect emerging from this research is the weak, or even absent, correlation between RH inside the stem and CT, which would suggest that silver fir trees with higher levels of CT are not necessarily associated with higher or lower humidity of trees. This may also reflect on the estimation of the risk of flammability by CT.

This preliminary research shows results that may have implications for forest management under changing climate conditions. The research explores tree health-environmental relationships in a relatively limited geographical area. Therefore, the relationships observed – perhaps extending to other variables - will need to be confirmed in other forests and regions. For example, the analysis of the distribution of the standard error (Figure 1) would confirm the need for more analysis to identify the type of pattern of interdependence between size of silver fir and RH.

6. Conclusions

This stage of the research directs attention to the monitoring of relationships between widely used tree stress or suffering indicators such as LAI and the symptoms of a severe pathology of silver fir, that is BR. Tree size data were also considered as they are fundamental for forest planning and management. The preliminary results of this research indicate that management of silver fir needs to carefully consider the interactions between type of management, silviculture, and stress factors (i.e., climatic and environmental changes).

6.1 Future research development

The extension of this research to other regions and/or species is critical for the effective monitoring and assessment of the relationships between serious diseases and stress indicators for sustainable forest management, and for the mitigation and adaptation of forest management to impacts of climate change. In this context, future research may be informed by the outcomes of our current research. They can be summarized as follows:

- Verifying the relationships between growth rate and BR at wider scale;
- Monitoring the relationships between growth rate and CT;
- Investigating the distribution and incidence of both BR and CT in relation to forest dynamics;
- Identifying the effects of forest management on the growth rate of silver fir by observing the influence of climate variability during time and vulnerability of silver fir to drought;
- Estimating the degree of flammability in silver fir with respect to fire risk in relation to climate trends, including the humidity in the trunk.

6.2 Aims of future research

The results obtained and future research can contribute to develop types or models of management and silviculture, aiming to:

a) improve the management of pure and mixed silver fir stands to improve stress tolerance and resilience to impacts of climatic and environmental conditions that are highly variable through time;

b) develop predictability models for reduction of growth, wood degradation, and mortality, to aid in forest planning and management;

c) check the distribution of the growth rate for age class, diameter, and social position, condition of the crown and/or incidence and level of wood degradation within the stem in relation to forest dynamics;

d) implement the measurement or estimation of stress indicators and/or symptoms as ordinary practices in forest management.

This would set a database for the identification of relationships between different factors; this can be used to improve points a), b), and c).

Preliminary results and the potential for further research have strengthened our interest and willingness to deepen this research. Thus, the aim would be to verify the relationships between CT, spreading of BR, and mortality rates to develop and apply predictive models of forest dynamism under climatic and environmental impacts (Beck, 2009).

Table 1. UTM coordinates, elevation of each transect, prevailing exposure, and average slope of the transects at CAM and VAL. Elevation is m. asl.

Parcel	*UTM*	*Elevation*	*Exp.*	*Slope*
VAL317	1704930-4846095	824	350°	15%
VAL474	1705447-4845690	914	350°	10%
VAL521	1706428-4845816	1134	344°	46%
VAL612	1705159-4845005	1068	20°	60%
CAM291	1726606-4853128	1054	44°	44%
CAM180	1727816-4853993	1229	256°	74%
CAM204	1726878-4854240	1025	165°	26%
CAM042	1725860-4855237	1147	130°	106%

Table 2. Classification of the level of degradation of BR and the cross section of the stem (S_x) starting from the center (S_c). Intermediate classes in BR are referred to as differences 0.5 (e.g., medium-light BR = 1.5).

Section		*BR*	
%	S_x	*Decay*	*Class*
<5	C	No	<0.5
5-35	1	Light	1
35-65	2	Moderate	2
>65	3	High	3
		Rotten	4
		Incoherent	5

Table 3. Frequency of the presence of BR of grade greater than 2 (BR >2) and greater than 1.5 (BR >1.5) in at least one of the subsections of the cross sections of the stem (S_c, S_1, S_2, S_3) in transects at CAM and VAL.

Transect	*BR >2*	*BR >1.5*
CAM142	61.1%	83.3%
CAM291	52.8%	91.2%
CAM180	36.1%	72.2%
CAM204	11.1%	33.3%
Mean	40.3%	70.0%
VAL472	47.2%	66.7%
VAL615	33.3%	66.7%
VAL521	22.2%	30.6%
VAL317	19.4%	30.6%
Mean	30.5%	48.7%

Table 4. LAI in the transects at CAM and VAL in June 2010. *Mean* is the average value given by the instrument, *transect* is the average value calculated as a mean of individual firs.

	Mean	*Transect*
CAM296	5.4	9.1
CAM180	8.0	8.7
CAM204	5.9	6.6
CAM42	6.9	8.0
Mean	6.5	8.1
VAL317	4.8	5.9
VAL474	5.7	6.4
VAL521	5.6	6.7
VAL628	4.7	5.3
Mean	5.2	6.1

Table 5. Pearson correlation coefficients of LAI compared to RH and BR in transects. RH: mean value; BR: mean value. Correlations that are not statistically significant are indicated by "ns".

	LAI							
	CAM 42	*CAM 180*	*CAM 204*	*CAM 291*	*VAL 612*	*VAL 317*	*VAL 472*	*VAL 521*
RH	-0.41	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
BR	n.s.	n.s.	-0.57	n.s.	n.s.	-0.39	n.s.	-0.36

Table 6. Correlation coefficient (Pearson's r) between LAI, H, D, and SP in transects. The values are averages obtained by the measurement of individual fir trees. The lack of statistical significance shown is as 'ns'.

	LAI							
	CAM 42	*CAM 180*	*CAM 204*	*CAM 291*	*VAL 612*	*VAL 317*	*VAL 472*	*VAL 521*
H	-0.40	0.43	-0.37	-0.47	n.s.	-0.79	n.s.	n.s.
D	-0.41	0.34	n.s.	-0.43	n.s.	-0.35	n.s.	-0.61
SP	0.45	n.s.	n.s.	0.39	0.38	0.51	n.s.	0.73

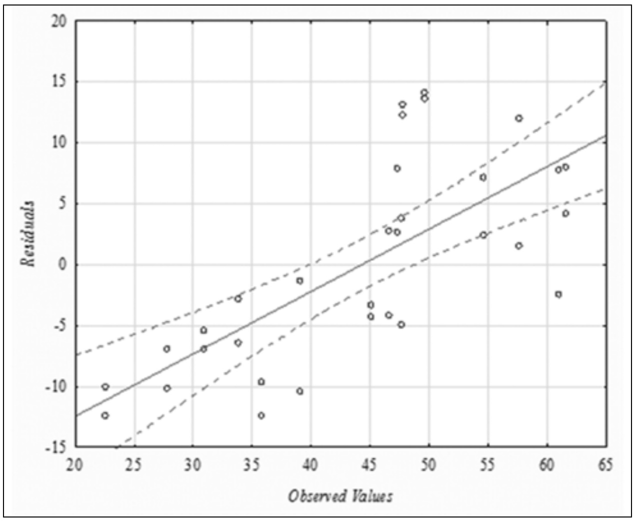

Figure 1. Residual error distribution (y-axis) versus observed values (x-axis) in the multiple linear regression of D (dependent variable) with respect to RH in subsections from S_c to S_3 (independent variables) in transect CAM204.

RIASSUNTO

Trasparenza della chioma e marciume interno del tronco dell'abete bianco (*Abies alba* Mill.) nell'Appennino toscano

La trasparenza della chioma è nota come uno dei principali indicatori di stress o sofferenza degli alberi forestali. Nell'abete bianco (*Abies alba* Mill.) il "cuore bagnato" (patologico) è una grave malattia complessa che affligge la pianta causando un progressivo marciume interno dalle radici al fusto. Tuttavia, la disponibilità di ricerche sulla diffusione ed espansione del "cuore bagnato" nelle foreste di abete bianco e sulle relazioni tra trasparenza delle chioma e "cuore bagnato" appare scarsa, almeno in Italia. Se assumiamo che un'alta trasparenza della chioma indica debolezza e/o stress dell'albero, che può riflettersi anche sull'accrescimento, il "cuore bagnato" può risultare correlato in caso che si manifesti in conseguenza della debolezza dell'albero. Oppure, il "cuore bagnato" può essere una causa primaria della debolezza e/o sofferenza della pianta che porta alla trasparenza della chioma. In entrambe le assunzioni, qualche forma di associazione è probabile che emerga se i due fenomeni sono correlati. Pertanto, abbiamo verificato se qualche relazione è presente tra trasparenza della chioma e "cuore bagnato" in due foreste ad abete bianco sull'Appennino toscano. I risultati preliminari mostrano che il "cuore bagnato" è altamente diffuso nelle abetine (fino al 70% delle piante) ma sembra scarsamente associato alla trasparenza della chioma ed all'umidità relativa interna del fusto; qualche relazione si nota fra dimensioni dell'abete e trasparenza della chioma. Cosi, i risultati preliminari suggeriscono che la trasparenza della chioma può non essere un indicatore adatto della diffusione e gravità del "cuore bagnato" in un contesto dove questa seria malattia colpisce l'abete bianco in modo elevato. Ulteriori ricerche - ed

il monitoraggio - sulla espansione del “cuore bagnato” sono necessarie nell’evidenza dell’alta incidenza della malattia, le sue relazioni con gli stress climatico-ambientali delle foreste di abete bianco, ed gli indicatori adatti per il monitoraggio.

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