White rot fungi in living Norway spruce trees at high elevation in southern Norway with notes on gross characteristics of the rot

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Abstract

Norway spruce suffers from serious root and butt rot problems from sea level up to the timber line in Norway. In this paper the most common fungi causing white rot is presented with special notes on gross characteristics of the rot. During the meeting we visited a stand near the timberline where logging was ongoing. Isolations were done from nearly hundred rotten logs and the results are presented.

Introduction

Norway spruce [*Picea abies* (L.) Karsten] suffers from serious root and butt rot problems that cause great economic losses also in the Nordic countries. Various wood-rot fungi are agents of this disease (Bendz-Hellgren *et al*. 1998). In 1992, a survey on the occurrence of butt rot on Norway spruce was undertaken in Norway (Huse *et al.* 1994); 5000 forest owners counted the rot on spruce stumps in newly-cut stands and identified roughly, according to instructions given by the Norwegian Forest Research Institute, the decay agent on the basis of rot type. The survey revealed that 27.8 % of the trees had butt rot, and that the dominating rot type was that caused by *Heterobasidion annosum* s.l. while *Armillaria* rot was less common. Both *Heterobasidion* and *Armillaria* are root rot fungi, while the most serious wound-rot fungus in Norway spruce is *Stereum sanguinolentum* (Roll-Hansen & Roll-Hansen 1980; Solheim & Selås 1986). Also other fungal species may cause butt rot of Norway spruce and be damaging in certain areas, particularly if final harvesting is delayed. This paper describes the most common white rot fungi in old Norway spruce at high elevation with notes about gross characteristics of the rot.

Heterobasidion parviporum Niemelä & Korhonen

Heterobasidion parviporum is the most common rot fungus in the natural distribution area of Norway spruce in Norway, whereas *H. annosum* (Fr.) Bref. *s.s.* seems to occur infrequently on Norway spruce in this area (Korhonen *et al*. 1998; Solheim, unpublished). Based on observations in Sweden and Finland, only *H. parviporum* would be expected to occur at high altitudes in Norway (Korhonen *et al*. 1998). At the west coast, where Norway spruce does not occur naturally, *H. annosum* is the only *Heterobasidion* species found in spruce plantations. (Solheim 1996; Heggertveit & Solheim 1999). The two species of *Heterobasidion* behave similarly in Norway spruce, but the decay caused by *H. parviporum* tends to rise higher up in the stem (Vasiliauskas & Stenlid 1998).

Heterobasidion infects wounds and freshly cut stumps. Further spread takes place along roots and from tree to tree via root contacts or grafts. Stumps have been mentioned as the main entrance of infection in stands, but in Norwegian studies also summer-time wounds on the lower part of stem are rather frequently infested by *Heterobasidion*. Roll-Hansen & Roll-Hansen (1980) found that 12 out of 72 Norway spruce trees wounded in July (17 %) were infested by *Heterobasidion*, while none or only a few trees were infested after wounding in May, September or December.

The rot in its advanced stages is typical white pocket rot. Incipient rot is straw-coloured to light brown, and in more advanced stages it becomes darker. In the heartwood, the first sign of the presence of *Heterobasidion* rot is a violet-stained wood called aniline wood. This stain may be seen as a ring around the rot in the heartwood (Fig. 1) or as spots in the light-brown incipient rot. In advanced rot short black streaks or specks are seen, which are accumulations of manganese oxide; also other white rot fungi can accumulate it (Blanchette 1984). Also white specks often occur, and sometimes the black specks are surrounded by white ones. The black and white specks are easily seen in longitudinal or radial cuts (Fig. 2).

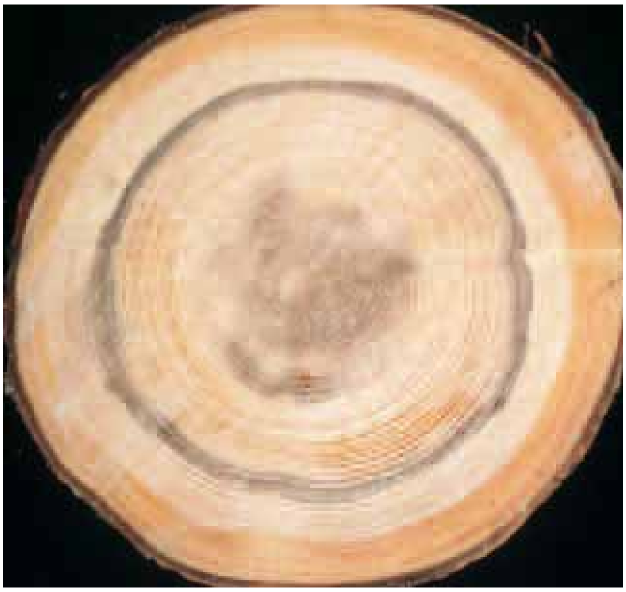

Fig. 1. A typical aniline wood ring surrounding the incipient Heterobasidion *rot in the heartwood of Norway spruce. Photo: H. Solheim*

Fig. 2. Black and white specks seen in a longitudinal cut of Norway spruce with Heterobasidion *rot. Photo: H. Solheim*

When the rot reaches the sapwood, the living cells react trying to stop further spreading of the fungus towards the cambium. This reaction zone is well described by Shain (1972). In fresh cuts it is nearly invisible, but there may be a weak light brownish colour. When oxidized it turns darker, greyish brown to olive brown, often with a greenish tint (Fig. 3). The rot column can rise high up in the stem, I have seen a 12-m-high column, but columns between 4 and 7 m are most common.

Fig. 3. A reaction zone surrounding Heterobasidion *rot in Norway spruce. Note the dry zone between the reaction zone and sapwood. Photo: H. Solheim*

Armillaria borealis Marxmüller & Korhonen

The *Armillaria* species are well-known saprophytes on all kinds of wooden material, but they can also act as pathogens on stressed trees, bushes etc. Young trees can be killed rather fast, while older trees may fight for many years. The crowns of attacked Norway spruce trees can become more and more yellow, while the shoots will be shorter and shorter until the trees die from the top. This occurs now and then in connection with summer drought in the southern part of Norway (Solberg *et al*. 1992).

Two species of *Armillaria* are common in Norway (Solheim & Keca, unpubl.). *Armillaria borealis* is the most common species and seems to be distributed all over Norway. *Armillaria cepistipes* Velenovsky is also common and has been found at least up to Trøndelag in the north. *Armillaria ostoyae* (Romagn.) Herink has for certain been found only once in Norway, but it is rather difficult to distinguish this species from *A. borealis*, and no one has looked for it in young pine stands where it locally occurs e.g. in Finland (Korhonen 1978). *Armillaria ostoyae* is usually darker, bigger, and has larger scales than *A. borealis* (Pegler 2000). Also genetically *A. borealis* and *A. ostoyae* are closely related (e.g. Sicoli *et al*. 2003). No comprehensive studies of the *Armillaria* species have been undertaken in Norway, but based on material in our herbaria and isolation studies at Skogforsk only *A. borealis* is found higher than 400 m a.s.l.

Armillaria species are agents of root and butt rot on various tree species and rather common on Norway spruce (Huse *et al*. 1994). In Norway, *A. borealis* is the most common *Armillaria* species associated to butt rot of spruce (Heggertveit & Solheim 1999, Solheim & Keca, unpubl.), and at high elevation it may be the only *Armillaria* species. However, there are no studies on this.

Armillaria species are not very aggressive pathogens of spruce, and the decay mostly keeps inside the heartwood. Incipient decay is grey to brown, often with a water-soaked appearance (Morrison *et al.* 1991). Yde-Andersen (1958) reported a yellowish colour in the early stage of decay, with caramel brown spots, and often short, dark cracks emanate from the medulla. Bacteria were often isolated from this stage. More advanced rot also often occurs as small spots (Fig. 4). Later on most of the heartwood may be decayed and rather soon totally destroyed. We call this «hullråte» («hollow rot») in Norwegian. Black sheets of hard fungal tissue (pseudoclerotial plates) are often observed in *Armillaria* rot (Greig *et al.* 1991). Other microorganisms may occur together with *Armillaria* rot, and often the colour is dark, nearly black (Roll-Hansen 1969). In Norwegian we call this «svartråte» («black rot») (Fig. 5). A combination rot with *Armillaria* and *Heterobasidion* is often observed. *Armillaria* rot usually reaches only a height of 1–2 m in the stem while *Heterobasidion* continues further up (Fig. 6).

Fig. 4. A small spot of Armillaria *rot on stump no. 5. Photo: H.Solheim*

Fig. 5. «Black rot» / «hollow rot» associated with Armillaria*. All the wood has disappeared in the centre, but the knots are left. Photo: H. Solheim*

Stereum sanguinolentum (Alb. & Schwein.) Fr.

This species is a wound specialist on Norway spruce, and it seems that every wound, from root to top, is vulnerable for infection. Usually the rot keeps inside the annual ring that is formed in the year of wounding. *Stereum* rot may be more common on Norway spruce than the stump investigations tell us. A small rot spot on stump may be an indication of root rot growing upwards, but it may also be a sign of *Stereum* rot growing downwards from a wound formed higher up on the stem (Fig. 7).

Fig. 6. A Norway spruce tree with a combination rot. Armillaria *has removed most of the wood up to the height of ca. 1 m, while* Heterobasidion *rot extends up to ca. 9 m. Photo: H. Solheim*

Fig. 7. A small spot of Stereum *rot on stump no. 3. Photo: H. Solheim*

S. sanguinolentum rot is typically a pale brown, stringy rot, but the colour may vary. Young rot is very homogenous and is separated from sound wood only by light brown or reddish brown colour. More advanced rot is also rather homogenous, but it may crack along the annual rings. A thin layer of whitish mycelium can be seen in the cracks. According to my observations the *S. sanguinolentum* rot it is always darker than *Heterobasidion* rot, sometimes the colour is almost chocolate brown. I have never seen white pockets or black specks in association with *S. sanguinolentum* rot. However, according to Cartwright & Findlay (1958), *S. sanguinolentum* rot is like other *Stereum* rots: It starts as a reddish-brown rot, turns eventually into a white pocket rot, and ends as a white stringy rot. In the sapwood, and in cases where the rot is progressing from heartwood to sapwood, a similar zone can be observed as the reaction zone surrounding *Heterobasidion* rot (Fig. 8). The colour is greyish green or has a violet tone. In wounds infested by *S. sanguinolentum* the bleeding fruit bodies may be found.

Fig. 8. Decay caused by S. sanguinolentum *16 years after wounding. The rot is kept inside the wood created before the year of wounding. A reaction zone can be seen in the sapwood outside the rot. Photo: H. Solheim*

Important factors for infection are wound size and depth, but also the wounding season. The annual fruit bodies are produced in the autumn, and millions of spores are released into the air. *S. sanguinolentum* is a strong wound colonizer and may also infect older wounds. At least Vasiliauskas *et al* (1996) found a positive correlation between wound age and infection of *S. sanguinolentum*. In a survey of Norway spruce damaged by deer in Western Norway 16 % of the wounds were infested 5–7 years after wounding, while 39 % of the trees with 15 to 20-year-old wounds were infected with *S. sanguinolentum* (Veiberg & Solheim 2000).

Climacocystis borealis (Fr.) Kotl. & Pouzar

This species may cause root and butt rot in old forest at all altitudes. Fruit bodies are usually not seen before trees are dead, when hundreds of fruit bodies may be seen on the lower stem and on roots (Fig. 9). The fruitbodies are, when young and in humid weather, rather watery which has given the Norwegian name «vasskjuke» («water polypore»). The colour of young fruit bodies is whitish, while later the conks turn yellowish and rather hard.

The borealis rot is very characteristic white mottle rot. Incipient rot is light brown, later it may be more reddish-brown (Fig. 10). The rot is rather uneven. At a closer look, the rot is cubic with white mycelium in between (Fig. 11). The cubes are much finer (1–2 mm) than those of typical cubical brown rot. *Climacocystis borealis* has a strong reaction for laccase (Käärik 1965).

Fig. 9. Numerous fruitbodies of C. borealis *on a killed standing Norway spruce tree in Ormtjernkampen national park. Photo: H. Solheim*

Fig. 10. End of a log (no. 11 at Kittelbu) with C. borealis *rot. Note the zone surrounding the rot. Photo: H. Solheim*

Fig. 11. Characteristic rot caused by C. borealis *with small cubes and white mycelium. Photo: H. Solheim*

Infection takes place through wounds on roots and lower part of the trunk. The rot is typical heartwood rot and seldom reaches a height more than 2–3 m. Sometimes the sapwood is also attacked, and in places where the fungus reaches the cambium fruit bodies may be seen even on living trees. A greyish-green or greyish-violet zone may be seen surrounding the rot (Fig. 10).

Phellinus chrysoloma (Fr.) Donk

This fungus is common in old Norway spruce forests, and may be the most common cause of rot in some stands at high elevation, as reported by Juul & Jørstad (1939) from Dragås, Midtre Gauldal, Sør-Trøndelag. A brief survey in a Norway spruce stand in Lierne, Nord-Trøndelag, some years ago revealed that *P. chrysoloma* was as common as *Heterobasidion* (Solheim, unpubl.). Also in the spruce stand that we visited near Kittelbu (see below) this species was isolated from more logs than any other rot fungus. However, surveys have very seldom been undertaken in stands at high elevation, and hence we have no reliable data about the frequencies.

P. chrysoloma infests mostly through broken branches and tops, but also through wounds. The mostly perennial fruit bodies develop often at the point of original infection, on branch stubs or elsewhere on the trunk where the fungus has reached the cambium, but they are more frequent on stumps and fallen logs (Fig. 12). The fruit bodies are rather hard and vary much both in size and form. The pores are angular.

Fig. 12. Wind thrown Norway spruce with fruitbodies of P. chrysoloma. *Photo: H. Solheim*

The rot is a white pocket rot, but may be rather variable. White cellulose patches are typical; they appear in large numbers at a certain stage of rot (Fig. 13). Eventually they turn into holes that may grow together, this resulting in a honeycombed or long-fibred appearance at the ultimate stage of decay (Jørstad & Juul 1939). The white patches are similar to those observed in *H. parviporum* rot, but bigger and often more numerous. Also black specks are associated with *P. chrysoloma* rot. They are rather thin, more like lines (Fig. 14).

Fig. 13. A longitudinal cut of P. chrysoloma *rot with the characteristic white, rather large pockets. Photo: H. Solheim*

Fig. 14. Black lines in rot caused by P. chrysoloma. *Photo: H. Solheim*

At first the rot keeps in the heartwood, but rather soon it expands to the sapwood. Then a zone similar to the *Heterobasidion* reaction zone occurs. Its colour is dirty violet (Fig. 15), and in some places a dark brown zone is seen in the rotten area just inside the «reaction zone» (Fig. 16). The rot spreads easily in Norway spruce and may occupy most of the trunk. Jørstad & Juul (1939) refer to an 11-m-high tree where the rot had spread more than 8 m up. Korhonen (personal comm.) measured in southern Finland a 25-m-high Norway spruce tree where *P. chrysoloma* decay extended from the base up to the height of 22 m.

Only a 3-cm-thick layer of the outer sapwood was sound, but externally the spruce looked relatively healthy.

Fig. 15. Rot caused by P. chrysoloma *with a dirty violet zone surrounding it. Dark brown lines are separating different individuals of the fungus. Photo: H. Solheim*

Fig. 16. A cross section of a rotten area caused by P. chrysoloma *with the dark brown zone which may be seen now and then just inside the «reaction zone». Photo: H. Solheim*

Inonotus leporinus (Fr.) Gilb & Ryv.

Three closely related species of *Inonotus* are rare in Norway and red-listed (Direktoratet for naturforvaltning 1999). *Inonotus tomentosus* (Fr.) Teng has straight setae, and the fruitbodies are typically stipitate to substipitate and mostly found associated with root of conifers. The two others species have curved setae. *Inonotus triqueter* (Fr.) Karst. attacks Scots pine trees and has probably been found only once in Norway and, in addition, a few times in southern Finland and Sweden. It is more common further south in Europe (Ryvarden & Gilbertson 1993). *Inonotus leporinus* is red-listed both in Norway and Sweden (Larsson 1997) but seems to be more common in Finland (Kotiranta & Niemelä 1996). In Norway this species is the most common of the group and more than 100 specimens have been collected, two-third during the last ten years. Most of the samples in southern Norway is collected above 500 m asl. It causes a basal white pocket rot in Norway spruce. The rot occurs mostly in the roots, and extends seldom more than a few meters up. It may reach the cambium in big roots and at the lower part of the stem, where many of the annual fruitbodies may be seen (Fig. 17). I have seen only incipient rot, which is rather light brown. More advanced rot is very similar to *P. chrysoloma* according to Jørstad & Juul (1939), and sometimes also a dirty violet zone surrounding the rot has been observed.

Fig. 17. The author is looking at fruitbodies of I. leporinus *at the lower stem of a living Norway spruce. Photo: N. Keca*

Rot in an old Norway spruce stand near Kittelbu

During the SNS meeting for Nordic and Baltic forest pathologists we visited a stand belonging to Statsskog near Kittelbu, in Gausdal municipalty, Oppland county. The altitude was between 850 and 900 m asl, and the timber line in that area is around 1050 m asl. Logging in the stand was going on, and the cut timber was sorted in two piles, one with timber of good quality, and a smaller pile with timber of secondary quality, mostly affected by rot. The participants were walking around in the forest where some stumps had been marked, and they also visited the pile with rotten logs (Fig. 18). A sheet of paper with pictures of the marked stumps and logs were handed out, and the participants were requested to discuss and «guess» the cause of rot in each occasion. However, it is not always easy to identify the rot type, especially based on horizontal cuts (stump surfaces or log ends). It may be easier if cuts can be made along the fibres. *Stereum*- like mycelium was isolated from stumps/logs no. 1, 3, 4 and 12. *Heterobasidion parviporum* was isolated from logs no. 10 and 13. *Climacocystis borealis* was isolated from logs no. 9 and 11. *Armillaria* mycelium was isolated from stump no. 7. A slow-growing mycelium with clamps was isolated from the log no. 8.

Fig. 18. Part of a pile with rotten log ends. C. borealis *was isolated from log no. 63;* H. parviporum *was isolated from logs no. 72 and 78;* P. chrysoloma *was isolated from logs no. 71, 74 and 82; S.* sanguinolentum *was isolated from log no. 66. Photo: H. Solheim*

After the SNS-meeting I visited the site again and I brought with me samples from nearly hundred logs. The most common rot agent was *P. chrysoloma* followed by *H. parviporum* and *S. sanguinolentum* (Table 1). As mentioned above, *P. chrysoloma* may be rather common in some stands at high elevation in Norway. Björkman *et al*. (1949) noted that this species could be the most common rot fungus in old and relatively intact spruce stands in the inner part of Norrland, Sweden.

In southern Norway the timber line is mostly between 1000 m and 1100 m asl. The same species of white rot fungi is found in the low land as near the timberline. However, some species seem to be more common at high elevation. The cause of that may partly be climatic. Important may also be that cuttings are more difficult and expensive at high elevation so we have more old growth forest at high elevation.

Table 1. Number of samples of each wood rotting fungus- from piles at Kittelbu (98 logs)

Wood rotting fungus	Number
Armillaria spp	12
Climacocystis borealis	13
Heterobasidion parviporum	25
Phellinus chrysoloma	36
Stereum sanguinolentum	24
Basidiomycetes spp.	13

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