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INFECTION OF SCOTS PINE AFFORESTATIONS (*PINUS SYLVESTRIS* L.) BY ANNOSUM ROOT ROT (*HETEROBASIDION ANNOSUM* (FR.) BREF.) IN THE EASTERN GERMAN LIGNITE DISTRICT

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Summary: During the last years an alarming dieback has occurred in 20 to 40 years old first-rotation pine stands (Pinus sylvestris L.) on mine sites, caused by the white rot fungus Heterobasidion annosum (Fr.) Bref. First thinning opens the infection path so that up to now 30 to 89 % of afforestations in different mining areas are affected. Infestation risk increases with rising pH of the top soil (0-30 cm). The mean pH(H_2O) of the infestation foci is 6.2, whereas it is below 5.0 in uninfected stands. Common practise of lime amelioration speeds up the infection. Furthermore, soil water availability (PAWC) has a significant impact on the course of disease. The plant available water (0-100 cm soil depth) of dieback gaps is about 80 mm. In contrast, the water storage capacity of uninfected reference plots falls below 50 mm.

Key words: Pine afforestation, *Annosum* root rot, forest dieback, mine soil, water storage capacity, soil pH

1. INTRODUCTION

In the Eastern German Lignite District (Lusatia) forest reclamation takes up a key position with 30,000 ha. Thereby, dumping of acid sands with poor water and nutrient sorption favours afforestations with unassuming and fast-growing Scots pine (*Pinus sylvestris* L.) [Preußner 1998]. Plantations usually show a good growth but they are considerable overstocked and therefore need urgent silvicultural treatment [Knoche 2001]. However, for several years infestation by the white rot fungi *Heterobasidion annosum* (Fr.) Bref. has caused alarming dieback in first thinning stands [Heinsdorf & Heydeck 1998, Emmrich 2000]. It is evident, that thinning opens the infection route to the pathogen [cp. Low & Gladman 1960, Woodward et al. 1998].

This leads to a silvicultural dilemma by calling well-established stand management models and reclamation strategies into question. On one hand there is an urgent demand of spacing, at the same time this promotes initial infection of residual stumps. To respond in terms of forest protection adequately, an assessment of the site-related infestation risk and especially edaphic factors associated with *Hetrobasidion annosum* is required.

2. RESARCH AREA AND SITE CHARACTERISTICS

The Eastern German Lignite District (Lusatia) is situated within the transition between north-east German lowland and east Saxonian hill and mountainous country. Coal bearing sediments of Miocene are covered by 10 to 150 m voluminous overburden layers which mainly consist of glacial fluvial sands [Nowel et al. 1994, Großer 1998]. The region belongs to the maritime influenced „Lusatian climate“ in transition to the continental minted „South Märkisch climate“ [Kopp & Schwanecke 1994]. Yearly mean temperature is 8.0 to 8.5°C with an amplitude of 19°C. Average annual precipitation varies from 450 to 700 mm; half of the rain falls in the vegetation period.

Conveyer bridge dumps are formed of sands with low water storing capacity containing variable portions of lignite. Mixtures of Quaternary and Tertiary sediments lead to a high and small scale soil heterogeneity. Overall virgin soils are characterised by very low nutrient availability (NPK), biological inactivity and a lack of humus. Furthermore, pyrite (FeS_2) bearing overburden shows a strong release of sulphuric acid, intensive silicate weathering and thus phytotoxic H, Al and Fe concentrations [Katzur 1998, Knoche 2001]. For reclamation an elevation of initial soil pH <3.0 to target pH 5.5 (forestry) and 6.5 (agriculture) respectively is necessary. According to the acid potential up to 300 t ha^{-1} soil active lime (CaO equivalent) are incorporated into the soil prior to cultivation [Knoche & Haubold-Rosar 2004].

Scots pine covers approximately 50% of afforested dump sites (15,000 ha), often planted as pure, even-aged and less structured monocultures with 80% younger than 40 years. Despite low water storing capacity and very special soil chemical properties, average yield class [Lembcke et al. 1975] is between I.0 (excellent growth) and II.2 (good growth), increment reaches almost 9 m^3 ha^{-1} yr^{-1}. However, the over-dense stockings are quite labile [Böcker et al. 1998, Bungart & Hüttl 1999], even if after fertilization vitality of dominating trees is high and mineral nutrition sufficient [Stähr 2003].

3. METHODS

With the dump sites Schlabendorf Nord (SD), Schwarzheide / Schipkau (SH) and the external pile Bärenbrücker Höhe (BB) post-mining areas with quite typical substrates and stocking were chosen for investigations in 2007. Thereby, our recordings refer to approximately 600 ha monostructured Scots pine stands, which represent 4% of the total pine afforestations on mine sites.

30 representative soil profiles were set up to a depth of 100 cm in the centre of dieback gaps. The pathogen was proved by standard microbiological methods [Emmrich 2000]. Gaps were measured beginning at the centre towards the even died bordering trees in segments of 45^{o} (compass rose).

As reference plots 15 soil profiles located in nearby uninfected sections of the stands were taken into account. Thus infected and symptom free stocking have comparable growth parameters such as yield class, number of trees, basal area and stand volume. During the last 15 years some pre-commercial thinning has been performed in all cases, so that initial spore infection of residual stumps is possible [Knoche & Ertle 2007].

For characterising the soil chemical and physical properties, sampling in the layers 0-30 cm, 30-60 cm and 60-100 cm was carried out according to German Soil Classification Scheme [AG Boden 2005]. Table 1 shows a synopsis of parameters, analytical methods and sampling design.

Counting of the soil water storage capacity (SWSC, 0-100 cm soil depth) and plant available water storage capacity (PAWC, 0-100 cm soil depth) were taken on the basis of pore size distribution.

Table 1. Parameters, methods and sampling design for the characterization of soil chemical and physical properties [Knoche & Ertle 2007]

Parameter	Methods	Sampling design
pH value (H_2O, KCl)	DIN ISO 10390	1 composit sample / layer
total C, N, S	DIN ISO 10694, 13878, 15178	1 composit sample / layer
total K, Ca, P, Mg	EPA 3052 DIN EN ISO 11885	1 composit sample / layer
water extract (1:2): K, Ca, P, Mg	HFA 3.2.2.1 DIN EN ISO 11885	1 composit sample / layer
carbonate ($CaCO_3$ + $MgCO_3$)	DIN ISO 10693	1 composit sample / layer
soil texture (7 classes)	DIN 19683-2	1 composit sample / layer
dry density	DIN ISO 11272	5 core cutter (100 cm^3) / layer
water storage capacity, plant available water storage, air storage capacity	DIN ISO 11274	5 core cutter (100 cm^3) / layer

DIN = German Industrial Norm

4. RESULTS AND DISCUSSION

4.1. Infestation situation

As table 2 illustrates about 30% (Schwarzheide / Schipkau, SH) to 90% (Bärenbrücker Höhe, BB) of investigated pine stands suffer from disease. Dieback gaps represent up to 4.8% of the stocking (Bärenbrücker Höhe). Their individual size varies between 8 and 830 m².

Table 2. Survey of Heterobasidion annosum (Fr.) Bref. dieback gaps in first-rotation pine forests on mine sites [Knoche & Ertle 2007]

		Schlabendorf Nord (SD)	Schwarzheide / Schipkau (SH)	Bärenbrücker Höhe (BB)
woodland	ha	141	648	181
pine stands	ha	127	400	62
mean stand age	yr	24	33	26
mean yield class	-	I.3	I.0	I.2
affected stands	ha	80	121	55
dieback gaps	-	50	48	186
total gap area	m²	11,383	7,445	29,692
mean gap area	m²	228 (31-755)	152 (25-830)	159 (8-618)

By way of example disease proceeding is monitored at severe damaged 44 ha Scots pine stands growing up in the south part of the dumping area Bärenbrücker Höhe (BB). As table 3 shows in 1996 first symptoms occur at a stand age of 15 to 19 years. This fact corresponds to the infection biology of the pathogen, since a minimum stem diameter of nearly 10 cm is required for a successful infestation [Morrison & Johnson 1999, Rishbeth 1951].

During the following years a very high disease progress is proved. Within ten years the number of infestation gaps increased by threefold and the whole dieback size raised from 2,350 m^2 (100%) to 19,652 m^2 (838%).

Table 3. Dynamics of infestation by root rot in the investigation area Bärenbrücker Höhe (only south part of the dump, forest cover 73 ha, thereof 44 ha Scots pine, mean stand age 16 years (1996) and 26 years (2006), ex-post-analysis using aerial photographs) [Knoche & Ertle 2007]

	Number	Size of dieback gaps [m^2]			
		Minima	Maxima	Median	Over all
1996	36	17	288	65	2,350
2006	119	16	652	165	19,692
1996-2006	331%	94%	226%	254%	838%

4.2. Site properties

Soil chemical factors

As figure 1 illustrates there is a close realationship between soil reaction and stand affection by root rot. The average pH(H_2O) of the top soil (0-30 cm) infestation gaps is 6.2 whereas pH of reference profiles is below 5.0. In contrast equal reaction conditions can be found in a soil depth of 30-100 cm in both, infestation gaps and reference plots. Increased pH values in the top soil of disease gaps refer to the application of highly reactive lime (non hydrated lime (CaO, CaO + >15% MgO), slaked lime ($Ca(OH)_2$)), which is amelioration practice for sulphuric acid dump substrates [cp. Katzur 1998]. Nowadays, conventionally used limestone ($CaCO_3$) does not exceed a pH >6.5, even by overdosing and inhomogeneous distribution [Knoche & Haubold-Rosar 2004]. Despite the very low carbonate content, at least there is a significant relation between infestation risk and $CaCO_3$ concentration (Figure 1). No carbonate was found in the reference profiles but the infestation plots show maximum 1% (top soil) to 3% (sub-soil).
These findings point out, that soil reaction has a determining effect on the incidence of root rot, whereas top soil pH >6.0 is considered as critical. Numerous papers confirm this correlation for first-rotation pine forests growing on former agricultural sites [Rishbeth 1951, Froelich et al. 1966, Evers 1973].

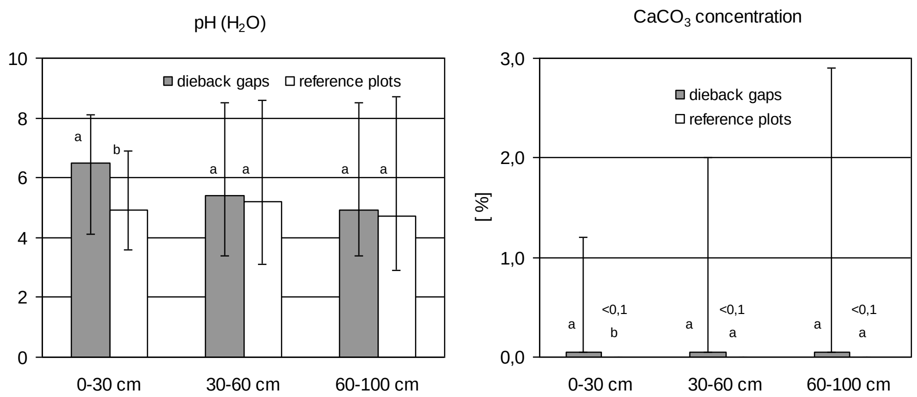

Figure 1. pH(H_2O) and $CaCO_3$ concentrations of dieback gaps and reference plots in 0-30 cm, 30-60 cm and 60-100 cm soil depth [median, minimum, maximum, n = 30 (dieback gaps) and n = 15 (reference plots), Mann-Whitney U test, p >0.05] [Knoche & Ertle 2007]

Other soil chemical parameters (see Table 1) have no significant influence on the infestation risk [data in Knoche & Ertle 2007].

Soil physical factors

The mainly sandy, partly clay and loam clumpy dump substrates (sand fraction >90% mass) have, with 23.7 to 35.5% a very high volume of air-filled soil pores (>50 µm equivalent diameter). Aeration is therefore within the optimum for forest plant growth of 20 to 30% [AK Standortskartierung 1996]. There is no evidence that rooting gets inhibited by soil compaction or insufficient aeration [Knoche & Ertle 2007].

However, because of the high macropore volume, the average plant available water storage capacity is, with 37 mm to 80 mm in 100 cm soil depth, quite low (Figure 2). As xylem flux measurements point out, drought stress in summer months with poor precipitation is probable [Scherzer 2001]. According to Towers & Stambaugh [1968] and Alexander et al. [1975] limited water supply is considered to be a further susceptible factor beside a high top soil pH. For example >70 % mass sand fraction in the top soil considerably endangers root rot in Loblolly pine stands (*Pinus taeda* L.) [Morris & Frazier 1966]. However, our results prove that within the entire spectrum of sandy substrates extremely dry sites show a less infection risk. The mean plant available water storing capacity of all dieback gaps is approximately 80 mm, whereas it is below 50 mm at the symptom-free reference plots (Figure 2). May be the pathogen finds unfavourable infestation conditions on markedly dry soils.

Finally, it needs to be stated that neither soil texture nor skeletal fraction or soil density correlate significantly to the infestation situation [data in Knoche & Ertle 2007].

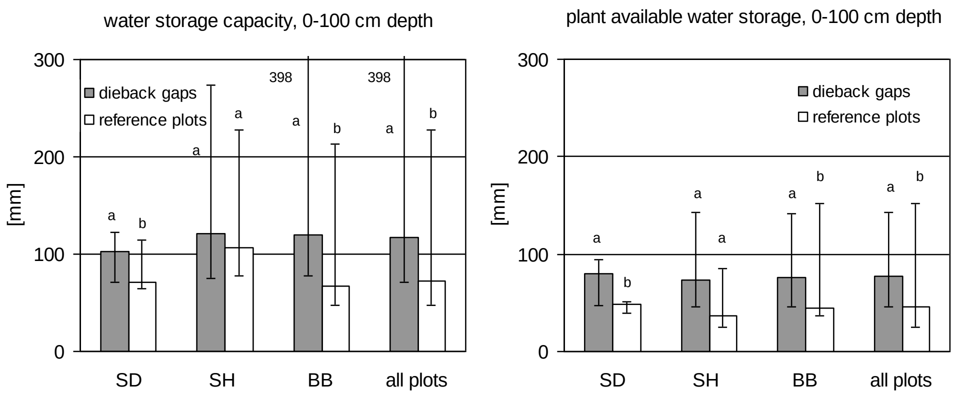

Figure 2. Water storage capacity (0-100 cm) and plant available water storage (0-100 cm) of dieback gaps and reference plots [median, minimum, maximum, n = 30 (dieback gaps) and n = 15 (reference plots), Mann-Whitney U test, p >0.05], SD = Schlabendorf Nord, SH = Schwarzheide / Schipkau, BB = Bärenbrücker Höhe (Jänschwalde), all plots [Knoche & Ertle 2007]

5. CONCLUSIONS AND SILVICULTURAL ADVICES

Apart from root rot risk it should be kept in mind that first-rotation pine stands on mine sites have a quite high biomass increment [Böcker et al. 1999]. The production of high value timber seems profitable, because of a pronounced slender branch and tree top related tree growth. However, in the course of upcoming first commercial thinning the infestation situation probably will get out of control, since spreading of the pathogen corresponds with thinning intensity [Powers & Verrall 1962, Vollbrecht & Agestam 1995, Vollbrecht et al. 1995]. Taking into account the site-related infection risk, preventive silvicultural treatment strategies are suggested, corresponding to common forest management guidelines and practice:

5.1. Treatment variant 1 / Pine stands which are free of symptoms or have moderate susceptibility to infestation (mean top soil pH(H_2O) <5.5)

For these stands the production of high value timber has priority. By elite tree oriented selective thinning many access points for stump infection are created. Despite moderate susceptibiliy punctual infestation risk may increase. Therefore, additional silvicultural measures of disease control are recommended especially to protect residual elite trees. Stump treatment by the application of highly competitive fungi especially *Phlebiopsis gigantea* (Fr.) Jülich [Rishbeth 1957, Greig 1976, Redfern et al. 1994, Heydeck 2000, 2005] is proved to be very effective. In addition, cuttings should be done only in wintertime when air temperature is below 0^{o}C. Under these weather conditions airborne basidiospores of the pathogen are marginally detectable, thereby eliminating colonization of freshly cut stumps [Brandtberg et al. 1996].

5.2. Treatment variant 2 / Stands with dieback symptoms or high disease risk (mean top soil pH(H_2O) 5.5-7.0)

To control damage progress a space-differentiated management strategy is proposed. Choosing the elite trees in symtom-free parts of the stands a safety clearance of at least 20 m towards existing root rot centres without any thinning should be adhered. A stump protection using antagonistic preparates is obligatory in order to avoid new disease gaps [Greig 1976]. On the other hand, recent investigations on containment of root contact infection show, that quarantine stripes can be initiated by application of the highly effective biological control agent PgIBL [Pratt et al. 2000]. This kind of sanitation thinning around root rot gaps seems to prevent spread of the pathogen [Sierota et al. 2007]. However, effectiveness of those measures depends on an early infestation diagnosis.

5.3. Treatment variant 3 / High-grade endangered and already collapsing stands (mean top soil pH(H_2O) >7.0)

Stands on high-risk soils very often show rapide coalesce of disease centres and heavy secondary damage (bark breeding beetles, wind throw). Further thinning is counterproductive, because hereby new access points for infection by root rot occur. Therefore, forest conservation by converting diseased stands to mixed forests with root rot tolerant species is coming first. As far as substrate properties permit and to avoid clear-felling, subsequent underplanting of site-adapted species should be carried out. Suitable admixtures on sandy to loamy sandy mine soils are broadleaves like *Robinia pseudoacacia* L., *Betula pendula* Roth., *Quercus robur* L., *Quercus petraea* (Matt.) Liebl., *Tilia cordata* Mill., *Carpinus betulus* L. and *Fagus sylvatica* L., arranged in the order of increasing soil moisture and nutrient supply [Knoche 2001].

Small and isolated dieback gaps (<0.10 ha) do not need underplanting, because natural regeneration is going on. For example, secondary succession of *Quercus petraea* and *Quercus robur*, which is silviculturally useable, is evidend in a distance of 1,000 m to the next seed dispender [Thomasius et al. 1999]. The required numbers of seedlings for an adequate quality of the next forest generation is about 3,000 plants ha^{-1} [Wünsche & Selent 2000].

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INFEKCJA ZADRZEWIEŃ SOSNY ZWYCZAJNEJ (*Pinus sylvestris* L.) WYWOŁANE PRZEZ KORZENIOWCA WIELOLETNIEGO (*Heterobasidion annosum* (FR.) BREF.) W OKRĘGU WYDOBYWCZYM WĘGLA BRUNATNEGO WE WSCHODNICH IEMCZECH

Streszczenie

W ostatnich latach wystąpiło niepokojące zjawisko zamierania 20-40 letnich sosen (*Pinus sylvestris* L.) pierwszej rotacji na terenach pokopalnianych, spowodowane przez korzeniowa wieloletniego (*Heterobasidion annosum* (Fr.) Bref.). Pierwsze przerzedzenie otwiera drogę zakażenia tak, że do tej pory objęło ono od 30 do 89% zadrzewień na różnych obszarach pogórniczych. Odnotowano wzrost ryzyka infekcji wraz ze wzrostem odczynu powierzchniowego poziomu gleb (0-30 cm). Średnia pH(H_2O) z ognisk zakażenia to 6,2, podczas gdy na powierzchniach niezakażonych wyniosła poniżej 5,0. Powszechną praktyką zahamowania tempa zakażenia jest wapnowanie gleb. Ponadto, na przebieg choroby znaczący wpływ wywiera dostępność wody w glebie (PAWC). Dostępna woda dla roślin (0-100 cm głęb.) na obszarach zamierania to ok. 80 mm. W przeciwieństwie, na obszarach nie zainfekowanych zdolność zatrzymywania wody spada poniżej 50 mm.