BLUE STAIN ON NORWAY SPRUCE – QUALITY LOSS AND EFFECT ON THE STORAGE TIME

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Abstract: *The logistics project "Timber – Network" detected strengths and weaknesses along the timber supply chain - from the producer to the saw mill - and the pulp and paper industry. Fundamental for the harmonization of the timber flow is the communication between the different companies along the supply chain, to ensure the permanent information transfer. Caused by the discontinuous timber supply stock piling occurs on several steps of the supply chain. Quality degrades and quality losses are the results of the long storage times and crop up mainly as blue stain.*
The factors for the infestation and the intensity of the blue stain fungi will be determined. The maximum cycle time is one of the most important input factors for a logistics system reaction time. If the real process cycle time is longer than the maximum cycle time (no blue stain occurs), it's possible to estimate the economic value loss.
The occurrence of blue stain fungi at the forest landings will be determined on spruce (picea abies) sample logs. During the first investigation period "high fungal areas" will be identified. A chemical pretreatment of some sample logs will allow the differentiation between blue stain fungi infested by bark beetles or aerogen fungi. Climatic parameters and wood moisture will validate the favorable conditions for the fungi colonization. Sample sections should help to determine the migration time for the different species.
The second investigation period is necessary to determine the influence of elevation, exposition, harvesting systems….
The results of these investigations should give us the seasonal differences for the quality degrades caused by blue stain. Different parameters should help to estimate the probability of the occurrence of blue stain fungi. The sample section tests will determine the economic quality loss depended of the storage time.

1. Introduction

The forest- and timber industry suffers enormous losses caused by blue stain fungi (Pechmann & Wutz 1963; Andrae 1989; Seifert 1993; Uzunovic *et al.* 1999). The damage of blue stain normally occurs in the sapwood (
) und constitutes just a "cosmetic problem" without appreciable reduction of the technical wood properties (Münch 1907, 1908; Seifert 1993). Nevertheless, blue stained wood means that you'll get much less money. Millonig (1984) estimated these losses after processing in the mills of more than 35 Million Euro per year just in Austria. Financial penalties before the
wood transfer to the mills are not quantified up to now.

Figure1: Blue stain at the sapwood of *Norway spruce*

The blue discoloration of the coniferous wood is caused by many different kinds of fungi inside the species *arcomycetes* and *fungi imperfecti*. (Seifert 1993; Wingfield *et al.* 1993). On round- and sawn wood are mainly the *ascomycetes* species *ceratocystis* and *ophiostoma* the reason for the blue color. (Münch 1907, 1908; Seifert 1993; Butin 1996). The main vectors for the spread of the fungi are bark breeding bark beetles (Figure 2), which live in symbiosis with the fungi, or abiotic, air-borne or by rain splash.

Figure 2: Blue stain origin at the gallery system of the *ips typographus*

Blue stain might occur at the standing stem, for example after infestation of bark beetles or stem damage as result of logging operations. For forestry and timber industry purposes the occurrence of blue stain at the log stores at the forest roads after the felling operation or at the industry mills is the most important damage. (Pechmann & Wutz 1963; Neumüller & Brandstätter 1995; Seifert 1993; Butin 1996; Uzunovic *et al.* 1999).

Due to the timber harvesting operations during the whole year, especially during the mild spring and summer months, when the fungi meets favourable conditions for the infection of the logs, blue stain gets more and more important for the coniferous woodlands of the boreal latitudes. It's a "new" challenge for the timber logistics. The quick timber extraction, the fast hauling and the soon processing in the mills are the effective activities to avoid the blue stain (Butin 1996; Seifert 1993).

The objects of earlier blue stain investigations in Central Europe were different pine species. Though there is a lot of knowledge about blue stain fungi species (Pechmann & Wutz 1963; Pechmann *et al.* 1966; Aufsess 1980), there is a substantial lack of knowledge about blue-stain infestation on *Picea abies*, depending on harvesting date and storage time. This lack of well founded facts, as well as reports from industry and land owners, that losses caused by blue stain increase, gave the reason fort his investigations.

2. Aims of the study

The increment of the loss during the time is an important parameter for every logistics system, because it defines the maximum time span without any damage of the logs. For modeling the timber supply chain it's a decision support system, because it defines the profit cuts depending on the storage time.
Following questions should be answered by the investigations:

- quantify the amount of blue stain in relation to the storage time.
- verify the influence of the harvesting date on the development of blue stain.
- describe geographical differences of the infestation of the round wood with blue stain fungi.
- estimate the relevance of air-borne and beetle vectored blue stain.
- examine the species spectrum of blue stain fungi.
- explain the relation between wood moisture and blue stain.

3. Experimental design

The most important influencing variables for the development of blue stain, the kind of spreading of the fungi (beetle and air-borne) and the seasonal difference of the blue stain are considered as follows:
At four forest companies were realized field experiments with four series (summer / winter, beetle / air-borne):
The first series (winter) were started in March – before the bark beetles starts to fly. The repetition – the summer series started in June. 30 sample logs with a length of 2 meters and a diameter between 20 and 30 cm represented one series.

3.1. Forest companies

To estimate the geographical differences of the fungi infestation dynamic the field experiments were done in four different forest companies.

3.2. Data collection

Solheim (1992) verified that there is no visible discoloration by blue stain during the first two weeks after beetle infestation. The first sampling date, considering the Solheim investigations, is set after 2 weeks storage time, the last after 15 weeks storage (Table 1). Five logs were investigated each sampling date. Considering a fixed sampling scheme, (shown in
Figure 3 und
Figure 4) stem discs were gathered.

Table 1: Sampling dates per series

Sampling date	*Storage time*
sd 1	2 weeks
sd 2	4 weeks
sd 3	6 weeks
sd 4	8 weeks
sd 5	10 weeks
sd 6	15 weeks

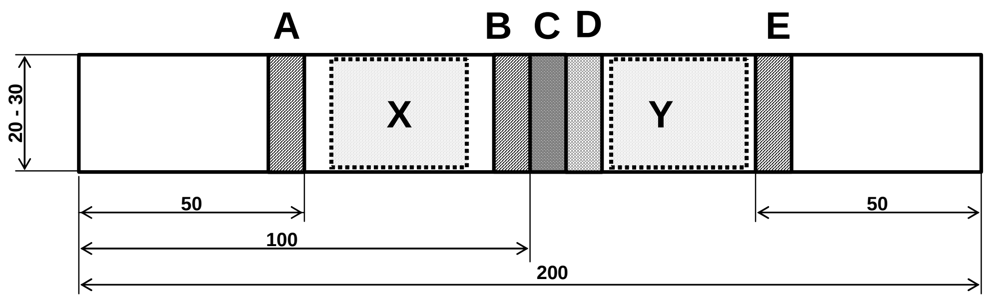

Figure 3: Cutting scheme at the beetle vectored series for the collection of stem discs (A-E) and the bark samples to determine the different kinds of the bark breeding beetles

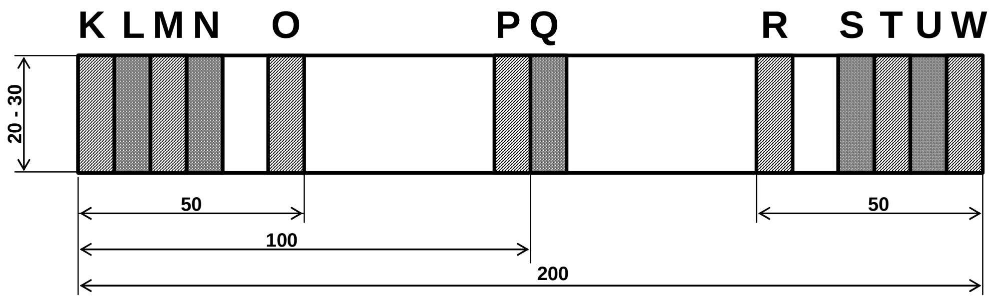

Figure 4: Cutting scheme at the air-borne series for the collection of stem discs (K-W)

The following parameters were determined at the stem discs:

- Damage of the bark.
- Blue stain of the lateral surface.
- Blue stain of the cross sectional area.
- Marking and measuring the sapwood.

The parameter to quantify the flue stain is the rate of the discoloured sapwood area. Each disc was numbered and photographed.

3.3. Data editing

Spectrum of fungi species
The determination of the different fungi species was done at one disc of each log (disc “D” at the beetle and disc “U” at the air-borne logs). The stem discs were split (fixed scheme) at the laboratory. At different radii and fixed distances from the surface, wood splints were extracted and fixed on a malt-agar medium. The fungi built their mycelium and fruit bodies on the culture medium, on which they could be determined.

Moisture
Disc “C” (beetle) and disc “Q” (air-borne) were further examined to determine the wood moisture using the dry kiln method.

Temperature
The temperature at each site was measured hourly and collected by Tiny data loggers. The average daily temperature was used for the further interpretations.

Determine the blue stained area
To describe the quantity of blue stain, the percentage of the discoloured area to the sapwood area had to be figured out. Therefore the images of the cross sections had to be edited with special imaging software. The total area, the heartwood- and the blue stained area were dyed with different colours. To determine the area of the different colours, the software Lucia32 B4.21 for laboratory imaging was used.

4. Results

4.1. Characteristics of the studies

Data were collected from March to October 2003. Totally 4080 stem discs were cut from the 480 invested sample logs. 5000 samples were isolated from the sapwood of the logs in the laboratory to determine the fungi species. 13 different fungi species were found at the beetle series. 5 species were found at the air-borne series (Table 2). *Ceratocystis coerulescens* was absent at the winter series, but most dominant and responsible for the intense blue discoloration at the summer series.

As the main vectors for the fungi spores the following beetles could be identified:

- *Ips typographus*
- *Pityogenes chalcographus*
- *Hylurgops palliatus*

At the summer series the appearance of longicorn (*Cerambycidae*) and snout beeles (*Curcullionidae*) was noted.

Table 2: Isolated fungi species at the beetle vectored and air-borne series

Kind of infestation	*Number of blue stain fungi*	*Dominant species*
beetle vectored	13	*Ceratocystis polonica* *Ophiostoma ainoae* *Ophiostoma bicolor* *Ophiostoma penicillatum* *Ophiostoma piceaperdum*
air-borne	5	*Ceratocystis coerulescens* *Ophiostoma piceae*

The run of the temperature fort he period of investigation depending on the sample site is shown in Figure 5. The location forest company Wittgenstein shows an obvious lower average monthly temperature. Frankenburg and Mayr-Melnhof are nearly indistinguishable. The location of the Esterházy company describes at the beginning of the series higher temperatures, but equals nearly the run of temperatures of Frankenburg and Mayr-Melnhof at the end of the field studies. Esterházy further varies in lower elevation and higher temperatures from the other locations.

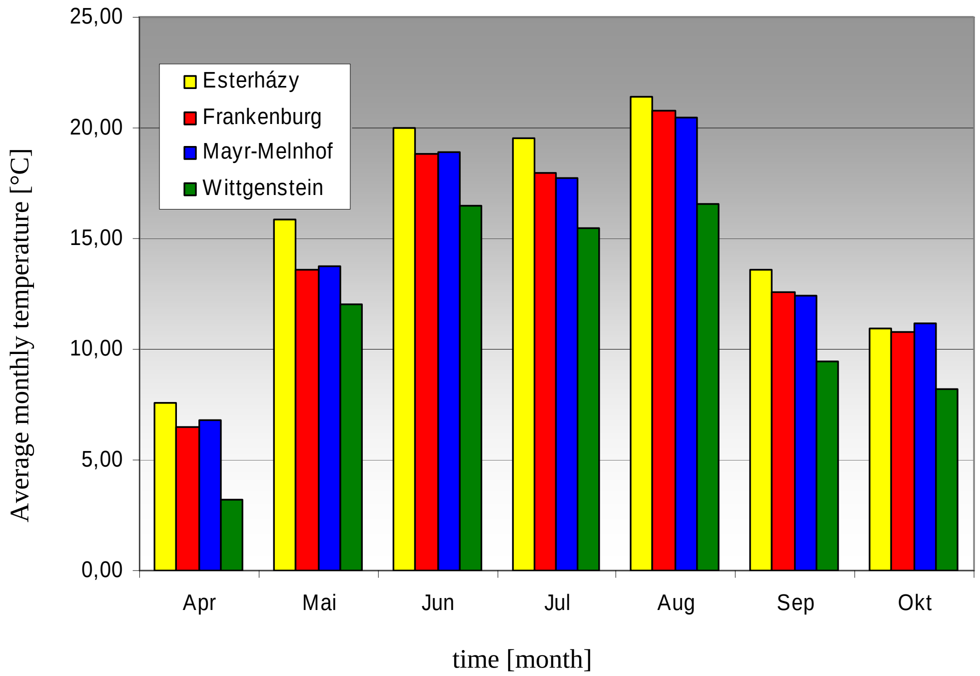

Figure 5: Average monthly temperature for the different locations of the forest companies

The occurrence of blue stain fungi just at the sapwood (Butin, 1996; Kirisits, 1996) causes the usage of the sapwood moisture to interpret the development of the discoloration. The moisture change cross the section is enormous. The heartwood moisture is nearly constant round 30%. The sapwood moisture reaches values up to 140%.

4.2. Development of a blue stain forecast model

A covariance analyses was used to calculate the data with „% blue stained sapwood area“ as the dependent and the aggregated temperature as the independent variable. The influence of the aggregated temperature on the blue stain was significant. The influence of the wood moisture on the intense of the blue stain was not significant. As there are significant differences between blue stain and the summer and winter series it was necessary to develop two different models (shown in equation 1 und 2).

The series air-borne / winter was not considered, because the blue stain ratio up to sample date sd5 was too low.

$$verbl\_1 = -9{,}486 + 0{,}02817 * tempsu\_2 \qquad R^2=0{,}65 \qquad (1)$$

$$verbl\_1 = -8{,}130 + 0{,}0188 * tempsu\_2 \qquad R^2=0{,}81 \qquad (2)$$

verhbl_1..........	blue stained sapwood area [%]
tempsu_2........	aggregation of the daily average temperature from the felling process to the sampling date [dd]

Figure 6 and Figure 7 show the scatter plots for the summer and winter series. Though there is a bigger spread of the values at the summer series, it’s clearer to quantify the blue stain because of the earlier appearance.

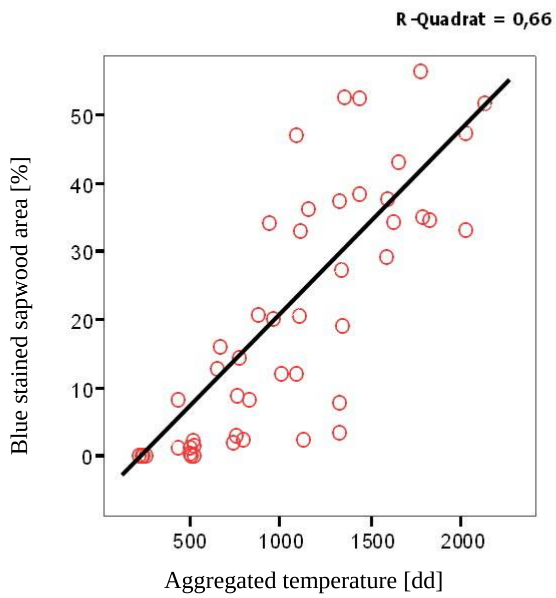

Figure 6: Scatter plot with linear regression of the summer series.

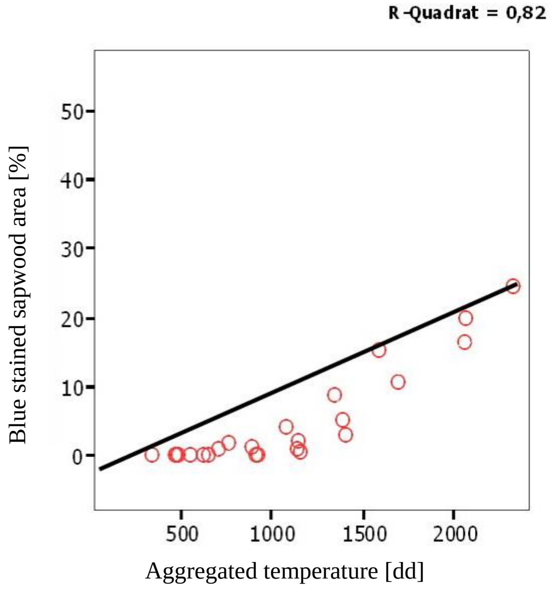

Figure 7: Scatter plot with linear regression of the winter series

Figure 8 shows the critical storage time for spruce round wood at the summer series, depending on the average daily temperature and different threshold values for the blue stain. The maximum storage time without blue stain percentage of more than 5% of the sapwood area decreases with increasing temperature. At 18°C average daily temperature for example, the maximum storage time is around 30 days.

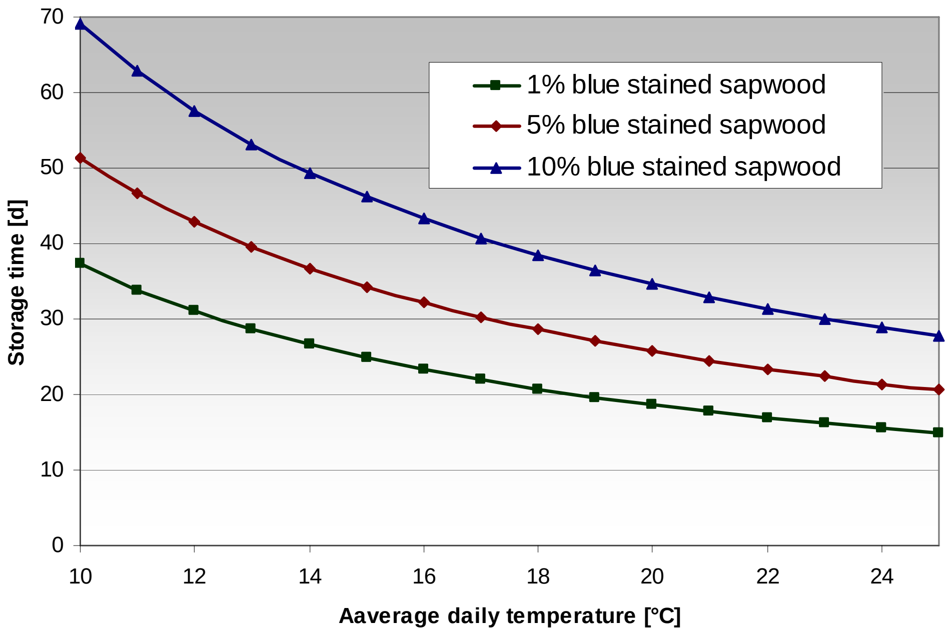

Figure 8: Connection between daily mean temperature and storage time of spruce round wood at different threshold values of blue stained sapwood für the summer series

Figure 9 links the model of the summer series and real temperature data (2006) from 4 climate measurement stations in Styria. They are located in Zeltweg (elevation 675m), Liezen (elevation 665m), Hartberg (elevation 330m) and Deutschlandsberg (elevation 365m). The blue curve shows the storage time until the appearance of blue stain at the minimum of 5% of the sapwood area. The red dashed line describes the average temperature of the 4 climate measurement stations.

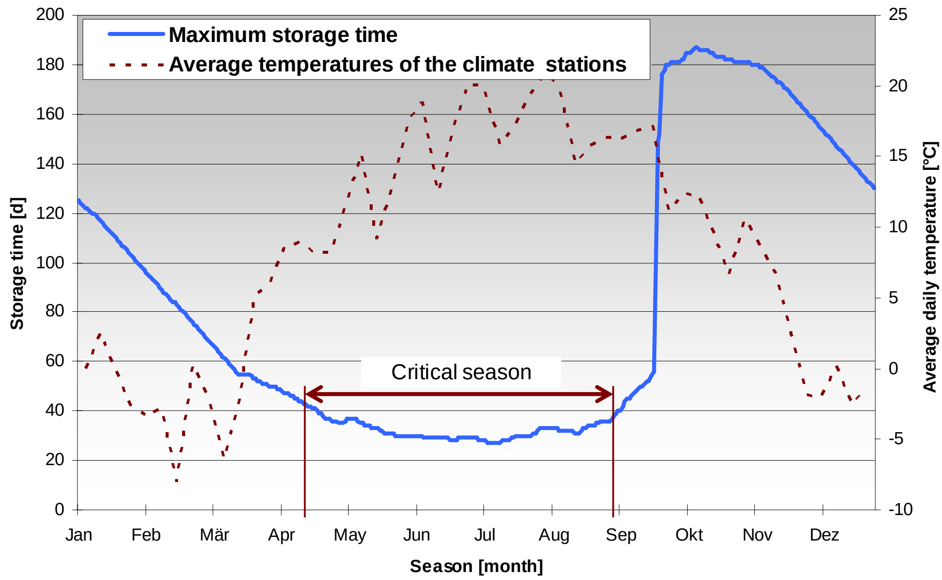

Figure 9: Maximum storage time of spruce round wood depending on harvesting time and percentage of blue stain

5. Important points

- The quantity of blue stain on Norway spruce logs was determined on field experiments, depending on harvest time (summer, winter) the storage time and the kind of spore spreading (beetle vectored, air borne).
- Considering a threshold of 5% blue stained sapwood area, the maximum storage time during the summer months (from May to September) is 3 to 4 weeks.
- There are no significant differences between beetle vectored and air-borne spreading blue stain in the summer series.
- The 5% blue stained sapwood threshold was reached after a 10 weeks storage time.
- The quantity of blue stain is generally higher during the summer months. The maximum blue stain quantity per log averages 50% of the sapwood area.
- There were great differences between the air-borne and beetle vectored series, considering the fungi species spectrum.
- Three bark beetle species were identified as the main vectors for the fungi spreading.

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