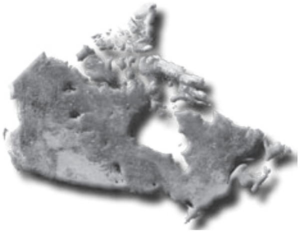


An Annotated Bibliography on the Effect of Bluestain on Wood Utilization with Emphasis on Mountain Pine Beetle-Vectored Bluestain

Tony Byrne, Kathy L. Woo, Adnan Uzunovic
and Paul A. Watson

Mountain Pine Beetle Initiative
Working Paper 2005–4

Natural Resources Canada, Canadian Forest Service,
Pacific Forestry Centre 506 West Burnside Road, Victoria, BC V8Z 1M5
(250) 363-0600 • www.pfc.cfs.nrcan.gc.ca

Natural Resources Canada | Ressources naturelles Canada

Canada

Canada

Mountain Pine Beetle Initiative
Canadian Forest Service

An Annotated Bibliography on the Effect of Bluestain on Wood Utilization with Emphasis on Mountain Pine Beetle-Vectored Bluestain

Tony Byrne, Kathy L. Woo, Adnan Uzunovic and Paul A. Watson

Mountain Pine Beetle Initiative
Working Paper 2005–4

PAPRICAN

PULP AND PAPER RESEARCH INSTITUTE OF CANADA
3800 Westbrook Mall
Vancouver, British Columbia V6S 2L9

Forintek Canada Corp.

FORINTEK CANADA CORP.
2665 East Mall
Vancouver, British Columbia V6T 1W5

Natural Resources Canada
Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, British Columbia
Canada
V8Z 1M5

2005

Printed in Canada

Table of Contents

Abstract 5

Acknowledgements 5

Introduction 5

Summary: Effects of bluestain on wood properties and the

utilization of solid wood products 6

Summary: Effects of bluestain on pulp and paper properties 7

Section 1. Mountain pine beetle and associated fungi – general

biology 9

Section 2. Effects of bluestain on wood properties and the 19

utilization of solid wood products 19

Section 3. Effects of bluestain on pulp and paper properties 47

An Annotated Bibliography on the Effect of Bluestain on Wood Utilization with Emphasis on Mountain Pine Beetle Vectored Bluestain

Tony Byrne[1], Kathy L. Woo[2], Adnan Uzunovic[1] and Paul A. Watson[2]

[1]Forintek Canada Corp., Vancouver, BC, Canada
[2]Pulp and Paper Research Institute of Canada, Vancouver, BC, Canada

Abstract

This bibliography provides a summary of studies on the effect of bluestain fungi on wood quality and forest products, particularly studies relevant to the bluestain vectored by the mountain pine beetle, *Dendroctonus ponderosae*. The references are given in three sections: 1) mountain pine beetle and associated bluestain fungi, 2) bluestain and solid wood utilization, and 3) bluestain and pulp quality. Research on the biology of the associated bluestain fungi is evolving and there is now a solid body of scientific literature on this subject. In terms of bluestain and solid wood there is little specifically on mountain pine beetle-killed lodgepole pine with the exception of some recent work on lumber properties. Recently killed bluestained lodgepole pine appears to be sound but may pose a marketing problem in some markets because of its colour. References on the dryness of trees initially induced by bluestain fungi are given. The splits and checks that occur as the trees dry cause processing problems and volume and grade recovery are reduced. These references are old and the modern economics of producing products from dry logs are unknown Due to substantial reduction in moisture content, bluestained wood generates more pins and fines during chip production. Literature detailing the effects of mountain pine beetle-associated bluestain on pulp quality is limited and the results are inconsistent In general, kraft pulping studies have suggested that pulp yield and paper strength properties are not significantly affected by bluestain. Mechanical pulp produced from bluestain wood exhibits acceptable quality; however, brightening costs are expected to be significantly affected, as bluestain pulp is more difficult to bleach.

Acknowledgements

Dr. Colette Breuil, Department of Wood Science, University of British Columbia, reviewed the document and contributed helpful comments, particularly on the biology of the MPB and the nomenclature of its fungal associates in Section 1. Barb Holder, librarian at Forintek Canada, assisted Tony Byrne in obtaining references for Section 2. Judith Mackenzie and Janice Dudas from the Pulp and Paper Research Institute of Canada assisted in obtaining citations for Section 3.

This project was funded by the Government of Canada through the Mountain Pine Beetle Initiative, a six-year, $40 million Program administered by Natural Resources Canada, Canadian Forest Service. Publication does not necessarily signify that the contents of this report reflect the views or policies of Natural Resources Canada – Canadian Forest Service.

Introduction

British Columbia is in the midst of the largest outbreak of the mountain pine beetle ever recorded. Mature lodgepole pine stands are under attack, particularly in the southern and central Interior. In 2003, the beetle had attacked an additional 173.5 million m^3 of mature lodgepole pine, which is a 60% increase over 2002. Furthermore, the beetle was threatening the remainder of the approximately 1 billion m^3 of mature pine in the province of British Columbia (Council of Forest Industries Mountain Pine Beetle Task Force 2003). Without sufficiently cold weather to check the spread of the beetle, the epidemic continues to grow and shows no sign of abatement.

The mountain pine beetle carries several specific bluestain fungi that lower wood moisture content and weaken tree-defense mechanisms, eventually leading to tree death. Bluestain develops quickly in the sapwood of dying trees and this bluestain carries over into products made from stained logs. This stain has implications for the use of these products. The trees also dry rapidly and check badly as the drying stresses are relieved. This also has implications for use of the logs.

The Canadian Forest Service requested that Paprican/Forintek/University of British Columbia compile a synthesis of available literature examining the impact of bluestain on the use of wood for major forest products. The format suggested was an annotated bibliography which is presented here. This bibliography is in three sections: 1) Mountain pine beetle and associated bluestain fungi, 2) Effects of bluestain on wood properties and the utilization of solid wood products , and 3). Effects of bluestain on pulp and paper properties. Because the bibliography is presented in annotated format, the references are listed in alphabetical order with key points noted under the references. Literature that specifically covers mountain pine beetle-associated bluestain and its effects on wood and pulp properties are in **bold text**.

Because the effects of bluestain on wood depend on the specific fungi concerned Section 1 of this bibliography contains key references to the biology of the mountain pine beetle and its associated fungi. This section is not meant to be a comprehensive review of the subject but sufficient to summarize what is known about the fungal associates of the mountain pine beetle. Much of this work is relatively recent and has considerably advanced our knowledge of the fungal associates of the mountain pine beetle.

Summary: Effects of bluestain on wood properties and the utilization of solid wood products

Throughout the world, bluestain is one of the major causes of loss in value of conifer timber, especially pine. Bluestain is always associated with sapwood and never, or very rarely, affects the heartwood. There is a modest amount of literature on the effect of (generic) bluestain on the properties of solid wood products, but these effects are thought to depend on the type of wood and specific fungus causing the bluestain. Some bluestain fungi, particularly tropical species cause decay, but most studies indicate that bluestain does not significantly affect the solid wood properties of temperate pine species. The two exceptions to this is that the permeability of the sapwood is increased and there are mixed reports of loss in impact bending strength mentioned in the general literature on the effects of bluestain. There are few studies on the specific stain associated with mountain pine beetle and its effects on wood properties and the studies are confined to wood sawn from trees shortly after attack. These were done recently by Forintek Canada Corp. in order to obtain data on the effect of the bluestain on lodgepole pine wood properties. These studies indicate no significant impairment of strength or gluing properties and confirmed that the permeability of the sapwood is increased. Bluestain is not desirable in most appearance-grade products. Although not regarded as a defect in most construction-grade solid wood, an excess of stain may make marketing of the wood more difficult.

A secondary effect of the bluestain fungi, the dryness of the mountain pine beetle-killed wood, poses technical challenges to wood use. Seasoning checks develop as the standing dead trees dry further, and the checks lead to splits in the solid wood produced. Dry wood requires more energy to process, is more brittle, and is liable to break during harvesting and log and lumber processing. Because of checking, more part-sheets of veneer result from rotary peeling. Also reviewed are key references about the use of dead standing trees, particularly pines. Frequently the cause of death of these trees is beetle infestation; for western pines, the mountain pine beetle is the most common cause of extensive tree death. The research reported in these papers generally shows that solid wood products can be made from standing dead lodgepole pine trees as long as the bark has not yet sloughed off. However the references are old and the modern economics of producing products from dry logs are unknown. Work on both southern and lodgepole pines clearly shows that secondary beetle attack, the onset of decay within the stems, and breakage will reduce product recovery and value with time. This has implications for determining the “shelf-life” of mountain pine beetle killed stands, a current subject of debate in the interior of British Columbia. Additionally there are many problems and costs in harvesting dead wood.

Summary: Effects of bluestain on pulp and paper properties

Pulp producers could potentially be the largest recipients of bluestained wood from mountain pine beetle-killed trees over the long term. The pulping and pulp properties of beetle-affected softwoods has been a source of much research since the early twentieth century. Due to substantial reduction in moisture content, bluestained wood generates more pins and fines during chip production. Literature detailing the effects of mountain pine beetle-associated bluestain on pulp quality is limited and the results are inconsistent. Moreover, existing studies on the evaluation of mechanical and chemical pulping of bluestained wood show wide variation in pulp quality. A majority of the papers suggest that trees that have been dead for up to two years can be used for kraft pulping without affecting pulp yield or paper properties, but in order to take – full advantage of this resource, rapid removal and processing of this material is required. Mechanical pulp produced from bluestained wood exhibits acceptable quality: however, brightening costs will be significantly affected, as bluestained pulp is more difficult to bleach. Owing to the nature of the pulpwood supply in British Columbia, we have also included selected key references on the use of dead wood in pulping. Such grey-stage wood will detrimentally affect both kraft and mechanical pulping operations and pulp quality.

Section 1. Mountain pine beetle and associated fungi – general biology

Prior to the Upadhyay monograph's publication in 1981 and the review of Seifert *et al*. (1993) on the accepted species of *Ceratocystis* and *Ophiostoma*, there were many conflicts over the use of these names. Given this, it is important for researchers to do their homework and verify the appropriate description. Furthermore, many fungus species vectored by different beetles have been synonymized. Recently, researchers have shown that some of these species are physiologically and molecularly distinct (Kim *et al*., 2003).

1. Ayer, W.A.; Browne, L.M.; Feng, M.C.; Orszanska, H.; Saeedi-Ghomi, H. 1986. The chemistry of the blue stain fungi: Part 1. Some metabolites of *Ceratocystis* species associated with mountain pine Beetle Infected Lodgepole Pine. Canadian Journal of Chemistry 64(5): 904–909.

Data are presented on the metabolites formed in culture by *C. clavigera, C. ips,* and *C. huntii* (three of the four species associated with bluestain). The complex formed by chelation of iron with 2,3-dihydroxybenzoic acid may be partly responsible for the bluestaining of the sapwood of diseased lodgepole pine [*Pinus contorta* var. *latifolia*].

Note: The dark bluish colour associated with bluestain fungi is usually attributed to the presence of the polymer melanin in the fungal cell walls and not to chelates. The Ceratocystis *species listed are now recognized as* Ophiostoma.

2. Ballard, R.G. 1982. The pathogenicity of blue-stain fungi on lodgepole pines attacked by mountain pine beetle. PhD diss., Utah State University, Logan, UT, USA. 89pp.

In the western regions of North America, mountain pine beetle *Dendroctonus ponderosae* Hopk. infestations take a tremendous toll on pines, especially lodgepole pine, *Pinus contorta* Dougl. var. *latifolia* Engelm. Mass attack by the beetles is a devastating event for the trees. As well as girdling the tree, a massive inoculation of bluestain fungus "complex" (composed of several species of *Ceratocystis*, numerous yeasts, and other mycelial fungi) is made beneath the bark. These fungi colonize and destroy the parenchyma tissue system of the host sapwood, primarily the ray parenchyma and resin-duct epithelium. A blue-coloured stain is produced in the sapwood as a consequence of destruction of the sapwood parenchyma. The stain develops inward through the sapwood, and the transpiration stream is cut off. As more and more sapwood is stained, foliar water stress increases. Foliage however, remains green and apparently healthy for up to 10 months after inoculation. When spring bud break begins the year following beetle attack, terminal buds of blue-stained trees begin to expand, and then abort. Soon after, the needles of these trees fade to a reddish-brown color. Transpiration-stream disruption was not caused by penetration of tracheids by fungal hyphae; tyloses were not observed; nor were microconidial blockage of bordered pits seen. Although the resin-duct epithelium was eventually destroyed, little resin soaking was observed in the initial bluestained regions. Many bordered pits of tracheids in stained regions appeared to be aspirated, suggesting introduction of embolisms.

Note: Microscopic evaluations completed at Paprican confirmed the presence of trabeculae in the longitudinal tracheids immediately adjacent to the cambium, which is indicative of fungal attack.

3. Ballard, R.G.; Walsh, M.A.; Cole, W.E. 1982. Blue-stain fungi in xylem of lodgepole pine: a light microscope study on the extent of hyphae distribution. Canadian Journal of Botany 60: 2324–2341.

This preliminary report examines distribution of the fungi in the secondary xylem and phloem of *Pinus contorta* var. *latifolia*[1] at the time of tree death. In midsummer, mountain pine beetles emerge from lodgepole pine trees and fly to unattacked trees. While chewing and producing vertical egg galleries in the inner bark of the tree, they inoculate into it a bluestain fungus complex. Initially, the fungi are confined to the beetle frass of the egg gallery, but they soon grow into the sapwood. The fungi spread radially via the parenchyma of the xylem rays. Once established in the xylem rays, fungal hyphae move into the tracheids of the axial water-conducting system. Here they occlude bordered pit pairs and occasionally the entire lumen of the cell. Fungal hyphae also attack and destroy resin-duct epithelial cells. This may result in release of resin into surrounding tissues. Destruction of storage and water-conducting tissues in the tree trunk is detrimental to renewed shoot-tip expansion the following spring.

4. Ballard, R.G.; Walsh, M.A.; Cole, W.E. 1984. The penetration and growth of blue-stain fungi in the sapwood of lodgepole pine attacked by mountain pine beetle. Canadian Journal of Botany 62: 1724–1729.

The growth of bluestain fungi was investigated in naturally bluestained lodgepole pine (*Pinus contorta* var. *latifolia*) sapwood. Events occurring at the leading edge of hyphal penetration were studied. Fungi are initially confined to the sapwood rays. Hyphae readily penetrate the primary cell walls of ray parenchyma cells and proliferate within. Hyphae also grow freely in the region of the middle lamella of the rays. Host cell walls breached mechanically by a penetration peg originating from an apressorium-like structure. Eventually, hyphae enter tracheids by penetrating the primary cell walls of pinoid, half-bordered pit pairs. Within the tracheid, fungal hyphae grow in a longitudinal fashion, branching infrequently. Hyphae may pass from tracheid to tracheid via bordered pit pairs. Ensuing water stress and eventual tree death is discussed in light of histological evidence presented.

5. Bergvinson, D.J.; Borden, J.H. 1992. Enhanced colonization by the blue stain fungus *Ophiostoma clavigerum* in glyphosate-treated sapwood of lodgepole pine. Canadian Journal of Forest Research 22(2): 206–209.

The study was conducted in a healthy 80-year-old lodgepole pine (*Pinus contorta* var *latifolia*) stand in British Columbia. Two experiments were conducted to assess the effect of glyphosate application (in July 1986) on the size of the lesion produced in response to inoculation of sapwood around the root collar with *Ophiostoma clavigerum*. Lesions in the sapwood were longer and wider in trees treated with glyphosate before inoculation with *O. clavigerum* than in untreated, control trees. A third experiment was conducted in 1988 to determine whether lesion size was associated with fungal colonization. *O. clavigerum* was recovered at seven-times-greater distance from the point of inoculation in trees treated with glyphosate three weeks before inoculation than in untreated, control trees. It is concluded that previously observed enhancement of brood development of the mountain pine beetle (*Dendroctonus ponderosae*) was caused by glyphosate-induced inhibition of the trees' secondary defense response to invasion by the beetle's symbiotic fungi.

6. Fox, J.W.; Wood, D.L.; Akers, R.P.; Parmeter, J.R. Jr. 1992. Survival and development of *Ips paraconfusus* Lanier (Coleoptera: Scolytidae) reared axenically and with tree-pathogenic fungi vectored by cohabiting *Dendroctonus* species. Canadian Entomologist 124(6): 1157–1167.

[1] The names of species (with or without authorities) and word spellings (e.g., color *vs* colour) used in this bibliography are generally given as used as found in the publication reviewed.

The survival and development of *Ips paraconfusus* larvae reared individually in intact *Pinus ponderosa* phloem without associated fungi and dietary supplements was demonstrated. Survival was reduced in intact ponderosa pine phloem previously occupied by other larvae or by bluestaining fungi (i.e. *Ophiostoma ips* vectored by *I. paraconfusus*; *O. minus* vectored by *Dendroctonus brevicomis*; *O. clavigerum* vectored by *D. ponderosae*; and *Leptographium terebrantis* vectored by *D. valens*) compared with those reared without fungi or symbiotic yeasts. The highest proportion of larvae initiating tunnels and surviving to adulthood was observed for untreated eggs, and the lowest proportion occurred in the *L. terebrantis* treatment. Size was reduced and the development rate was slower for larvae reared without fungi compared with larvae reared with associated fungi. Tunnels excavated by first and second-instar larvae reared without associated fungi were longer than those excavated by larvae reared with associated fungi. The most frequent larval turnabouts occurred with larvae reared axenically and reared with *Ips* yeast and *O. ips*. The fewest occurred with larvae reared with *Ips* egg niche-plugs and from untreated eggs. Females reared free of any fungi or with *Penicillium* or *Aspergillus* did not oviposit in surface-sterilized logs of *P. ponderosa*. Naturally enclosed females from logs of *P. ponderosa* in which they developed, laid eggs in these sterilized logs. The potential for a new association among bark beetles and fungi is discussed.

7. Kim, J.J.; Kim, S.H.; Lee, S.; Breuil, C. 2003. Distinguishing *Ophiostoma ips* and *Ophiostoma montium*, two bark beetle-associated sapstain fungi. FEMS Microbiology Letters 222(2): 187–192.

Two synonymous sap stain species, *Ophiostoma montium* and *Ophiostoma ips*, which are vectored by *Dendroctonus ponderosae* and various bark beetles, respectively, were differentiated into separate species using growth and molecular characteristics. Analysis of 32 isolates of the two species from different countries showed that *O. ips* was able to grow at 35°C while *O. montium* was not. This growth-based differentiation was strongly supported by sequence data for the internal transcribed spacer (ITS), 5.8S and partial 28S rDNA, and the beta-tubulin genes. The beta-tubulin gene sequence data indicate that the two species can easily be differentiated with a single polymerase chain reaction (PCR) assay.

8. Lee, S.; Kim, J.J.; Fung, S.; Breuil, C. 2003. A PCR-RFLP marker distinguishing *Ophiostoma clavigerum* from morphologically similar *Leptographium* species associated with bark beetles. Canadian Journal of Botany 81(11): 1104–1112.

Ophiostoma clavigerum, carried by *Dendroctonus ponderosae* and *Dendroctonus jeffreyi*, has morphological characteristics that are similar to other *Ophiostoma* and *Leptographium* species. The partial beta-tubulin gene of 45 strains belonging to seven species was amplified by PCR and digested by the restriction enzyme HinfI. The specific restriction fragment length polymorphism obtained for *O. clavigerum* provided the means for its reliable identification. We are also reporting that *O. clavigerum* ascocarps have short necks; this fact has not been shown previously.

9. Mathre, D.E. 1964. Pathogenicity of *Ceratocystis ips* and *Ceratocystis minor* to *Pinus Ponderosae*. Contributions from Boyce Thompson Institute 22: 363–388.

Mechanism of pathogenicity studies showed that water is conducted around but not through infected areas of sapwood. Infected areas were dry. Disruption of the transpiration stream usually took place 0 to 6 mm in advance of the fungi. Histological and histochemical tests for plugging substances in infected sapwood were negative. While a plugging substance was isolated from culture filtrates of *Ceratocystis ips* and *Ceratocystis minor*, plugging tests with water extracts of infected sapwood and nonconducting sapwood from inoculated trees were so variable that an artifact in these tests is suspected. Inoculation of limbed trees showed that, although little upward water movement occurred, sufficient water moved radially through the sapwood to produce drying. No evidence was found for phloem-translocated toxin. The evidence appears to favour a theory that the mechanism of pathogenicity of *C. ips* and *C. minor* involves entry of air into the sapwood causing permanent breakage of the water columns.

Note: *The* Ceratocystis *species listed are now recognized as* Ophiostoma. O. ips *is not an associate of the mountain pine beetle* (O. ips *was probably* O. montium).

10. Nevill, R.J.; Safranyik, L. 1996. Effects of neem seed extract on the growth of fungal associates of mountain pine beetle. Journal of the Entomological Society of British Columbia 93: 129–130.

This study investigated the fungal effects of neem seed extract, active ingredient azadirachtin, on *Ophiostoma clavigerum* (Robins. Jeff. & Davids) and *Ophiostoma ips* (Rumb.), the fungal associates of the mountain pine beetle, *Dendroctonus ponderosae* Hopk. When added to malt extract agar, concentrations of 100 ppm significantly reduced the growth of both fungal associates, and concentrations above 250 ppm killed both fungi.

11. Nevill, R.J.; Safranyik, L. 1996. Interaction between the bluestain fungal associates of mountain pine and pine engraver beetles (*Dendroctonus ponderosae* and *Ips pini*, Coleoptera: Scolytidae), and their effects on the beetles. Journal of the Entomological Society of British Columbia 93: 39–47.

The authors investigated the potential antagonism between the fungal associates of the pine engraver and mountain pine beetles. They measured and compared their rates of growth in bolts of lodgepole pine and in living trees: *Ophiostoma ips* from *Ips pini* against *O. clavigerum* from *Dendroctonus ponderosae*. They measured the length of lesions shown by discolored xylem, but found both fungi outside of visibly stained areas, which showed that mere staining is not a reliable indicator of the full extent of fungal growth. There were no significant differences in brood development or survival between the two beetle species/specimens when bolts were inoculated with either fungal associate.

12. Paine, T.D.; Hanlon, C.C. 1994. Influence of oleoresin constituents from *Pinus ponderosa* and *Pinus jeffreyi* on growth of mycangial fungi from *Dendroctonus ponderosae* and *Dendrotonus jeffreyi.* Journal of Chemical Ecology 20(10): 2551–2563.

Dendroctonus jeffreyi and *D. ponderosae* are morphologically similar sympatric species of pine bark beetles over portions of their geographic ranges; however, *D. jeffreyi* is monophagous on *P. jeffreyi* while *D. ponderosae* is highly polyphagous. Both species carry species of mycangial fungus that are also very similar in appearance. Growth of the two mycangial fungi and of the fungi *Leptographium terebrantis* (associated with the poly-phagous and non-tree-killing *Dendroctonus valens*) in the presence of oleoresin constituents of host and nonhost conifers was tested by placing individual chemicals on agar growth medium and by growing the cultures in saturated atmospheres of the chemicals. The fungus associated with *D. jeffreyi* showed greater tolerance for chemical constituents placed on the growth medium than the other two fungi, and growth after three days was enhanced by heptane, which is the dominant constituent of *P. jeffreyi* oleoresin. Growth of all three species of fungi was reduced by the resin constituents when the chemicals were presented as saturated atmospheres. The results suggest that the influence of the tree on growth of the symbiotic fungi of the bark beetles during the initial attack process may be different than after colonization by the beetles is complete. The difference in the responses of the apparently related species of mycangial fungi may provide new insight into the evolutionary history of these beetle – mycangial fungus – host tree systems.

13. Reid, R.W. 1961. Moisture changes in lodgepole pine before and after attack by the mountain pine beetle. Forestry Chronicle 37(4): 368–375.

The moisture content of the outer sapwood of non-infested lodgepole pine is normally about 85 to 165% of oven-dry weight. In trees that have been infested by the mountain pine beetle for one year, the sapwood moisture content can be as low as 16%. There is a steep moisture gradient from about 160% in the outer sapwood to about 30% in the heartwood. The moisture content in the centre is slightly higher than in the adjacent wood. In infested trees, the sapwood moisture is greatly reduced within a year after the attack, but moisture in the heartwood is not altered appreciably. Trees infested early in the season drop to a lower moisture content by fall than do trees infested later in the season. In non-infested trees, there is a diurnal and a seasonal moisture march; these do not occur in infested trees. The rapid moisture loss in the sapwood of infested trees is associated with bluestain infection and successful establishment of the bark-beetle broods.

14. Reid, R.W.; Whitney, H.S.; Watson, J.A. 1967. Reactions of lodgepole pine to attack by *Dendroctonus ponderosae* Hopkins and blue stain fungi. Canadian Journal of Botany 45: 1115–1125.

The reaction in lodgepole pine in response to attack by *Dendroctonus ponderosae* and subsequent infection by bluestain fungi varies with the degree of resistance manifested by the tree. In both resistant and successfully attacked trees a sequence of changes, which increase in space with time, occurs in the inner bark and sapwood. In resistant trees, a condition termed secondary resinosis develops which is lethal to bark-beetle broods and blue stain fungi. In contrast, successfully infested trees do not exhibit secondary resinosis, and bark-beetle broods and bluestain fungi survive and complete their development. In resistant trees, bluestain fungi are responsible, directly or indirectly, for the extensive reaction and condition of secondary resinosis which is associated with the insect gallery. Changes in stem tissues associated with wounding are discussed.

15. Robinson, R.C. 1962. Blue stain fungi in lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) infested by the mountain pine beetle (Dendroctonus *monticolae* Hopk.). Canadian Journal of Botany 40: 609–614.

A complex of fungi was isolated from lodgepole pine (*Pinus contorta* Doug. Var. *latifolia* Engelm.) at various stages of mountain pine beetle (*Dendroctonus monticolae* Hopk.) attack. *Ceratocystis montia* Rumb., *Leptographium* species, *Pichia pini* (Holst) Phaff, *Hansenula holsii* Wickerham, *Hansenula capsulata* Wickerham, and some unnamed yeasts were isolated from beetles, fresh galleries, and bluestained sapwood. Perithecia of *C. montia, Ceratocystis minor* (Hedgc.) Hunt, *Certocystis minuta* (Siem.) Hunt, *Ceratocystis* species, and *Euphorium* species were found on the bark and in sapwood of dead, bluestained trees. Beetles are conclusively shown to be vectors of bluestain fungi. The known ranges of *C. montia* and *P. pini* are extended by this study; and a possible succession of organisms associated with the development of beetle infestation is discussed.

16. Rumbold, C.T. 1941. A blue stain fungus, *Ceratostomella montium* N. Sp., and some yeasts associated with two species of *Dendroctonus*. Journal of Agricultural Research 62(10): 589–601.

The fungus that is disseminated by bark beetles *D. ponderosae* and *D. monticolae* when they infest pines is *Ceratostomella montium*. It is doubtful whether *C. montium* will spread from the mountain forests, for in artificial culture this fungus does not tolerate high temperatures. It has been found to grow best at a temperature of 16°C, and grew well between 12°C and 22°C. The beetles also carry with them two types of yeast, which are an anascosporous mycelium-forming group and *Zygosaccharomyces pini*.

Note: Ceratostomella montium *is now called* Ophiostoma montium.

17. Safranyik, L.; Shrimpton, D.M.; Whitney, H.S. 1975. An interpretation of the interaction between lodgepole pine, the mountain pine beetle and its associated blue stain fungi in western Canada. Pages 406–428 *in* D.M. Baumgartner, ed. Management of Lodgepole Pine Ecosystems: symposium proceedings held October 9–11, 1973 at Washington State University, Pullman, WA, USA. Washington State University Cooperative Extension Service, Pullman, WA, USA.

Describes the relation between *Pinus contorta* and *Dendroctonus ponderosae* with its associated bluestain fungi (*Ceratocystis montia* and *Europhium clavigerum*). Climatic variables that affect this relation are identified and a map of hazard ratings for western Canada is presented based on these variables. Methods are outlined for reducing losses from attacks by *D. ponderosae*.

18. Seifert, K.A.; Wingfield, M.J.; Kendrick, W.B. 1993. A nomenclator for described species of *Ceratocystis*, *Ophiostoma*, *Ceratocystiopsis*, *Ceratostomella* and *Sphaeronaemella*. Pages 269–287 *in* M.J.Wingfield, K.A Seifert, and J.F. Webber, eds. Ceratocystis and Ophiostoma: Taxonomy, Ecology, and Pathogenicity. American Pyhtopathological Society, St.Paul, MN, USA.

This book discusses the morphological taxonomy of the ophiostomatoid fungi, including their anamorphs. Non-morphological taxonomic approaches are considered, including genetic, biochemical, developmental, and molecular characters. The pathological aspects are introduced and reviews of a variety of insect vector systems and host responses to both the insects and the fungi are included. A few chapters include information on methods for handling ophiostomatoid fungi as well as a key for their identification.

19. Shrimpton, D.M.; Whitney, H.S. 1968. Inhibition of growth of blue stain fungi by wood extractives. Canadian Journal of Botany 46: 757–761.

Resistance by lodgepole pine to invasion by bluestain fungi is affected by an initial flow of oleoresin followed by a gradual impregnation with resinous substances of the tissues adjacent to the wound. The addition of such resinous sapwood to growth media caused inhibition of growth, whereas non-resinous sapwood enhanced growth; however, extracts from both resinous and nonresinous sapwood caused inhibition of bluestain fungi. Volatile components in the extracts were responsible for this inhibition.

20. Shrimpton, D.M. 1973. Extractives associated with wound response of lodgepole pine attacked by the mountain pine beetle and associated microorganisms. Canadian Journal of Botany 51: 527–534.

Extractive changes that occur in the sapwood of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Englm.) in response to attack by the bark beetle (*Dendroctonus ponderosae* Hopk.) and associated microorganisms were studied. The most striking change was a large increase in total terpene to levels well above that normally observed in sapwood or heartwood. Free acids, phenolics, and neutral components increased to a final concentration that was about the same as that in heartwood, but at a much slower rate than terpenes did. Free sugar levels decreased. With the single exception of ß-phellandrene, no unusually high or unusually low levels of any one compound were observed in the wound response. All components found in the wound response were normal constituents of heartwood.

21. Shrimpton, D.M. 1978. Resistance of lodgepole pine to mountain pine beetle infestation. Pages 64–76 *in* A.A. Berryman, G.D. Amman, R.W. Stark and D.I Kibbee, eds. The Theory and Practice of Mountain Pine Beetle Management in Lodgepole Pine Forests: symposium Proceedings held April 25–27, 1978 in Moscow, ID, USA. University of Idaho, Forest Wildlife and Range Experiment Station, Moscow, ID, USA .

This paper discusses the possible relationships between the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) and the physiological processes of the lodgepole pine (*Pinus contorta* Douglas var. *latifolia* Engelmann) stem that act to heal wounds of the type caused by bark beetles. The resin canal system of lodgepole pine and production of secondary resins are described. The effects of moisture stress and the relationship of each resin system to maturation of the tree are also described. The interaction between tree response and the attacking beetle and bluestain complex, and the relationship between mountain pine beetle outbreak and physiological maturity of lodgepole pine are discussed.

22. Sigler, L.; Yamaoka, Y.; Hiratsuka, Y. 1990. Taxonomy and chemistry of a new fungus from bark beetle infested *Pinus contorta* var. *latifolia*. Part 1. *Arthrographis pinicola* sp. nov. Canadian Journal of Microbiology 36(2): 77–82.

Arthrographis pinicola sp. nov. (Hyphomycetes) is described; it was isolated from galleries and adult beetles of *Ips latidens* and from galleries of *Dendroctonus ponderosae* in *Pinus contorta* var. *latifolia* in western Canada. In *I. Llatidens*-infested lodgepole pine, this species extensively colonizes nuptial chambers and egg galleries, characteristically forming floccose conidiomata composed of repeatedly branched hyphae which divide to form arthroconidia having schizolytic dehiscence. The fungus is antagonistic to some bluestain fungi *in vitro*. *Arthrographis pinicola* is compared with other species of *Arthrographis*, and with *Arthropsis microsperma* and the discomycete *Pezizella chapmanii*.

23. Six, D.L.; Paine, T.D. 1997. *Ophiostoma clavigerum* is the mycangial fungus of the Jeffrey pine beetle, *Dendroctonus jeffreyi*. Mycologia 89(6): 858–866.

Dendroctonus jeffreyi and *D. ponderosae* are sibling species of bark beetles (Coleoptera: Scolytidae) with few morphological and molecular genetic differences. The two species are believed to have diverged relatively recently. *Dendroctonus jeffreyi* colonizes only *Pinus jeffreyi*, while *D. ponderosae* colonizes up to 13 *Pinus* spp., but not *P. jeffreyi*. Adult beetles of both *D. jeffreyi* and *D. ponderosae* carry symbiotic fungi in mycangia located on the maxillary cardines. *Dendroctonus ponderosae* was known to carry two fungi, *Ophiostoma clavigerum* and *O. montium*, in its mycangia. However, it was not known which fungi might by carried by *D. jeffreyi*. Fungi were isolated from the mycangia of more than 900 *D. jeffreyi* collected from a large portion of its geographic range. Using morphology, isozyme phenotypes, and growth rates at different temperatures, all isolates from *D. jeffreyi* mycangia were determined to be *O. clavigerum*; *O. montium* was not isolated from *D. jeffreyi* mycangia.

24. Six, D.L.; Paine, T.D. 1998. Effects of mycangial fungi and host tree species on progeny survival and emergence of *Dendroctonus ponderosae* (Coleoptera: Scolytidae). Environmental Entomology 27(6): 1393–1401.

Dendroctonus jeffreyi Hopkins and its sibling species, *D. ponderosae* Hopkins, are bark beetles associated with symbiotic fungi disseminated in maxillary mycangia. Although both *D. jeffreyi* and *D. ponderosae* are associated with the fungus *Ophiostoma clavigerum* (Robinson-Jeffrey & Davidson), *D. ponderosae* is also associated with a second fungus, *Ophiostoma montium* (Rumbold von Arx). Adult *D. jeffreyi* and *D. ponderosae* that carried *O. clavigerum* (isolated from *D. jeffreyi*), *O. clavigerum* (isolated from *D. ponderosae*), *O. montium*, or were fungus-free, were reared in the laboratory and introduced into bolts of *Pinus contorta* Douglas ex Louden and *Pinus jeffreyi* Greville & Balfour, hosts of *D. ponderosae* and *D. jeffreyi*, respectively, to test for effects of the fungi on progeny survival and fungal ability to use different host tree species. *Dendroctonus ponderosae* associated with *O. clavigerum* (isolated from *D. jeffreyi*) and *D. ponderosae* associated with *O. montium* produced brood in both *P. contorta* and *P. jeffreyi*. The average weight of female progeny was not significantly affected by fungus or tree species. However, the production of progeny adults was significantly higher, and emergence significantly earlier, for *D. ponderosae* associated with *O. clavigerum* (isolated from *D. jeffreyi*) and developing in *P. contorta* than for *D. ponderosae* developing with *O. montium* in *P. contorta*. No brood was produced by *D. jeffreyi* or by fungus-free *D. ponderosae*. Larval galleries were shortest in the *O. clavigerum – P. contorta* treatment, whereas the longest larval galleries were produced in the *O. montium – P. jeffreyi* treatment. Both host tree species and mycangial fungi species have an effect on the ability of progeny to successfully develop.

25. Six, D.L.; Paine, T.D. 1999. Phylogenetic comparison of ascomycete mycangial fungi and *Dendroctonus* bark beetles (Coleoptera: Scolytidae). Annals of the Entomological Society of America 92(2): 159–166.

The existence of a long-shared evolutionary history among *Dendroctonus* bark beetles and their symbiotic mycangial fungi (Ascomycotina: Ophiostomataceae) was investigated by comparing independently derived phylogenies of the 2 groups of organisms. Two phylogenetic comparisons were made. In the 1st comparison, all mycangium-associated fungi were included in the fungal phylogeny (some beetles possessed 2 mycangial associates). In the 2nd comparison, only the most common mycangial associate of each beetle was included. Statistical tests did not support the existence of widespread cospeciation among the beetles and fungi in the 1st comparison. In the second comparison, a maximum of 4 cospeciation events was statistically supported.

26. Six, D.L. 2003. A comparison of mycangial and phoretic fungi of individual mountain pine beetles. Canadian Journal of Forest Research 33(7): 1331–1334.

Two ophiostomatoid fungi, *Ophiostoma clavigerum* (Robinson-Jeffrey & Davidson) Harrington and *Ophiostoma montium* (Rumbold) von Arx, are known to be associated with the mycangia of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins. However, virtually nothing is known regarding the phoretic fungi carried on the external surface of the exoskeleton of this beetle. In this study, the author compared the phoretic fungi of individual *D. ponderosae* with the fungi carried in their mycangia. As many beetles carried ophiostomatoid fungi on the exoskeleton as they did in their mycangia; however, the species of ophiostomatoid fungus carried phoretically on an individual beetle was not always the same as was carried in the beetle's mycangia. *Ophiostoma montium* was isolated more often from exoskeletal surfaces than from mycangia, while the reverse was true for *O. clavigerum*. It appears that *O. clavigerum* is highly adapted for mycangial dissemination, while *O. montium* is adapted to phoretic as well as mycangial dissemination. *Ophiostoma ips* (Rumbold) Nannf. was phoretic on two beetles, indicating that cross-contamination with fungi from cohabiting *Ips spp*. may sometimes occur. Several non-ophiostomatoid fungi were isolated from exoskeletal surfaces, but none consistently so. All non-ophiostomatoid fungi isolated were common saprophytes often found in beetle-killed trees. Yeasts were also common and were isolated more often from the exoskeleton than from mycangia.

27. Solheim, H. 1995. Early stages of blue-stain fungus invasion of lodgepole pine (*Pinus contorta*) sapwood following mountain pine beetle attack. Canadian Journal of Botany 73(1): 70–74.

The early stages of fungal invasion in sapwood of lodgepole pine (*Pinus contorta*) trees infested by mountain pine beetle in British Columbia were studied. *Ophiostoma clavigerum* and *Ophiostoma montium* fungi were commonly isolated, both of which are known to be carried by the beetle. Among other findings, it was noted that bluestain always seems to trail behind the leading edge of fungus penetration.

28. Solheim, H.; Krokene, P. 1998. Growth and virulence of mountain pine beetle associated blue-stain fungi, *Ophiostoma clavigerum* and *Ophiostoma montium.* Canadian Journal of Botany 76(4): 561–566.

The mountain pine beetle (*Dendroctonus ponderosae*) is commonly associated with the bluestain fungi *Ophiostoma clavigerum* and *Ophiostoma montium*. *Ophiostoma clavigerum* is the primary invader of sapwood after beetle infestation and is thought to be the more virulent of the two fungi. Growth of these fungi was studied under oxygen-deficient conditions on malt agar in test tubes and Petri dishes. In addition, growth was studied in phloem and sapwood of young living shore pines (*Pinus contorta* var. *contorta*) and western white pines (*Pinus monticola*) inoculated with fungus in low densities (eight inoculations per tree). In test tubes with limited oxygen *O. clavigerum* grew for a longer time than *O. montium*. Both fungi are fast growing on malt agar (maximum growth 4.4-9.4mm/day), but *O. clavigerum* grew better at temperatures below 25°C. The rapid growth and ability to tolerate low oxygen, levels may be important adaptations for *O. clavigerum* as the primary invader of fresh sapwood. However, although *O. clavigerum* grew better in the phloem of both tree species, there were no differences between the two fungi in their ability to colonize the sapwood of the inoculated trees.

29. Tsuneda, A.; Hiratsuka, Y. 1984. Sympodial and annellidic conidiation in *Ceratocystis clavigera*. Canadian Journal of Botany 62(12): 2618–2624.

Ceratocysis. clavigera produces the *Graphiocladiella* anamorph in pupal chambers of the mountain pine beetle (*Dendroctonus monticolae*) in mature lodgepole pine (*Pinus contorta* var. *latifolia*). Besides this anamorph, at least five different sympodial or annellidic anamorphs occur in culture. These are a hyaline *Verticicladiella*-like state, a *Hyalorhinocladiella* state, a holoblastic-yeast state, a *Leptographium* state, and an anellidic-yeast state. Apparently, interconversion between sympodial and annellidic ontogenies occurs. As the cultures are repeatedly transferred on agar media, relative dominance of these states tends to shift from complex to simpler forms in both ontogenetic lines, and conidia tend to become smaller and roundish. Results of this study urge the necessity for condensation of some ontogenetically and anatomically based anamorph genera connected to *Ceratocystis*.
Note: Ceratocystis clavigera *is synonymous with* Ophiostoma clavigerum.

30. Upadhyay, H.P. 1981. A Monograph of *Ceratocystis* and *Ceratiopsis*. University of Georgia Press, Athens, GA, USA. 176 pp.

Descriptions of all the species of *Ceratocystis* are brought together for the first time (and the relevant literature compiled) in this extremely useful text. Fifteen species are segregated in *Ceratocystiopsis* and the remaining species are distributed among four sections in *Ceratocystis: Ceratocystis*, 28 species, *Endoconidiophora*, 5 species, *Ips*, 13 species and *Ophiostoma*, 29 species. Thirty-nine species are reduced to synonymy and 15 excluded for taxonomic reasons.

31. Whitney, H.S.; Farris, S.H. 1970. Maxillary mycangium in the mountain pine beetle. Science 167: 54–55.

An examination of the maxillary mycangium containing bluestain fungi and yeasts, located in the cardo of the maxilla of the mountain pine beetle, *Dendroctonus ponderosae* Hopk. was studied. The bluestain fungi and yeasts found in lodgepole pine attacked by mountain pine beetle were cultured from mycangia. The microorganisms that were present consisted of the bluestain fungi, *Ceratocystis montia* and *Euphorium clavigerum*, and the yeasts, *Pichia pini, and Hansenula capsulata* or *Hansenula holstii,* as well as the *Trichoderma* species, *Penicillium* species, and *Cladosporium* species. Some mycangia yielded yellow bacterial colonies as well.

Note: Euphorium clavigerum *is now synonymous with* Ophiostoma clavigerum*.*

32. Whitney, H.S. 1971. Association of *Dendroctonus ponderosae* (Coleoptera: *Scolytidae*) with blue stain fungi and yeasts during brood development in lodgepole pine. The Canadian Entomologist 103(11): 1495–1503.

The physical association between *Dendroctonus ponderosae* Hopk. and its associated bluestain fungi, *Ceratocystis montia* Rumb. and *Euphorium clavigerum* Robinson and Davidson, and the yeasts *Pichia pini* (Holst) Phaff, *Hansenula capsulate* Wickerman, and *H. holstii* Wickerman is described in single broods reared in bolts of lodgepole pine, *Pinus contorta* Dougl. var. *latifolia* Engelm. Eggs just prior to hatch and first-instar larvae were always in contact with the microorganisms whereas newly laid eggs, second-, third-, and fourth-instar larvae were not. During pupation, bluestain fungi and yeasts colonized pupal chamber walls. Transfer of these microorganisms to the new generation of insects was ensured when tenerals contacted the microorganisms lining the pupal chamber. Ensured physical contact between these organisms supports the hypothesis of a symbiosis between them.

33. Yamaoka, Y.; Hiratsuka, Y.; Maruyama, P.J. 1995. The ability of *Ophiostoma clavigerum* to kill mature lodgepole-pine trees. European Journal of Forest Pathology 25: 401–404.

Lodgepole pine, *Pinus contorta* var. *latifolia*, about 80 years old, inoculated in the field in Alberta, Canada, in July 1988, with *Ophiostoma clavigerum* either alone or in combination with *Ophiostoma montium* died within one year of inoculation, but the trees inoculated with *O. montium* alone or with control inoculum did not.

Section 2. Effects of bluestain on wood properties and the utilization of solid wood products

34. Allen, J.F.; Maxwell, T.T. 1982. Creosote production from beetle infested timber. Georgia Forestry Commission, Athens, GA, USA. Research Paper 25. 11 pp.

Increased pitch production is reported in beetle-attacked trees. This reference compares creosote accumulation in stovepipes and chimneys following burning of beetle-killed southern pine, green pine, seasoned hardwood (oak and hickory), and green hardwood. Accumulation depended more on air supply to the stove than on type or moisture content of wood burned. There was no more of a problem from beetle-killed pine, which should not be rejected as a fuel wood on the basis of creosote production.

35. Arganashvili, L.N.; Filonenko, V.V. *et al.* 1982. Utilization of beech wood with brown stain in the manufacture of sliced veneer. Derevoobrabatyvayushchaya Promyshlennost 12: 13–14.

Sap stain developing in stored beech (*Fagus orientalis*) logs is regarded mainly as an aesthetic defect. Strength tests, factory slicing and veneer gluing trials in Soviet Georgia showed that the stained veneers were not significantly different from normal veneers. Possible uses in furniture manufacture are briefly discussed.

36. Aufsess, H.V. 1981. Effects of silver fir dieback on the wood properties of affected trees. Forstwissenschaftliches Centralblatt 100(3-4): 217–228.

Several healthy, diseased, or dead firs were examined for fungal attack and possible changes in their strength properties immediately after felling or after three or six months of forest storage. After several months storage, white rot (*Ceratocystis piceae*) appeared along with other fungi. Wood density and strength properties were not significantly affected by dieback or storage.

37. Barron, E.H. 1970. Utilization of beetle-killed southern pine trees. Paper Trade Journal. 154(42, Oct. 19): 62.

A brief summary of a thesis studying changes in moisture content and density, and decay, in trees killed by *Dendroctonus frontalis* sp. gr. declined by 3% to 8% in three months and by 5% to 16% in six months, varying with time of felling and treatment (left standing, felled, or felled and sprayed with a BHC-type chemical). Moisture loss was rapid during the first month (amounting to 29 to 52%), but then declined, the maximum for 6 months being 62%. Felling trees soon after attack greatly reduced moisture loss in all felling series, but considerably increased decay, especially in summer-felled trees. Tree size, height in bole, and chemical treatment had no significant effect on loss of wood substance and moisture changes. Chemical treatment was effective in reducing stain and attacks of subterranean termites. It is suggested that existing price scales should be adjusted to encourage early utilization.

38. Barron, E.H. 1971. Deterioration of southern pine beetle-killed trees. Forest Products Journal 21(3): 57–59

This reference reports regression equations from measurements of specific gravity and moisture content from one to six months following southern pine beetle attack. Specific gravity reductions after six months varied from 5% to 16%. Moisture content declined 29% to 52% within the first month. Reductions in both parameters were related to the season in which the trees were killed. Felling trees soon after attack reduced moisture loss by one-half, but approximately doubled wood substance loss.

Note: Reductions in specific gravity are indicative of decay within the stem

39. Basham, J.T. 1986. Biological factors influencing stem deterioration rates and salvage planning in balsam fir killed after defoliation by spruce budworm. Canadian Journal of Forest Research 16(6): 1217–1229.

The rate at which sap stain and sap rot develop in balsam fir (*Abies balsamea*) killed 0–5 years earlier by *Choristoneura fumiferana* was studied in stands in three widely separated areas in Ontario and Minnesota, with distinctly different populations of the bark beetle, *Pityokteines sparsus*. Average deterioration index (reflecting the extent and type of fungal deterioration) in merchantable stem volume generally increased with time after tree death and with size of the bark beetle population. Wood losses of individual trees during barking were significantly correlated with the deterioration index, wood density, and wood wasp activity, but not with sawyer beetle activity or bark beetle holes. On a stand basis, average density of bark beetle holes was correlated with the extent of stem sap rot. The use of bark beetle holes to assess the economic feasibility of salvage logging is discussed.

40. Byrne, A.; Uzunovic, A. 2000. Does beetle-killed lodgepole pine lack strength? Forintek Canada Corp., Western Division, Vancouver, BC. Internal Report. 9 pp.

A preliminary Forintek Canada Corp. study compared the modulus of elasticity and modulus of rupture of small clears cut from bluestained sapwood and adjacent heartwood of two mountain pine beetle-killed trees. In this ASTM D143 test, the sapwood gave higher values for both these properties than did the heartwood – indicating that factors other than bluestain would influence the mechanical properties of full size lumber.

41. Byrne, A. 2003. Characterising the Properties of Wood Containing Beetle-Transmitted Bluestain: Background, Material Collection, and Summary of Findings. Report to Forest Innovation Investment. Forintek Canada Corp., Western Division, Vancouver, B.C. [W-1975]. 9 pp.

This is a summary compilation of Forintek Canada Corp. work on the properties of beetle-transmitted bluestained wood. Approximately 270 pieces each of bluestained lodgepole pine lumber cut from beetle-attacked trees and equivalent non-bluestained lumber were collected from 14 different sawmills in the British Columbia Interior. These were delivered to the Forintek Vancouver laboratory for conditioning and processing into test specimens. The specimens were allocated, in equal proportion from each mill, between tests of mechanical, dimensional stability and permeability, gluing, and finishing properties. The results are summarized here and in more detail in three associated reports (see references 87, 91 and 138). Overall, the research indicates that this wood can be used, without compromising performance, for structural, furniture, and preservative-treated end uses.

42. Carr, W.R. 1978. Comparison of lodgepole pine lumber recovery from live and dead timber. USDA Forest Service, Missoula, MT, USA. Office Report. 19 pp.

This reports that dead lodgepole pine has mainly been harvested for pulpwood, but in the late 1970s there was interest in determining yields particularly for house logs and lumber. Results of studies of value comparisons from trees categorized as live, recently dead (red-needled), and older dead (no needles, standing, and down). The differences between lumber value from dead and living trees varied from $15.71 to $71.58 per thousand board feet, reflecting the lumber quality. Highest value came from 1-inch boards. The lumber recovery was smaller for the dead trees. Changes to scaling practices are recommended. However it was clear that positive returns are possible from processing dead saw logs. Not considered in the study were increased logging and manufacturing costs and marketing problems due to appearance of the boards from dead trees.

43. Chapman, A.D.; Scheffer, T.C. 1940. Effect of bluestain on specific gravity and strength of southern pine. Journal of Agricultural Research 61(2): 125–133.

The effect of blue stain on the specific gravity and strength of pine wood inoculated with pure cultures of four species of fungi (*Ceratostomella pilifera, C. pini, C. ips*, and *Graphium rigidum*) was essentially the same as reported for prior, similarly controlled studies [Journal of Agriculture Research 1933, 47:369-374]. Specific gravity was reduced by 1 to 2%, hardness by 2 to 10%, bending and crushing by 1 to 5%, and toughness by 25 to 30%. Although all strength properties appeared to be lowered generally, only toughness was affected to an extent of general practical importance. The different species of fungi did not affect the wood with equal severity, nor was their relative order in this respect entirely the same for all properties tested. There was some evidence of a broad relation between the abundance of direct cell-wall penetration by the fungi and reduction in toughness. The intensity of discoloration caused by the different fungi was not indicative of the severity neither of attack nor of the comparative weakening caused by each. The frequency of association between a particular bluestain fungus and a certain kind of wood apparently does not necessarily indicate the inherent ability of the fungus to attack the wood and to affect its strength.

44. Christophersen, K.A.; Howe, J.P. 1979. High-value paneling from dead western white pine. Forest Products Journal 29(6): 40–45.

A sample of dead western white pine (*Pinus monticola*) was sawn to determine volume and value recovery of panel stock with defects such as bluestain, centre rot, wood borer holes, and cracks. Regression equations were produced relating volume recovery to several variables mainly concerned with the extent of particular types of defect. Lumber recovery was lower for dead trees than for healthy trees. However, when processed into 'distressed' interior panels and other products in which these characteristics are considered to be assets rather than defects, the low recovery was often more than offset by the increase in value.

45. Dobie, J. 1978. An overview of dead timber potential in Canada. Pages 1–10 *in* The dead softwood lumber resource: proceedings of the symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

The overview summarizes types of dead timber available in Canada. It mentions that salvage logging cannot keep up with mountain pine beetle infestations and predicts larger volumes to become available in the 1980s. This reference is the first to classify mountain pine beetle-killed trees as green top, red top, grey tight bark, and grey loose bark. It states that positive returns can be obtained from sawing lumber from the first three classes unless the market is buoyant, when even grey loose bark logs can profitably be converted to lumber. The percentages of #2 and better lumber for the four classes were 84, 82, 77 and 63 respectively. The lumber was increasingly down graded as age since death of the trees increased.

46. Dobie, J.; Wright, D.M. 1978. Lumber values from beetle-killed lodgepole pine. Forest Products Journal 28(6): 44–47.

Pinus contorta var. *latifolia* trees in a part of the East Kootenay region, British Columbia, heavily attacked by *Dendroctonus ponderosae*, were sampled in four classes based on foliage and bark characteristics related to time since beetle attack. Lumber recovery factors and grade yields are tabulated. The study showed that positive conversion returns could be obtained unless trees have started to shed their bark and develop severe checking. Net values for 'green top' and 'red top' classes were similar ($8-10/100 ft^3 of logs); those for the 'grey, tight bark' class were $5-6 less. Returns for the 'grey, loose bark' class were negative.

47. Encinas, O.; Daniel, G. 1995. Wood cell wall biodegradation by the bluestain fungus *Botryodiplodia theobromae* Pat. Mat. und Organismen 29: 255–272.

Light, scanning electron microscopy, and weight-loss studies were conducted on wood samples of birch (*Betula pendula*), Scots pine (*Pinus sylvestris*) and Caribbean pine (*Pinus caribaea*) after colonization by the important tropical bluestain fungus, *Botryodiplodia theobromae*. Under soil block burial conditions. *B. theobromae* colonized within one month all three wood species and caused after six months inoculation 5% dry weight loss in the pine species and 9% weight loss in birch. Detailed microscopic examination showed *B. theobromae* to cause incipient soft rot decay with S2 cell-wall delamination of birch fibres and total destruction of parenchyma cells. Cell-wall degradation of softwood tracheids was not noted, but both ray and longitudinal parenchyma cells were highly degraded.

Note: B. theobromae *is now synonymous with* Lasiodiplodia theobromae, *an economically important tropical bluestain fungus and one of the few that is known to be capable of significant cell-wall degradation, thereby causing considerable strength loss*

48. Encinas, O. 1996. Development and significance of attack by *Lasiodiplodia theobromae* (Pat.) Griff. & Maubl. in Caribbean pine wood and some other wood species. Swedish University of Agricultural Sciences, Acta Universitatis Agriculturae Sueciae, Uppsala, Sweden. Silvestria 8. 1 v.

This thesis comprises a detailed description of the whole research project and six papers published elsewhere that cover specific aspects. The process of cell-wall degradation by the bluestain fungus, *Lasiodiplodia theobromae,* was investigated in two softwoods (*Pinus caribaea* var. *hondurensis* and *P. sylvestris*) and three hardwoods (*Betula verrucosa* [*B. pendula*], *Hevea brasiliensis,* and *Populus tremula*). The effects on cell-wall chemistry, wood structure, and mechanical properties of the wood were studied. The laboratory studies indicated wide variations between different strains of *L. theobromae*.

Note: L. theobromae *is an economically important tropical bluestain fungus and one of the few that is known to be capable of significant cell-wall degradation, thereby causing considerable strength loss.*

49. Encinas, O.; Henningsson, B.; Daniel, G. 1998. Changes in toughness and fracture characteristics of wood attacked by the blue stain fungus *Lasiodiplodia theobromae*. Holzforschung 52(1): 82–88.

Losses in toughness correlated with losses in weight were found in birch (*Betula verrucosa* [*Betula pendula*]), Scots pine (*Pinus sylvestris*), and Caribbean pine (*Pinus caribaea* var. *hondurensis*) over a six-month period after inoculation with the bluestain fungus, *Lasiodiplodia theobromae*. Differences between wood samples loaded radially and tangentially in the toughness-testing device were not found. Higher strength losses at later stages of incubation were strongly correlated with degree of degradation of parenchyma cells that produced weak planes of brash fracture and abrupt transwall failure. Transwall failure revealing the S2 microfibrillar angle in early stages of incubation and a very smooth surface in more advanced stages of incubation were also observed. Vessels in birch showed transwall failure after initial failure following degraded terminal parenchyma cells. Intrawall failure was also observed, particularly between the S1-S2 interface. Results indicate that this stain fungus could have a negative effect on the mechanical wood properties of the hardwoods and softwoods studied.

Note: L. theobromae *is an economically important tropical bluestain fungus and one of the few that is known to be capable of significant cell-wall degradation, thereby causing considerable strength loss.*

50. Encinas, O.; Daniel, G. 1999. Depletion of non-structural compounds during attack of pine and birch wood by the blue stain fungus *Lasiodiplodia theobromae*. Journal of Tropical Forest Products 5(2): 184–196.

Caribbean pine (*Pinus caribaea* var. *hondurensis*), Scots pine (*Pinus sylvestris*), and birch (*Betula verrucosa* [*Betula pendula*]) sapwood blocks were incubated with the tropical bluestain fungus, *Lasiodiplodia theobromae,* under axenic conditions for five months. After five months incubation, the weight loss in birch (8%) was higher than in Scots pine (3.5%) and Caribbean pine (4.5%).

Note: L. theobromae *is an economically important tropical bluestain fungus and one of the few that is known to be capable of significant cell-wall degradation, thereby causing considerable strength loss.*

51. Fahey, T.D. 1980. Evaluating dead lodgepole pine for products. Forest Products Journal 30(12): 34–39.

The value ($/ton) of dead lodgepole pine for various uses was calculated, based on oven-dry weight. Roundwood products such as power poles, house logs, and corral poles have high values, but also have restrictive specifications and limited markets. Sawn wood products such as random-length dimension lumber, studs, and core veneer have lower values, but there are fewer restrictions and the markets are greater.

52. Fahey, T.D.; Snellgrove, T.A.; Plank, M.E. 1986. Changes in product recovery between live and dead lodgepole pine: a compendium. Pacific Northwest Research Station, USDA Forest Service, Portland, OR, USA. Research Paper PNW-353. 25 pp.

Product recovery studies were conducted at six mills (two for dimension stock, two for scantlings and one each for boards and veneer) in the western USA using live, recently dead (1-2 yr), and older dead (3 yr) lodgepole pine trees. Results indicated that bluestain caused by *Ceratocystis* sp., and probably also checking, occurred before trees killed by *Dendroctonus ponderosae* could be harvested. Changes in volume recovery between classes, in grades and in average value of primary products are discussed for each product. At all mills, the value of products manufactured from dead trees was less than that for live trees. Some loss in volume of lumber and veneer could be recovered by including the value of chips in the total log value, but losses because of poor grade could not be recovered. For an average log (12 ft^3), absolute values were in the order: boards > dimension stock > veneer > scantlings for both live and dead timber. The percentage change in value from live to dead timber, however, showed the reverse trend, with scantlings losing the least value. The paper mentions that the primary factors causing losses of grade and volume from dead trees are stain and checks that become splits in lumber or veneer. Heavy stain eliminates lumber from two common and better grades, but has no effect on lower grades of common lumber. It has no effect on lumber grade at dimension or stud mills or on core veneers.

53. **Fell, D. 2002. Consumer visual evaluation of Canadian woods. Forintek Canada Corp. Report to Natural Resources Canada, Vancouver. 110 pp.**

A consumer preference test of various wood species for appearance grade end-uses included bluestained lodgepole pine. Heavily bluestained wood was highly noticeable by participants and largely disliked for all appearance end-uses. A small proportion of the participants found bluestained wood “interesting” and this indicates there would be niche markets for this wood. Light bluestained wood was less noticeable than the natural colour variation in lodgepole pine such as the distinct heartwood/sapwood boundary and a small amount of lightly bluestained wood might therefore be included in some appearance-grade wood.

54. Findlay, W.P.K. 1939. Effect of sap-stain on the properties of timber. II. Effect of sap-stain on the decay resistance of Pine sapwood. Forestry 13: 59–67.

The author ran decay tests of small wood blocks inoculated with *Ophiostoma coerula* and other blocks that were from naturally bluestained wood. Although decay was slightly more rapid in stained wood than in stain-free wood, Findlay concluded it did not have any practical significance because pine sapwood is already not resistant to decay. Comparative tests showed that bluestained wood absorbs more water than clean wood and this may be the reason why stained wood decays more rapidly. The rate of seasoning of bluestained and clean wood was similar.

55. Findlay, W.P.K. 1959. Sap-stain of timber. Forestry Abstracts 20(1 and 2): 1–14.

Findlay reports that the effects of staining on the mechanical strength of wood to be used for building purposes are not significant.

56. Findlay, W.K.; Pettifor, C.B. 1937. The effect of sap-stain on the properties of timber 1. Effect of sap-stain on the strength of Scots pine sapwood. Forestry 11: 40–52.

The presence of bluestain fungi had no appreciable effect on the compressive strength or bending strength, but it caused a marked reduction in toughness and a slight reduction in hardness. It is suggested that bluestained sapwood never be used for purposes where timber having a high resistance to suddenly applied loads is required.

Note: This is one of the most quoted papers on the effects of bluestain on strength properties.

57. **Forintek Canada Corp. 2003. Properties of lumber with beetle-transmitted bluestain. Forintek Canada Corp., Western Division, Vancouver, B.C. Wood Protection Bulletin. 4 pp. [also available in Japanese].**

This short bulletin covers the findings of Forintek research into characterizing the properties of pine sapwood carrying mountain pine beetle-vectored bluestain (see references 41, 87, 91 and 138).

58. Centre Technique du Bois. 1978. Le bleuissement des bois par les champignons [Fungal blue stain of timber]. Paris, France. Bulletin Bibliographique, Centre Technique du Bois 116. 4 pp.

Descriptions are given of bluestain and its method of attack, the physiology of the fungus, and the properties of stained timber. Protection measures for timber in the forest, in the sawmill, and when in use are indicated.

59. **Giles, D. 1986. Salvage and storage of beetle-killed timber. Pages 10–14 *in* R.W. Nielson, ed. Harvesting and Processing of Beetle-Killed Timber: proceedings of a seminar sponsored by Forintek Canada Corp. and COFI, Northern Interior Lumber Sector held May 10, 1985, in Prince George, B.C. Forintek Canada Corp., Western Division, Vancouver, B.C. Special Publication 26.**

This reference discusses how salvage of beetle-killed timber can reduce the loss of timber by the forest industry. Protection of logs from wood-destroying insects and fungi after initial attack has occurred will increase the period during which the resource may be converted to marketable products. Moisture, oxygen, and temperature are the factors, which determine the rate and extent of physical and biological deterioration of wood. Control of one or more of these factors is required for effective long-term storage. Reduction of moisture below fibre saturation point will help preserve wood from fungal attack. This process is expedited if bark is removed either mechanically or as an affect of beetle or fire activity. Lumber production from beetle-killed spruce showing heavy weather checking gave 82% of normal recovery and 72% of lumber value 20 years after initial attack. Temperature control has limited application, but may be used at higher elevations where snow accumulations remain until early summer. Water spraying or water storage shows the most promise for long-term storage on an operational scale. Water spraying must be complete, but may be intermittent. Studies indicate that cost of mill-year spraying may be only a fraction of the benefit received. Water storage has been effective in reducing log deterioration, as demonstrated in a large-scale project initiated after a forest fire in Australia. Environmental concerns associated with water storage must be considered. If the beetle-killed pine and spruce resource of British Columbia is to be used to the greatest advantage, industry, government, and research organizations must cooperate with efforts to develop long-term storage strategies for the resource.

Note: There is a considerable body of literature on water storage of logs especially after natural disasters, which produce more logs than, can be processed. This literature is not reviewed here, but is reviewed in another Forintek report.

60. **Giles, D. 1986. Harvesting and processing of beetle-killed pine. Pages 15–17 *in* R.W. Nielson, ed. Harvesting and Processing of Beetle-Killed Timber: proceedings of a seminar sponsored by Forintek Canada Corp. and COFI, Northern Interior Lumber Sector, May 10, 1985 in Prince George, BC. Forintek Canada Corp., Western Division, Vancouver, B.C. Special Publication 26.**

The attack of pine resource by bark beetles and associated biological agents has resulted in protection measures, salvage operations, and discussion of storage techniques to ensure protection and use of the affected resource. The effort to improve the use of beetle-killed timber cannot stop at the mill log storage yard or the infeed deck. In 1983, Forintek surveyed 15 interior mill operations to discuss and note the problems experienced in sawmilling beetle-killed pine. This paper summarizes the problems cited at these operations as well as pertinent information from the literature.

61. Glos, P. 1989. Strength of spruce structural timber with insect and fungus attack: compressive and tensile strength. Holz als Roh und Werkstoff 47(9): 365–371.

In continued work, 340 compression and 288 tension tests were done on Norway spruce (*Picea abies*) lumber with cross-sections averaging 20x150 mm. Attack by wood wasp (*Sirex* sp.) and the long-horn borer (*Tetropium* sp.) reduced compressive and tension strength, largely independent of wood quality. Attack by *Xyloterus lineatus* [*Trypodendron lineatum*] and red-stain influenced only the compressive strength of largely defect-free wood, and this effect declined with increasing knot ratio. Bluestain did not reduce strength or modulus of elasticity.

62. Gottsche Kuhn, H.; Fruhwald, A. 1986. Wood properties of Norway spruce from forest dieback areas: studies on stored wood. Holz als Roh und Werkstoff 44(8): 313–318.

Studies were made on samples from five healthy and 14 damaged spruce trees felled in 1984 at eight different sites in West Germany. Observations were made immediately after felling and after four and seven month's storage of logs (with bark) in a forest depot. After four months in storage, discoloration caused by fungal attack (bluestain, red stain) was more intense in damaged logs (because of lower initial moisture content), whereas after seven months in storage, discoloration was greater in healthy logs. Wood density and strength properties (bending, compression, modulus of elasticity in bending, toughness) were not significantly different in relation to discoloration or damage.

63. Grantham, J.B. 1978. How can dead softwood timber contribute to the nation's energy needs? Pages 53–59 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

The remoteness of this dead resource limits industrial or domestic fuel uses, as transportation costs are high. For a coal-fired power plant there would be little incentive to switch to burning wood if the hauling distance is 100 miles. Forest industry plants may be able to consume some of the wood, but it is assumed to be a break-even proposition compared to natural gas. Comments that a managed program involving highly efficient logging, small-log milling maximizing value, limited processing for energy, and selling chips to pulp or board mills is required to use significantly more of this resource.

Note: Discusses the energy equivalent and potential use of dead lodgepole pine in Northeast Oregon.

64. Hapla, F. 1992. Wood quality of Scots pine from a damaged forest area after five years of wet storage. Holz als Roh und Werkstoff 50(7-8): 268–274.

Roundwood from badly [decline-]damaged Scots pine (*Pinus sylvestris*; damage class 3) and from undamaged trees (class 0) was wet-stored for five years in Germany under continuous sprinkling, and the wood properties were then compared with freshly felled wood. The results showed that neither the damage class nor prolonged wet storage had an adverse effect on wood density or on strength properties. Wet storage prevented any degradation of the wood by bluestain fungi.

65. Harvey, R.D., Jr. 1979. Rate of increase of blue stained volume in mountain pine beetle killed lodgepole pine in northeastern Oregon, USA. Canadian Journal of Forest Research 9(3): 323–326.

Recently killed lodgepole pine (*P. contorta*) were examined to determine the rate of spread of bluestain fungi introduced by the mountain pine beetle. Trees were felled, dissected at 2.5 m intervals and photographed at each cross section to determine area of stain. Rate of spread was so rapid that salvaging such trees before staining becomes severe is difficult. Bluestain appears during the first 40 days after beetle attack – usually before foliar colour change is seen. Between 30% and 60% of the total main stem volume is stained within nine months. By the time identification of the attack can be detected from foliage appearance more than 50% of the cubic volume or nearly 100% of the sapwood, was stained.

66. Holtam, B.W. 1966. Blue stain – a note on its effect on the wood of homegrown conifers and suggested methods of control. Great Britain Forest Commission, London, England. Leaflet 53. 4 pp.

This leaflet is directed to the forest manager in terms of guidelines to prevent bluestain occurring in logs. The leaflet describes increased sapwood permeability and appearance as the only practical effects. The increased permeability results in increased absorption of preservatives and paints (resulting in lack of colour uniformity). Decreased value for blustained logs is also noted. The author also claims that stained wood is not more susceptible to attack by wood-destroying fungi and is less suitable for the development of harmful boring insects.

67. **Howard, A.F.; Gasson, R. 1989. A recursive multiple regression model for predicting yields of grade lumber from lodgepole pine sawlogs. Forest Products Journal 39(4): 51–56.**

This study was done to determine the efficacy of an alternative to least squares methods for fitting regression models to lumber-grade yield data. A method based on a simultaneous system of equations was used to specify the regression model. The system of equations was fitted using techniques suitable for models with limited dependent variables. The regression model was used in a study of value loss from beetle-killed timber for four sawmills with unique product lines. The method was shown to give accurate predictions of the yields of individual grades. The rate of decline (since death) in recoverable lumber value from dead lodgepole pine (*Pinus contorta*) was faster for board mills than for dimension or stud mills.

68. Howe, J.P. 1978. Uses of dead timber in specialty products. Pages 61–66 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

Discusses possibilities for selling dead-timber “distressed”-appearance products containing stain, borer holes, checks, decay, and weathering features. Bluestained pine was at this time being sold in Colorado for exterior siding and fencing, interior paneling, furniture, and other products such as picture frames. Textured Blue-Stain Pine is a sandblasted interior paneling. An Oregon company was making paneling from distressed ponderosa pine studs, which are dried, blanked and edge-glued followed by ripping, resawing, and sanding. “Primitive Pine”, “Blue Mountain Pine” and “Old Barn Pine” are sold as bluestained furniture, paneling, or plywood products.

69. **Ince, P.J. 1982. Economic perspective on harvesting and physical constraints on utilizing small dead lodgepole pine. Forest Products Journal 32(9) 65–68.**

Costs, energy requirements, and physical characteristics of the wood were investigated for small dead lodgepole pine harvested from the Umatilla National Forest in eastern Oregon during a three-month demonstration harvest. An informal market survey of several dozen local timber buyers was conducted in order to ascertain the current problems and potential in use. Results showed that the cost of producing chips alone was lower and less variable than the cost of producing roundwood and chips. Market prices of both roundwood and chips varied considerably with time. Harvesting presented no major difficulties and small dead lodgepole pine wood was generally acceptable to buyers and used for a variety of products. Energy inputs to harvesting were small (6%-7%) relative to the recoverable heat if the deadwood is used as fuel. The cost-to-energy-value ratio of delivered dead lodgepole pine chips was less than the price-to-energy-value ratio of oil and gas, but not coal. However, the price-to-energy-value ratio of dead lodgepole pine chips is likely to be higher and more variable than the cost ratio, due to alternative and competing end uses and variable market prices.

70. Keen, F.P. 1955. The rate of natural falling of beetle-killed ponderosa pine snags. Journal of Forestry 53: 720–723.

Observations on thousands of marked trees show that the rate of fall of beetle-killed trees varies primarily with time elapsed since death. The rule of thumb that the last 10 years' loss can be calculated from the total number of snags is a useful approximation in cruising. Soil conditions, diameter, and other variables modify the rate of falling. On moister loams 15%, 40%, 60%, 80% and 90% had fallen in 4, 6, 8, 12 and 20 years respectively, the rate being slower on drier pumice soil. Larger diameters may stand more than 40 years and economy in snag disposal requires that trees of 30 inches in diameter (25% of the stems) should be felled first, the smaller diameters falling naturally.

71. Keepf, C.J. 1978. Industry recovery experience in operating a sawmill on dead timber. Pages 11–18 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

Reports product recovery information from two Colorado studies on a mix of 75% Engelmann spruce and 25% lodgepole pine dead for 20 to25 years. The fallers selected only sound trees. For Engelmann spruce, 69-87% of the value of live trees was obtained. Spiral checks and downed material had considerably less value than standing material with a straight check.

72. Kelly, M.W.; Barefoot, J.E.; Swint, W.H.; Levi, M.P. 1982. Properties of particle- and hardboard made from healthy and beetle-killed southern pine. Forest Products Journal 32(3): 33–39.

Particleboards were prepared from wood of: (a) healthy shortleaf pine trees; (b) shortleaf pine trees that had been killed by southern pine beetle (*Dendroctonus frontalis*) three months previously; and (c) trees that had been killed by beetles 30 months previously. Results of tests showed that particleboards produced from beetle-killed pines met industry specifications for modulus of rupture, modulus of elasticity, internal bond strength, screw withdrawal, hardness, water absorption, and thickness swelling. However, in these tests, linear expansion (LE) was not adequate for (a), (c) or a 50/50 mixture of (a) and (b). Hardboards made from (a), (b) and (c) also met industry specifications for all properties except LE; boards prepared from 100% (b) or (c) failed this specification, but when 50% (a) was added they met the specifications. The yield of wood fibre from beetle-killed wood was slightly lower, the percentage of fines was higher, and the moisture content was lower than these for healthy trees.

73. Kim, G.; Kim, J.; Ra, J. 2002. Development of fungal sap stain in logs of Japanese red pine and Korean pine. Mokchae Konghak – Journal of the Korean Wood Science and Technology 30(2): 128–133.

Bluestain developed in summer stored Japanese red pine (*Pinus densiflora*) and Korean pine (*P. koraiensis*) and was associated with bark-beetle (*Tomicus piniperda*) attack. Decay fungi subsequently started to develop in the logs.

74. Koch, P.; Keegan, C.E. III; Burke, E.J.; Brown, D.L. 1989. Proposed wood products plant to utilize sub-sawlog size and dead lodgepole pine in northwestern Montana – a technical

and economic feasibility analysis. Intermountain Research Station, USDA Forest Service, Missoula, MT, USA. General Technical Report INT-258. 145 pp.

The primary purpose of the proposed plant is to facilitate harvesting and reforestation (at minimum public expense) of vast, stagnated stands of lodgepole pine (*Pinus contorta* var. *latifolia*) in diameter classes 3-7 inches. Annual stemwood consumption would be 200 000 oven-dry tons. Output from the plant would be mainly (90% of revenue) Oriented Strand Board, fabricated joists (with webs of waferboard and flanges of minimally machined dowels), and edge-glued lumber panels for mill work. The remaining 10% of revenue would come from small roundwood products (tree props and fence rails), studs, pulp chips, and particleboard furnish. Most of the residues would be hog-fuel burned for process heat requirements of the plant. Some 271 mill workers would be employed, in addition to woods and transport workers. Capital investment is estimated to be $62 million, annual revenue in the first full year of production should be $40 million and annual operating costs before depreciation should be $30 million.

75. Kohrt, R. 1978. Harvesting and delivery to plant. Pages 187–192 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

Logging dead timber is an expensive operation, often only economically feasible if there is green wood mixed in and if markets are above average. Factors that increase the normal logging risks when dealing with dead timber are safety, shorter logging season, potential for windthrow and fire, negative employee attitude, low operating margins, and idealistic attitude of the selling agency. The paper describes dead wood harvesting techniques and equipment.

76. Lemaster, R.L.; Troxell, H.E.; Samson, G.R. 1983. Wood utilization potential of beetle-killed lodgepole pine for solid wood products. Forest Products Journal 33(9): 64–68.

A comparison was made between the properties of lodgepole pine killed by *Dendroctonus ponderosae*, thinnings produced as a result of practices necessary to cope with the beetle problem, and live lodgepole pine timber. The test results were combined into property groupings that were considered to represent the most important qualities for a given product. An average index value was derived from the property groupings to indicate suitability to a particular end use. Beetle-killed material maintained much of its physical integrity; most of the value loss resulted from drying defects occurring before felling. The thinnings had good properties, except that there was a high incidence of warp and wane; the suitability index for most products was greater than that for live sawtimber. Timber from trees that had been dead a long time (loose bark) was less suitable for most products than timber from trees recently killed (tight bark).

77. Levi, M.P.; Dietrich, R.L. 1976. Utilization of Southern Pine beetle-killed timber. Forest Products Journal 26(4): 42–48.

Reviews, in relation to an enquiry on the policy of various buyers in North Carolina toward the purchase and use of southern pine timber killed by *Dendroctonus frontalis*, literature on the use of wood from beetle-killed trees. The evidence suggests that trees recently killed by *D. frontalis* can be used economically for dimension lumber and pulpwood, but that a considerable degree of prejudice against the wood exists among some classes of buyer. The need for further information on the rate of deterioration of beetle-killed trees and the effect of such deterioration on utilization is stressed.

78. Levi, M.P. 1981. Southern pine beetle handbook. A guide for using beetle-killed southern pine based on tree appearance. U.S. Department of Agriculture, Washington, D.C., USA. Agriculture Handbook 572. 19 pp.

This handbook summarizes the work done at the USDA Combined Forest Pest Research and Development Program on southern pine beetle (see references 72, 79, 116-123, 136 and 151). Bluestain fungi carried by the beetle and secondary boring insects commonly attack beetle-infested trees. Decay fungi and other insects (e.g. termites) attack after tree death. Utilization, processing, and wood properties are described for two appearance classes of dead trees: A) trees which may or may not have needles but still have twigs attached, and B) trees which range from those with smaller branches attached to those with broken tops. The report mentions that bluestain fungi can decrease wood toughness and increase permeability. It is not suitable for conventional appearance-grade lumber and should not be used where toughness is important (for example in poles and posts). The high permeability may present problems for gluing and finishing. Mechanical pulps are darker than those from unstained wood. Chemical pulps require more bleach. The utility of the trees decreases with time and should be harvested and processed as soon after attack as possible. The speed of deterioration of standing trees depends on season of attack and local climatic conditions. The grade of lumber from beetle-killed trees is lower than from sound trees, but yields of particleboard, hardboard and pulp are similar. The dryness of the beetle-killed trees dulls saws and chipper knives.

79. Levi, M. 1978. Blue-flecked paneling: a new market for southern pine beetle-killed trees. South Lumberman 237(2994): 70–71.

Promotes the use of interior panels made from bluestained beetle-killed southern pine for a character look. The main prerequirements of wood to be used for this purpose are: 1) that the wood needs to have sufficient strength and integrity to survive handling, sawing and planing; 2) that the wood is kiln dried to kill insects in the wood. It is apparent that no commercial producers were supplying such a product, which would also require willing purchasers.

80. Lieu, P.J.; Kelsey, R.G.; Shafizadeh, F. 1979. Some chemical characteristics of green and dead lodgepole pine and western white pine. Intermountain Forest and Range Experiment Station, USDA Forest Service, Missoula, MT, USA. Forest Research Note INT 256. 7 pp.

The chemical composition and combustion characteristics of wood from single dead and live lodgepole pine and western white pine (*Pinus monticola*) trees in Western Montana were determined. There was very little difference between sound dead wood and the corresponding live wood in either species. This suggests that dead wood could be used as a source of chemicals and fuel, and as a substitute for live timber in the manufacture of wood products.

81. Lindgren, R.M.; Scheffer, T.C. 1939. Effect of blue stain on the penetration of liquids into air-dry southern pine wood. American Wood Preservation Association 35: 325–336.

Permeability is noticeably altered making preservative treatment easier and this can be an advantage with less permeable species such as spruce. In addition, stained wood may dry more quickly, although this can cause checks as stained areas dry differently then unstained areas.

82. Lowery, D.P. 1978. Using dead softwood timber: kiln drying procedures for lumber and preservative treatments for fenceposts. Pages 99–111 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

Moisture content for lumber from dead (mountain pine beetle-killed) western white and lodgepole pine logs was about half of that for green lumber of the same species. Kiln drying time for the dead lumber should therefore be about half that of green lumber. Fenceposts treated by six hours of soaking in preservative were inconsistently treated and did not meet the preservative retention specification but the normal 24-hour soaking period could clearly be shortened for dead tree posts. Pressure treatment can be reduced from 3.5 hours for air-seasoned green posts to about 45 minutes. This gives an advantage to the use of dead trees for fenceposts, making the use of small dead lodgepole pine trees particularly advantageous for this end use. Care should be exercised in selecting posts from dead trees for preservative treatment. Dead tree posts tend to be stripped of an excessive amount of wood in debarkers, especially passing over deep or irregular checks on the post surface. These posts should be avoided.

83. Lowery D.P. 1982. Dead softwood timber resource and its utilization in the west. Intermountain Forest and Range Experiment Station, USDA Forest Service, Missoula, MT, USA. General Technical Report INT-125. 18 pp.

A comprehensive summary review of the characteristics of deadwood and estimates of its standing inventory. Standing-tree deterioration is discussed mainly based on reviews of literature on fire-killed trees. The longer the dead trees are exposed to the degrading elements, the lower the quality and quantity of usable material that can be recovered. The report summarizes the available information on the use of dead trees and logs including lodgepole pine. These can be used for essentially the same purposes as green trees of the same species: lumber house logs, posts, poles, firewood, and in the production of pulp paper and particleboard. The use of dead trees in plywood manufacture is often restricted.

84. Lowery D.P.; Pellerin, R.F. 1982. Evaluation of dimension lumber made from dead-tree logs. Intermountain Forest and Range Experiment Station, USDA Forest Service, Missoula, MT, USA. Research Paper INT-286. 7 pp.

This paper concludes that in lumber cut from a sample of lodgepole pine in western Montana there were no marked differences in moduli of elasticity between wood from live trees or dead ones.

85. Lowery, D.P.; Hast, J.R. 1979. Preservation of dead lodgepole pine posts and poles. Intermountain Forest and Range Experiment Station, USDA Forest Service, Missoula, MT, USA. Research Paper INT-241. 12 pp.

Discusses the use of dead lodgepole pines for posts and utility poles. Advantages of using dead trees for poles and posts are: reduction in seasoning time required, inventory reduction, and better preservative penetration. Three studies using posts and poles cut from dead lodgepole pine trees are reported. Selection of posts and poles needs to be done carefully. There is a higher cull factor in dead trees due to long deep checks and insect holes that reduce product quality. Processing also resulted in higher than usual fibre loss during debarking of posts but not of poles. Surfaces of the products were rougher than those made from live trees. Steeping in preservative gave inconsistent preservative retentions and was unsatisfactory for fence posts. Poles treated by hot- and cold-bath non-pressure method, and posts treated by the pressure method, had retentions exceeding minimum specification requirements.

86. Lowery, D.P. and Hearst, A.L. 1978. Moisture content of lumber produced from dead western pine and lodgepole pine trees. Intermountain Forest and Range Experiment Station, USDA Forest Service, Missoula, MT, USA. Research Paper INT-212. 11 pp.

Within recent years, disease and insects have killed many western white pine (Pinus monticola) and lodgepole pine trees in the timber stands of Idaho and Montana. About 10% of the dead trees are salvaged for lumber. The dead logs are usually processed with green logs, and the lumber is mixed for drying and surfacing. The moisture content before drying of lumber cut from dead logs of the two species was measured with a moisture meter and by the standard oven-dry test. For both species, the moisture content value for the dead lumber was about half the usual value for green wood, averaging 29% for white pine dimension lumber and 23% for lodgepole pine studs. The use of separate drying schedules for green and dead lumber is recommended to reduce energy costs and prevent excessive degrade of the dead lumber.

87. **Lum, C. 2003. Characterizing the mechanical properties of wood containing beetle-transmitted bluestain. Report to Forest Innovation Investment. Forintek Canada Corp., Western Division, Vancouver, B.C. [W-1984]. 17 pp.**

This is the first of three studies done at Forintek Canada Corp. to characterize the properties of mountain pine beetle-killed bluestained sapwood. The objective was to determine whether this bluestained lumber differs in its strength properties from non-stained lumber. Small clear bending and toughness tests, and the standard test method ASTM D143 were done on bluestained and non-stained lumber pieces. A subset of the bluestained and non-stained lumber sample was also selected and used to prepare metal plate-connected tension splice specimens. The tests and the measured mechanical properties were judged to be sensitive indicators of any possible effects of bluestain on the structural performance of full-size lumber. For bluestain, an impact on the clear wood strength or the strength of the connector could be considered a precursor to a possible reduction in the structural performance of full-size lumber. The results showed that wood with beetle-transmitted bluestain and non-stained wood have comparable clear wood bending properties and truss plate grip capacity. The observed 5% lower mean toughness of bluestained wood compared to non-stained wood was found to be only marginally significant ($p = 0.05$) but at toughness levels below the lower quartile of the strength distribution. A small (5%) increase in mean truss plate connector grip capacity was found. Both of these effects are more likely to be masked by differences in the mechanical properties of the heartwood and sapwood, and, in the case of full-size lumber, by the presence of strength-reducing growth characteristics such as knots and slope of grain.

88. Maloney, T.M.; Talbott, J.W.; Strickler, J.W.; Lenz, M.D.; Martin, T. 1978. Composition board from standing dead white pine and dead lodgepole. Pages 19–51 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

States that dead western white or lodgepole pines are not normally acceptable for plywood manufacture and have limited acceptance as lumber. However even after standing dead for many years the pines were still suitable for manufacture of flakes and fibres. These can be effectively made into board products such as underlayment, furniture core, door core, structural flakeboard, hardboard, and medium-density fibreboard with some minor refinement of the manufacturing processes. Suitable properties were found in almost all cases studied. However lodgepole pine flakeboards had relatively poor internal bond strength due to poorer quality flakes from the dead trees, and linear expansion was greater than commercial standards, probably a species effect. Deep log checking, widespread bluestain, and pockets of decay, which limit the use of dead trees for lumber and plywood, had no appreciable effect on the suitability of the logs for board manufacture.

89. **Mancini A.J. 1978. Manufacturing and marketing older dead lodgepole pine. Pages 193–196 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ. Pullman, WA, USA.**

In salvage logging of lodgepole pine this Wyoming company is required to remove live, dead and down trees to 8 (or 16)-ft length, 6-inch tip diameter and 1/3 (or half) sound. Only rot voids, char, and unchippable broken pieces are considered defects. Problems encountered are: breakage at every handling; debarking, which does not work well on dead wood; deep checking which causes falldown; dirt on the logs and in the checks which causes twice the normal saw wear and filing and also health problems for the crew; heavy slabbing of the logs is required; overdrying and drying defects in the dead wood; poor grade recovery (e.g. more than triple the normal green percentage of economy studs); lower mill productivity (by nearly half in pure deadwood); marketing bluestained wood and the lower selling price. Shorter log lengths and smooth roads and yards are recommended to reduce breakage. Modification of debarkers is required, and log ponds or spray washing logs are recommended. With dead timber it is important to keep product sizes as large as possible, for example slabbed house logs will hold together but 1 x 4-inch boars will often fall apart from the checks. Sawing deadwood also requires developing markets for the large amount of "junk" produced.

90. Matyushkina, A.P.; Ageeva, M.I. 1971. Investigation of the wood of dead standing pine. Lesnoi Zhurnal 14(5): 117–121.

Compares the moisture content and chemical composition of wood of dead standing Scots pine trees and growing trees in Soviet Karelia. Data are also given on the chemical composition of wood of standing trees that have been dead for various periods of time (1-100 years) and of wood of dead standing trees affected by bluestain and by decay. The heartwood of dead standing trees was similar in chemical composition to that of living trees, and bluestain scarcely affected the chemical composition of the sapwood. The authors also found that decayed wood caused significant changes in wood chemistry and should not be used in the manufacture of sulphate pulp.

91. McFarling, S.; Byrne, A. 2003. Characterizing the dimensional stability, checking, and permeability of wood containing beetle-transmitted bluestain. Report to Forest Innovation Investment. Forintek Canada Corp., Western Division, Vancouver, B.C. 13 pp. [W-1985].

This is the second of a series of studies done at Forintek Canada Corp., to characterize the properties of mountain pine beetle-killed and bluestained sapwood, in this case the permeability, wood-preservative uptake and dimensional stability. Pieces of bluestained and non-stained 2 x 4-inch, lodgepole pine lumber were subjected to wetting-drying cycles after which the amount of bow, crook, cupping, twist, and checking was measured. When repeatedly wetted and dried, bluestained wood was more dimensionally stable (less cupping and twist) and checked less than non-stained sapwood, but was more permeable to water. In bluestained wood the stresses appear to be relieved by many micro-checks rather than fewer large checks. The improved dimensional stability should result in the lumber made from stained wood remaining straighter. Weighing end-matched specimens before and after a 1 – 24-hour dip treatment or after a pressure treatment cycle with chromated copper arsenate preservative, and then calculating the uptake and preservative retention determined the permeability of the wood. Increased permeability of the bluestained sapwood was confirmed by data showing enhanced chromated copper arsenate (CCA) uptake and penetration. One implication of the stained sapwood treating more readily than non-stained wood is that in batches of preservative-treated wood, the stained wood is liable to be over treated or the non-stained wood under treated. As anticipated, bluestain in the sapwood had no effect on the penetration of preservative into the heartwood, the most refractory part of the wood. Treatment with CCA also masked the bluestain by coloring it green.

92. McLain, T.E.; Ifju, G. 1982. Strength properties of blue-stained wood from beetle-killed southern pine timber. Pages 55–67 *in* How the environment affects lumber design: assessments and recommendations: proceedings of a workshop held May 28–30, 1980 in Madison, WI, USA. Forest Products Laboratory, Madison, WI, USA.

This study indicates that heavily bluestained southern pine lumber may be of lower strength than lumber clear of such stain. Heavily bluestained clear wood specimens sawn from beetle-killed southern pine were found to be weaker in toughness (by 30-40%), bending, and compression than those from healthy trees. Significant reductions in modulus of rupture (19%) and modulus of elasticity (11%) were noted as early as two months following foliage fade. This was possible attributable to incipient decay which accompanied the bluestain in the sapwood. The longer the time after foliage fade of the infected trees, the greater the strength loss. When grading rules were applied conservatively, in-grade strength properties of full-size beams of the infested material were comparable to those from healthy trees. It is suggested that the apparent contradiction between the results on small clears and full-size lumber was attributable to unusually restrictive grading out of sapwood decay. However the work serves as a warning that bluestain should be considered as a warning signal for the grader to apply grading rules conservatively.

93. Mejer, E.I. 1946. Stimulatory action of staining fungi on the development of house fungi. [In Russian]. Moskovskoe obshchestvo ispytateiei prirody. Otdel biolobicheskii 51: 3–45 (Also as: Bulletin de la Societe imperiale des naturalistes de Moscou. Section biologique.)

Mejer (1946) reported that the growth of the fungus that causes dry rot in buildings was stimulated by prior infection of bluestain fungus *Leptographium lundbergii*.

Note: L. lundbergii has not been associated with the mountain pine beetle.

94. Nelson, R.M. 1934. Effects of bluestain fungi on southern pine attacked by bark beetles. Phytopathologische Zeitschrift 7: 327–353.

This paper reviews the relationship between bark beetles and the bluestain fungi they carry. *Ceratostomella pini* and *Ceratostomella ips* were inoculated into the sapwood of some pine samples. Experiments were carried out to compare the water relation of unattacked pines to pines infested with *Dendroctonus frontalis*. It is concluded that the beetle-infested tree is unable to draw water through the stained parts. Furthermore, although the girdling effect of the beetle tunnels would in time kill infested pines, it is believed that the cause of death is due to the action of bluestain fungi on the tori in the wood tracheids.

Note: These fungi are now known as Ophiostoma minus *and* O. ips*. Both are associated with mountain pine beetle-vectored bluestain.*

95. Nielson, R.W. 1986. Beetle-killed pine processing problems and opportunities: a British Columbia perspective. Pages 6–9 *in* R.W. Nielson, ed. Harvesting and Processing of Beetle-Killed Timber: proceedings of a seminar sponsored by Forintek Canada Corp. and COFI, Northern Interior Lumber Sector held May 10, 1985 in Prince George, B.C. Forintek Canada Corp., Western Division, Vancouver, B.C. Special Publication 26.

The overall purpose of the study was to review the processing of mountain pine beetle-killed lodgepole pine in various forest products operations, to examine the particular problems this presents, and determine further work that might be carried out to help alleviate any of the problems identified. The study concentrated on sawmilling, but also covered veneer and plywood, pulp particleboard, and treated wood-products manufacturing. Literature was reviewed and a survey made of milling operations in the Cariboo region that were salvaging and processing beetle-killed timber.

96. **Nielson, R.W.; Mackay, J.F.G. 1986. Sorting of dry and green lodgepole pine before kiln drying. Pages 31–34 *in* R.W. Nielson, ed. Harvesting and Processing of Beetle-Killed Timber: proceedings of a seminar sponsored by Forintek Canada Corp. and COFI, Northern Interior Lumber Sector held May 10, 1985 in Prince George, B.C. Forintek Canada Corp., Western Division, Vancouver, B.C. Special Publication 26.**

Three sorting alternatives are briefly assessed and it is concluded that it would be advantageous to sort dead timber in the forest as soon as possible during harvesting, and haul and process it separately. The disadvantage of separate treatment is that it results in the production of packages in which almost all the pieces are bluestained and therefore more difficult to market.

97. Nielson, R.W.; Wright, D. 1984. Utilization of beetle-killed lodgepole pine. Report. Forintek Canada Corp., Western Division, Vancouver, B.C.

This reference reviewed existing literature as well as visiting 15 operations processing dead timber. These included sawmilling, plywood, pulp, fingerjointing, lumber remanufacturing and preservative treating operations. Bluestain, the dryness of the wood and splits and checks were the main characteristics of this wood that negatively affected production operations and/or product value. The effect of these varied by product. For lumber the dryness and the splitting of tree stems reduced product yield and value. Kiln drying mixtures of green and dry lumber resulted in over drying and high degrade levels in the already dry wood. For lumber and plywood operations dead timber must be salvaged quickly. For kraft pulp production decay in dead timber is the primary concern and the effect of bluestain on brightness is also a consideration.

98. Patterson, D.W.; Murphey, W.K.; Massey, J.G. 1983. Moisture content of beetle-killed southern pine timber in eastern Texas. Forest Products Journal 33(1): 67–68.

In 1981, beetle-killed southern pine trees were harvested. Moisture content was measured in samples taken from the butt of the tree, the top of the butt log, and above the last log if more than one log was taken. Analysis of variance showed that moisture content varied significantly with time since death and position in the tree.

99. Peckinpaugh, S. 1978. The log home market for dead timber. Pages 67–70 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

This paper reports increased use of dead trees for log homes in the western states. The logs are dry, inexpensive, and in good supply. Most logs are shaped with a planer, turned on a lathe, or sawn on two sides. Log homes are built at the buyer’s site or are pre-built at a construction plant. Basic criteria for logs are that they be free from rot, without spiral checks, ¼-inch. minimum check, 7-inch. minimum diameter, 16-foot minimum length, straight, no crook, minimal sweep, 3-inch taper in 40 feet or less. Dead lodgepole pine is a preferred species for log homes.

100. **Plank, M.E. 1979. Lumber recovery from live and dead lodgepole pine in the northern Rocky Mountains. Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, Portland, OR, USA. Research Paper PNW-344. 15 pp.**

A sample of 120 live and 147 dead lodgepole pine trees was selected in southwestern Wyoming to represent stands many timber managers and mill operators are processing. The trees were put through a conventional circular headsaw sawmill to determine lumber yield and relative differences in product recovery. Of the total lumber volume for live trees, 47% was graded standard and better, 17% was graded utility and 8% was graded economy. For the dead trees, the recoveries were 24%, 37% and 13% respectively, with checking being the primary reason for lower grade of dead log products. Based on the gross cubic volume of the log, the average lumber volume recovered was similar, at 32% for live trees and 31% for dead trees.

101. Plank, M.E. 1984. Lumber recovery from insect-killed lodgepole pine in the northern Rocky Mountains. Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, Portland, OR, USA. Research Paper PNW-320. 12 pp.

A sample of trees killed by *Dendroctonus ponderosae* in the Bridger-Teton National Forest in Wyoming and the Targhee National Forest in Idaho were processed through a stud mill. Logs from similar live trees were sawn to compare their product recovery. There was a significant difference between the volume of logs from live trees and that from trees dead for one to three years, but this was not thought to be of practical importance. Less cubic volume was recovered from trees dead for four years or more. Average stud recovery was 86% of the volume in the live sample, compared with 73% in the dead sample.

102. Plank, M.E., Snellgrove, T.A.; Fahey, T.D. 1986. Volume and value recovery from live and dead lodgepole pine. Pages 27–30 *in* R.W. Nielson, ed. Harvesting and Processing of Beetle-Killed Timber: proceedings of a seminar sponsored by Forintek Canada Corp. and COFI, Northern Interior Lumber Sector held May 10, 1985 in Prince George, B.C. Forintek Canada Corp., Western Division, Vancouver, B.C. Special Publication 26.

A brief report of six studies in the western United States on value and volume losses associated with processing dead lumber into boards, random-length dimension stock, studs, and veneer. Absolute values for the average-sized log (12 ft^3) were highest for boards, followed by dimension stock, veneer, and studs. Value reductions from live to dead wood were greatest for boards and least for studs.

103. Radvan, R. 1951. Effect of *Ceratostomella pilifera* on the decomposition of lignocellulosic membranes (cell walls) by wood-destroying fungi. [In Czech]. *Spisy Vydávané P_irodov_deckou Fakultou Masarykovy Univ. Brno,* No. K3(326):79–96.

Radvan (1951) found contradictory results while experimenting with pine sapwood stained with *Ceratocystis sp.* He found some indication that wood containing living sap-staining fungus was more resistant to decay while wood containing the dead staining fungus was less resistant compared with clean wood.

Note: This fungus, now called Ophiostoma piliferum*, is common in Canadian softwoods but is not normally carried by the mountain pine beetle.*

104. Reid, R.W. 1961. Moisture changes in lodgepole pine before and after attack by the mountain pine beetle. Forestry Chronicle 37(4): 368–375.

The moisture content of the outer sapwood of non-infested lodgepole pine is normally about 85 to 165% of oven-dry weight. In trees that have been infested by the mountain pine beetle for one year, the sapwood moisture content can be as low as 16%. There is a steep moisture gradient from about 160% in the outer sapwood to about 30% in the heartwood. The moisture content in the center is slightly higher than in the adjacent wood. In infested trees, the sapwood moisture is greatly reduced within a year after the attack, but moisture in the heartwood is not altered appreciably. Trees infested early in the season drop to a lower moisture content by fall than trees infested later in the season. In non-infested trees, there is a diurnal and a seasonal moisture march; these do not occur in infested trees. The rapid moisture loss in the sapwood of infested trees is associated with bluestain infection and successful establishment of the bark-beetle broods.

Note: The rapid drying of lodgepole pine caused by mountain pine beetle attack affects processing. Dry logs become brittle and are more liable to break. Checks associated with dry logs reduce widths, and length of boards produced.

105. Sachs, I.B.; Nair, M.G.; Kunz, J.E. 1970. Penetration and degradation of cell walls in oaks infected with *Ceratocystis fagacearum*. Phytopathology 60(9): 1399–1404.

Describes the decay of invaded wood cells caused by the bluestain fungus, *Ceratocystis fagacearum*.

Note: This oak-wilt fungus attacks hardwoods and is not associated with the mountain pine beetle.

106. Safranyik, L.; Shrimpton, D.M.; Whitney, H.S. 1974. Management of lodgepole pine to reduce losses from the mountain pine beetle. Pacific Forest Research Centre, Victoria, B.C. Forestry technical report (Canadian Forest Service) 1. 24 pp.

This report is directed at forest managers and covers procedures and guidelines for dealing with mountain pine beetle infestations. The report mentions that bluestain fungi do not appreciably weaken the wood because they cannot use wood fibre for food. The only significant detrimental effect on wood properties is a slight reduction in the modulus of elasticity. Less significant effects noted are the faster penetration of wood preservatives and more rapid curing of concrete in bluestained forms.

Note: No data source for the statement on reduced MOE is given. Contact with the senior author indicated that this statement was probably based on references to bluestain caused by some other fungus and was not meant to necessarily apply to mountain pine beetle-vectored bluestain.

107. Saling, W.M. 1930. The effect of bluestain on the penetration and absorption of preservatives. Pages 183–187 in proceedings of the 26th Annual Meeting of American Wood Preservers' Association held January 28–30, 1930 in Seattle, WA, USA. The Association, Washington, D.C., USA.

In carefully controlled tests, penetration and absorption of zinc chloride and creosote were greater in bluestained wood than in clean wood.

108. Scheffer, T.C.; Lindgren, R.M. 1940. Stains of sapwood and sapwood products and their control. U.S. Department of Agriculture, Washington, D.C. Technical Bulletin 714. 123 pp.

A comprehensive review of the major works done before 1937 on the strength properties of bluestained wood. The conflicting work of the effect of bluestain on wood strength properties is summarised. The author concludes that ordinarily only material that is badly stained is likely to be weakened significantly, mainly with respect to the toughness of the wood. Since the conditions that favour development of heavy sap stain also favour decay, it is wise to examine heavily stained material for decay and discard it. Literature on the decay resistance of bluestained wood is also reviewed and the author concludes any differences there may be are not of practical importance. The review of preservative impregnation, drying characteristics and gluing and paintability studies indicate that stained wood can be used in the same way as non-stained wood.

109. Scheffer, T.C. 1973. Microbiological degradation and its causal organisms. Pages 31–106 *in* D.D Nicholas, ed. Wood Deterioration and its Prevention by Preservative Treatment, Volume 1: Degradation and Protection of Wood. Syracuse University Press, New York.

Stained wood is not recommended in products subjected to high-impact stress such as tool handles and scaffold boards. Small losses in specific gravity (1-2%), in surface hardness (2-10%), in bending strength, and in crushing resistance (1-5%) have been reported.

110. Schirp, A.; Farrell, R.L.; Kreber, B. 2000. Capability of staining fungi to cause structural changes in New Zealand radiata pine: toughness testing and enzyme production. IX Reunion y I Congreso Iberoamericano sobre Investigacion y Desarrollo en Productos Forestales, Concepcion, Chile, 18-20 octubre 2000. Maderas, Ciencia y Technologia 2(2): 119-129.

The potential of sap staining fungi to induce weight loss and changes in toughness (impact bending strength) in unseasoned sapwood of radiata pine (*Pinus radiata*) was investigated. Sets of side-matched specimens were inoculated with New Zealand isolates of the staining fungi *Ophiostoma floccosum*, *O. piceae*, *O. pluriannulatum*, *Leptographium procerum,* and *Sphaeropsis sapinea*. Additional sets were inoculated with the white rot fungus *Schizophyllum commune* and the brown rot fungus *Gloeophyllum trabeum* to serve as references for weight and toughness loss. Weight loss was determined by comparing the dry weight of inoculated samples with untreated control samples. After eight or 16 weeks incubation, the samples were equilibrated to 14% moisture content before recording toughness and weight losses. Neither toughness nor dry weight was significantly different ($p < 0.05$) between inoculated wood samples and controls, irrespective of staining fungi used. *G. trabeum* reduced toughness by 61% and caused a weight loss of 8%, whereas *S. commune* produced a toughness loss of 32% without any significant weight loss. In enzyme assays of wood, *S. sapinea* produced more xylanase (1.6-1.9 mmol/min/ml) than the *Ophiostoma* species and the two decay fungi. It is concluded that *Ophiostoma* species do not have the enzyme capacity to degrade the main structural wood components of radiata pine. However, *S. sapinea* produces xylanase without inducing significant toughness and weight loss.

Note: Xylanase is an enzyme that breaks down hemicelluloses in wood.

111. Schirp, A.; Farrell, R.L.; Kreber, B. 2003. Effects of New Zealand sap staining fungi on structural integrity of unseasoned radiata pine. Holz als Roh und Werkstoff 61(5): 369–376.

In a laboratory test, side-matched specimens of radiata pine (*Pinus radiata*) sapwood were incubated with individual isolates of *Ophiostoma floccosum*, *O. pluriannulatum*, *O. ips*, *O. piceae, Leptographium procerum* and *Sphaeropsis sapinea* for eight or 16 weeks, along with non-inoculated control samples. Three decay fungi, *Gloeophyllum trabeum*, *Phlebiopsis gigantean,* and *Schizophyllum commune*, were included as references for weight and toughness loss. Overall toughness and dry weight were not significantly ($p < 0.05$) different between wood specimens inoculated with sap staining fungi and the controls, except for *O. ips* 308 which caused 18% toughness loss, but not weight loss, in one out of three experiments. In contrast, *G. trabeum* reduced toughness by 61% and caused a weight loss of 8%, and *S. commune* and *P. gigantea* produced toughness losses of 32 and 16%, respectively, without any significant weight losses. None of the sap staining fungi tested degraded lignin or structural carbohydrates in radiata pine sapwood after 16 weeks' incubation.

Note: O. ips *is not implicated in mountain pine beetle-vectored bluestain but is one of the fungi that can be isolated from mountain pine beetle-killed trees after they have been standing dead.*

112. Schirp, A.; Farrell, R.L.; Kreber, B.; Singh, A.P. 2003. Advances in understanding the ability of sap staining fungi to produce cell wall-degrading enzymes. Wood and Fiber Science 35(3): 434–444.

The ability of selected sap staining fungi to produce the enzymes cellulase, xylanase, mannanase, pectinase, and amylase was investigated in vitro. While all test fungi secreted low amounts of xylanase (up to 1.64 æmoles/min/ml) and pectinase (up to 0.11 æmoles/min/ml) into the growth medium, extracellular cellulase was not detected. Furthermore, mannanase was produced only by *Ophiostoma piceae* (Munch) Syd. & P. Syd. (0.29 moles/min/ml). To the best of our knowledge, this is the first report of mannanase activity for any *Ophiostoma sp*. Amylase activity was higher than xylanase, mannanase, and pectinase activities for all test fungi. This confirms that sap-staining fungi preferentially metabolize readily accessible, nonstructural wood components, such as starch.

113. Schmid, J.M.; Mata, S.A.; McCambridge, W.F. 1985. Natural falling of beetle-killed ponderosa pine. Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Fort Collins, CO, USA. Research Note RM 454. 3 pp.

Trees killed by *Dendroctonus ponderosae* in the front range of Colorado deteriorated slowly for three to five years, during which time they were relatively sturdy and not unusually susceptible to windthrow. As deterioration progressed, toppling depended mainly on the occurrence of strong (> 75 m.p.h.) winds. Trees broke at or within 2 ft of ground level.

114. Shitova, A.E.; Biryukova, T.S. 1972. Effect of bluestain on the acoustic constant of spruce resonance wood. [In Russian]. Derevoobrabatyvayushchaya Promyshlemost 9:12–13.

Describes tests on specimens in which bluestain extended to (1) 10-20%, (2) 50-60%, or (3) 80-90% of the depth. The acoustic constant of (1) was about 10% greater, but that of (2) and (3) was respectively 8-15% and 50-60% lower than that of specimens without bluestain. It is concluded that wood with superficial bluestain can be used for the sounding boards of musical instruments.

115. Shitova, A.E.; Biryukova, T.S. 1973. Effect of bluestain on some strength properties of resonance wood. Derevoobrabatyvayushchaya Promyshlennost 7:16.

Describes further investigations on spruce resonance wood. Data on the density, static bending strength and radial impact hardness of the wood confirmed that resonance wood with up to 20-30% bluestain can be used for the sounding boards of musical instruments.

116. Sinclair, S.A. 1979. A mill operator's guide to profit on beetle-killed southern pine. U.S. Department of Agriculture, Washington, D.C., USA. Agriculture Handbook 555. 15 pp.

One of a series on the southern pine beetle (*Dendroctonus frontalis*) produced as part of the Combined Forest Pest Research and Development Program. The handbook is a tool to assist an operator determine whether a profit can be made from beetle-killed logs based on mill operating costs, cost of buying and processing logs, and lumber selling price.

117. Sinclair, S.A. 1980. SAWMOD: a tool for optimizing profit from beetle-killed southern pine sawtimber. Wood and Fiber 12: 29–39.

By using actual lumber grade yields, estimated residual volume, current market prices, and production variables, this computer model can provide economically optimal processing schemes. A particular version of the model is described which is concerned with butt logs and upper logs from southern pine that had been killed 12 or 20 months previously by *Dendroctonus spp*. The paper states that there is generally little problem marketing bluestained wood as it is not considered a defect within Southern Pine Inspection Bureau grading rules.

118. Sinclair, S.A.; Ifju, G.; Heikkenen, H.J. 1977. Bug boards: lumber yield and grade recovery from timber harvested from southern pine beetle-infested forests. Southern Lumberman 234(2900): 9–11.

Logs were sampled from plots of standing dead beetle-killed southern pines and from green control trees. The logs were converted in a sawmill and following grading, the recovery of 1-inch boards was determined. Although bluestain was prevalent in the lumber, the major causes of degrade were rot and large borer holes. Lumber grade yields were lower for beetle-infested timber and particularly for upper logs of infested trees. This indicates deterioration is faster in the upper part of the standing dead tree. Bluestain was also heavier in the upper part of the tree. The study also concluded that the lumber recovery factor was lower for beetle-infested wood than for sound saw-timber. Other problems with felling 12-month-dead trees were safety hazards from breaking branches and contractor reluctance to take salvage jobs because of lower profits.

Note: Bluestain is not considered a defect in grading southern pine.

119. Sinclair, S.A.; Ifju, G. 1977. Processing beetle-killed southern pine – an opinion survey in Virginia. Southern Lumberman 235(2916): 11–14.

In the 1974-75 epidemic of the southern pine beetle 47% of the southern pine acreage was infested. The paper reports the results of a questionnaire survey of sawmills processing beetle-killed material. The most common problem reported was the wide variation in moisture content and increased permeability caused by decay fungi, which causes faster than normal drying. Also reported were debarker jamming, because of sheets of bark sloughing off, and boards breaking in the planer, as well as other chipping and sawing problems. The most serious degrade of lumber was due to rot and large borer holes. The sawmillers reported an average of 11-20% loss in lumber recovery factor and on average received somewhere between 1% and 25% less for lumber from beetle-killed trees.

Note: The increased permeability may have been wrongly ascribed by the author to decay in this case. Bluestain fungi can also cause increased permeability.

120. Sinclair, S.A.; Ifju, G. 1979. Lumber quality of beetle-killed southern pine in Virginia. Forest Product Journal 29(4): 18–22.

Beetle-killed (*Dendroctonus frontalis*) southern pine (*Pinus* 'Southern') trees were harvested (a) 12 months, (b) 20 months (2 winters and 1 summer) and (c) 20 months (2 summers and 1 winter) after foliage fade. Out-turn of lumber of grade 2 or better was 96% for green control trees, 55% for (a), and 24% for (c). The major causes of degrade were decay and large borer holes. Lumber recovery factor was also significantly lower for beetle-killed trees because of extra slabbing of the logs by the sawyer and greater amounts of cull boards. The value of a log from (c) was less than half that from the control. The report concludes that profitable processing of upper pine logs into lumber when left on the stump for two summer seasons and one winter season after foliage fade appears unlikely in climates similar to the piedmont of Virginia. Problems not addressed in this study include harvesting difficulties and weight-scaling problems due to the beetle-killed logs being dry.

121. Sinclair, S.A.; Ifju, G.; Johnson, J.A. 1978. Changes in toughness of wood from beetle-killed shortleaf pine. Forest Products Journal 28(7): 44–47.

Matched groups of sapwood specimens from healthy trees of *Pinus echinata*, and from trees killed by bark beetles and dead on the stump for 2 months (light stain), 12 months (heavy stain with incipient decay), and 20 months (partial decay) were tested for traditional and fracture toughness. Both types of toughness were sensitive to the effects of early (2-month) fungal sap stain and incipient decay, but fracture toughness was less affected than traditional toughness, strength retained after 20 months decay being 83% and 42% respectively. Fracture and traditional toughness were linearly related over the 20-month period they were measured.

122. Sinclair, S.A.; McLain, T.E.; Ifju, G. 1979. Strength loss in small clear specimens of beetle-killed southern pine. Forest Products Journal 29(6): 35–39.

Samples of shortleaf pine (*Pinus echinata*) and loblolly pine (*P. taeda*) killed by *Dendroctonus frontalis* Zimm. were taken at various times after foliage fade in several areas of the southern Piedmont and Coastal Plain of Virginia in 1975 and processed into lumber; healthy trees were also sampled. Small clear specimens were prepared from the lumber and examined for strength loss. The results indicated that consideration should be given to the effect of incipient decay and associated sap strain in the grading of structural lumber taken from beetle-killed trees that have remained on the stump for more than two months after foliage fade. However, it was thought that it would be necessary to study these effects on the behaviour of full-sized lumber to quantify the severity of the problem. In particular, further examination of the moduli of elasticity and rupture of full-sized graded lumber was considered necessary before any changes to design stresses or grading procedures could be contemplated.

123. Sinclair, S.A.; McLain, T.E.; Ifju, G. 1979. Toughness of sap-stained southern pine salvaged after beetle attack. Wood and Fiber 11(1): 66–72.

Approximately 1200 small clear specimens were machined from visually graded dimension lumber and tested for toughness. Dimension lumber was obtained from green healthy southern pine and beetle-killed southern pine at various times after foliage fade. The specimens machined from beetle-killed material were free of defects with the exception of sap stain. Toughness generally decreased with increasing time between foliage fade and the harvesting of the beetle-killed sawtimber. Most of the loss in toughness occurred during the first year after foliage fade. For certain structural applications where toughness or shock resistance of wooden members may be of some importance, caution should be exercised in the utilization of beetle-killed southern pine.

124. Snellgrove, T.A.; Fahey T.D. 1978. Values and problems associated with utilization of dead timber. Pages 1–10 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

Snellgrove, T.A.; Fahey, T.D. 1977. Market values and problems associated with utilization of dead timber. Forest Products Journal 27(10): 74–79.

These identical references discuss mountain pine beetle-killed lodgepole pine, but mainly focus on dead true firs and white pine. Dead trees resulted in more logging and handling losses in the woods and mill yards, decreased lumber volume from logs sawed and degrade of lumber due to deterioration-related defects, such as drying checks, sap rot, borer damage. The percentage of narrower lumber increased as time since death increased to a maximum of 38% after seven years. For white pine, the average total value per 100 ft^3 of logs depended on the trees' diameter. Total losses in value (dollars/100 ft^3 gross tree volume) for white pine dead for 0-2, 3-6 and >7 yr were 26%, 55% and 69%, respectively, of initial value. Loss in value for true fir dead for 0-2 yr was 26%. The major obstacles to utilization of dead trees are the shorter lengths of dead logs (owing to breakage), manufacturing problems (e.g., the need to install larger chip-processing facilities), market considerations, and bias in the industry).

125. Snellgrove, T.A.; Cahill, J.M. 1980. Dead western white pine (*Pinus monticola*): characteristics, product recovery, and problems associated with utilization. Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, Portland, OR, USA. Research Paper PNW-270. 63 pp.

This pivotal report concerns white pine that has been killed by white pine blister rust or mountain pine beetle. The changes that occur in the standing tree are described and the effects of these on product recovery are evaluated. There was a substantial difference in lumber quality between live and dead timber, the latter in three classes of logs. Live trees produced a high percentage of No. 2 and better, and shop grades, whereas older dead material produced more Nos. 4 and 5 Commons. Loss of lumber grade was greatest in highest quality logs because there was more grade to lose. Lumber width also decreased as time since death increased. The average value of lumber produced decreased by about 50% from live trees to the oldest dead class. This decrease in value reflects both lower quality and narrower widths. Losses in log values result from combined loss of lumber volume and value. The average value decreases from live logs through the oldest dead logs. Log value also decreases with a decrease in diameter; consequently both size and deterioration should be considered when values of logs are considered. Drying of the logs with age since death resulted in brash breakage that increased with time since death. This also should be combined with lumber volume and value losses. Mathematical equations to predict product recovery and value are included.

126. Snellgrove, T.A.; Ernst, S. 1983. Veneer recovery from live and dead lodgepole pine. Forest Products Journal 33(6): 21–26.

Results are presented of a sawmill study of timber obtained from healthy lodgepole pine and from lodgepole pine that had been killed one to three years previously by *Dendroctonus ponderosae*; all the trees were selected from sites in the Winema National Forest, Oregon. Volume recovery of veneer from one-year dead trees was not significantly different from that of live trees, but recovery from three-year dead trees was about 30% less. Veneer grade recovery was not affected by time-since-death, but a higher percentage of random-width strip was produced from the older dead logs.

127. Tang, J.L. 1983. Wood properties affected by mold, blue-staining, and wood destroying fungi. [In English]. Quarterly Journal of Chinese Forestry 16(4): 421–425.

This paper presents a selected review of past findings and thought in the general field of wood deterioration, and various property changes. It attempts to relate basic phenomena of anatomical, chemical, and physical property changes of the wood infected by mold, blue-staining, and wood-destroying fungi. As a result of different patterns of attack on wood by the microorganisms, various degree of wood property changes were shown.

128. Tegethoff, A.C.; Hinds, T.E.; Eslyn, W.E. 1977. Beetle-killed lodgepole pines are suitable for powerpoles. Forest Products Journal 27(9): 21–23.

Beetle (*Dendroctonus ponderosae*)-killed stems of lodgepole pine (*Pinus contorta*) from Southeast Idaho were tested as poles meeting the American National Standards Institute (ANSI) standard (1972). The dead trees examined yielded 38% of standard poles 35-40 ft long. Basal decay caused half the total decay (which affected 12% of all dead trees) and could usually be removed by long-butting at 4-8 feet from the base. Conks were found on only 19% of trees suitable for poles; other external signs were not reliable indicators of decay. The moisture content of upper portions of dead trees fell rapidly after death, but root and butt rots continued to develop in the butt, which remained relatively moist. It is recommended that beetle-killed trees suitable for poles should be harvested soon after death.

129. Thunell, B. 1952. Einwirkung der Bläue auf die Festigkeiseigenschaften der Kiefer. [Effect of blue-stain on the strength properties of Pine.] [In German]. Holz Roh und Werkstoff 10(9): 362–365.

Thunell found that stain caused by *Ceratocystis pini* significantly reduced the bending and compressive strength of pine sapwood (up to 30%), but the wood was still acceptable for construction uses.

Note: This fungus is not associated with the mountain pine beetle.

130. Tomminen, J.; Nuorteva, M. 1992. Pinewood nematode, *Bursaphelenchus xylophilus* in commercial sawn wood and its control by kiln-heating. Scandinavian Journal of Forest Research 7(1): 113–120.

In commercial green pine sawnwood (50 X 150 mm) imported from Canada into Finland, the pinewood nematode *Bursaphelenchus xylophilus* was found more frequently and in greater numbers in bluestained sections of lumber boards. Heat treatment was shown to an effective means of control of pinewood nematode in lumber.

Note: Indicates that bluestained wood needs to be heat treated to ensure pests are not carried within.

131. Troxell, H.E.; Tang, J.L.; Sampson, G.R.; Worth, H.E. 1980. Suitability of beetle-killed pine in Colorado's front range for wood and fiber products. Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Fort Collins, Co, USA. Resource Bulletin RM-2. 10 pp.

Beetle-killed *Pinus ponderosa* wood is suitable for most of the traditional uses of the species, e.g., boards, lumber, paneling, and pallets. However, the beetle-killed timber is drier, is usually bluestained due to the presence of fungi, and may contain woodborers and decay. Mechanical properties, which may be affected, are discussed. The specific gravity of heartwood of beetle-killed timber is similar to that of live timber, but the specific gravity of sapwood is slightly lower than that of live timber. The moisture content in beetle-killed trees decreases rapidly after the tree dies. The moisture content is higher at the base of the tree and decreases with height. The amount of drying depends on the length of time since death. The wood's tendency to split and warp during drying is indicated by the difference in shrinkage between radial and tangential directions. Increased amounts of dissolved substances from the dead tree may be formed from the attack of fungi. Differences in pH between green wood and beetle-killed wood are minor and should not affect most wood products, including those involving adhesives. The wettability of wood from beetle-killed trees is apparently greater than that from living trees and should produce glue bonds comparable to or better than normal wood. Products suited to dead ponderosa pine wood and fiber include particleboards, plywood, laminated wood products, and pulp and paper. The authors suggest that the use of beetle-killed ponderosa pine wood for pulp and paper is dependent on the moisture content, the amount of blue staining, and on the degree of decay, which affects pulp yield and quality.

132. Tsukiji, R. 1952. Decay durability of blue-stained timber. [In English]. Wood Industry Tokyo 7: 16–18.

This author found *Pinus densiflora* sapwood stained by *Ceratocystis ips* to be as resistant as clean timber is when tested against four species of decay fungi.

133. Uusvaara, O.; Loyttyniemi, K. 1977. The effect of injuries caused by summer storage of sawlogs on the quality and value of sawn timber. Metsantutkimuslaitoksen Julkaisuja 89(3): 1–61.

Unbarked logs of pine (*Pinus sylvestris*) and spruce (*Picea abies*) were stored each month at five locations in southern, eastern, and northern Finland for two, four or six weeks each month from April to September. After storage, logs were sawn and graded. Bluestain was abundant during June and July (caused by insect galleries and mechanical injuries), and August (caused by air-borne fungi); value losses were greatest during this period, especially after four- or six-week storage.

134. Von Schrenk, H. 1903. The 'blueing' and the 'red rot' of the western yellow pine, with special reference to the Black Hills forest reserve. U.S. Department of Agriculture, Washington, D.C., USA. Bureau of Plant Industry Bulletin 36. 40 pp.

This author was among first to report the compression strength of wood infected with a bluestain fungus did not differ from unstained wood. He reported a series of tests with stained and unstained pieces of wood and concluded that stained wood for all practical purposes was as strong as the unstained. Neither the specific gravity nor resistance to compression were altered. He also observed a greater resistance to splitting along a tangential plane in bluestained wood.

135. Wallace D.E. 1978. The challenges of marketing products from dead timber. Pages 95–97 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

The first and most important stage of dead timber lumber marketing lies in the timber management decision to salvage early and fast when catastrophe strikes. Grade rules for lumber are complex tools based on scientific data on the characteristics of the lumber. They do not differentiate between stain, checks, or insect holes that appear in salvage timber, and are not more grade restrictive than stain, shake, or white speck found in live timber. However there is a disproportionate request for reinspection of salvage lumber compared to material manufactured from living trees. Lodgepole pine develops checks as the bark falls off but full recovery of the sapwood will be lost if the harvest isn't immediate. The limiting characteristics of stain and seasoning checks are most prevalent in the part of the tree where selects, shops, and upper-grade commons are realized. As demonstrated in bark beetle attacks in the 1950s, speciality items that can be made from dead trees can be successfully promoted. Quick access to dying timber at an economically sensible price is the bottom line.

136. Walters, E.O.; Weldon, D. 1982. Utilization of southern pine beetle killed timber for lumber in East Texas. Texas Forest Service, College Station, TX, USA. Circular 256. 4 pp.

Green lumber volume and grade recovery were evaluated for trees salvaged 0, 45, 90, 180 and 360 days after being killed by *Dendroctonus frontalis*. Trees had either been left standing after kill or had been felled but not topped soon after kill (cut and leave). Tabulated results show that grade is more adversely affected than yield in beetle-killed timber. Lumber value for beetle-killed timber salvaged after 45 days compared well with that for green timber; thereafter the value decreased steadily. Trees dead for 90 days yielded 75-79% of green sawlog lumber value and about 89% of green sawlog volume. It appears that 180-360-day beetle-killed timber is uneconomic to use because of decay.

137. Walters, E.O. 1982. Bending strength loss for southern pine beetle (SPB)-killed timber. Texas Forest Service, College Station, TX, USA. Circular 260. 4 pp.

Bending strength for timber from trees killed by the southern pine beetle, *Dendroctonus frontalis*, and trees felled healthy were compared. Relative density, modulus of rupture and modulus of elasticity values were assessed at 12% moisture content for test samples from trees felled at 0, 45, 90, 180, and 360 days after kill. Reductions in modulus of rupture of 10% were found 90 days after kill, and of 12% by 180 to 360 days. The decrease in bending strength is thought to be caused by incipient decay and associated sap stain. No reduction in relative density was found. By 45 days, 75% of the standing trees were grade 2 or better by 90 days, 26% were grade 2 or better. It is recommended that beetle killed trees are salvaged within 45 days in Texas.

138. Williams D.; Mucha, E. 2003. Characterizing the gluing and finishing properties of wood containing beetle-transmitted bluestain. 19 pp. Report to Forest Innovation Investment. Forintek Canada Corp., Western Division, Vancouver, B.C. [W-1986].

The third of three studies done at Forintek Canada Corp. to characterize the properties of mountain pine beetle killed and bluestained sapwood, in this case the gluing and finishing properties. Pieces of bluestained and non-stained 2 x 4-inch lodgepole pine lumber were dried to a moisture content typically targeted by the furniture sector, and edge-glued panels were made with bluestained-to-bluestained joints and non-stained-to-non-stained joints. Panels were cut into samples for ASTM D1101 and D905 standard (durability and shear strength) tests and for tests of various finishes that could potentially mask the bluestain. Various finish coatings either used alone or in combinations with others were subjectively evaluated. The laminating tests show that gluelines in lodgepole pine that contains beetle-transmitted bluestain were not significantly different in strength from gluelines in unstained wood when polyvinyl acetate and phenol resorcinol formaldehyde adhesives are used. The durability and shear strength of the bluestained beetle-killed wood gluelines easily met the requirements specified by the ASTM standards. The appearance of bluestained wood can be enhanced or highlighted by a simple standard clear furniture finish. Bluestain in parts of edge-glued panels can be masked if certain types of finishes are employed. The finishes that gave more consistently good masking results were those containing blue, red, and charcoal tints in the stain, toner, or glaze coatings. Increased permeability of the bluestain did not affect the adherence of any of the finishes.

139. Woodson, G. 1985. Utilization of beetle-killed southern pine. USDA Forest Service, Washington, D.C., USA. General technical report WO 47. 27 pp.

Notes on the physical appearance, wood properties, harvesting and storage, weight scaling, milling, seasoning and preservation, and suitability for lumber, plywood, pulp and paper, composite products, specialty products and firewood of southern pine trees killed by *Dendroctonus frontalis*.

140. Work, L.M. 1978. Dead timber evaluation and purchase – firewood or lumber. Pages 179–185 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

Oregon resources of larger dead trees have a larger percentage of heartwood and this enables them to hold their values longer. Three types of losses are described:

a. Any fibre loss has a detrimental effect on commercial uses whether firewood, lumber or paper.
b. Quality loss results from bluestain, particularly in ponderosa and lodgepole pines. The greatest value loss of stained versus green logs results in top-quality ponderosa pine logs. Grade 1 logs loose 55-66%; Grade 2 logs loose 44-56%, Grade 3 logs loose 23-50% and Grade 5 logs loose 17-44%. The greatest quality loss normally occurred in the mid-range diameter classes for each log grade.
c. 3) A third type of loss is from "product loss", physical characteristics, such as checking. It is often impossible to saw solid lumber products from spiral grain logs. Studs are easier to produce than longer lengths. The biggest value losses in dead logs are associated with handling. Dry, brash trees are more susceptible to breakage (11% in four year dead trees versus 0% in live trees). Log skidding, loading, hauling, unloading, mill deck loading, and scaling all involve handling with large machinery where handling losses occur, resulting in shorter lumber lengths of lower quality. Secondary problems with handling dead wood are higher accident rates (and workman's compensation rates), health problems, or psychological letdowns. Toppled trees cause delays in skidding and the author's study of portable chipping productivity showed a 20% decrease when chipping dead wood. Harvesting costs are higher. Selection of quality stems is impaired; for example, a spiral checked log may not be recognized as such until it has been hauled to the landing when it has to be culled.

141. Worth, H.E. 1978. Marketing considerations for products from dead timber. Pages 87–94 *in* The dead softwood lumber resource: proceedings of symposium held May 22–24, 1978 in Spokane, WA, USA. Washington State Univ., Pullman, WA, USA.

Summarizes a technique being used at the Rocky Mountain Forest and Range Experiment Station to evaluate product potential for dead timber. The approach involves: 1) Inventory of all materials available at a logically and geographically determined processing center; 2) Deduction of all committed production, leaving additional product opportunities available; 3) Evaluation of technological characteristics of these unused resources; 4) Postulation of markets that can be conceivably penetrated, comparing estimated product costs with projected market volumes and prices, and; 5) Determination of what production and marketing strategies would work. At presentation time this method was still under development, but was put forth as a realistic framework for assessing dead timber utilization options.

Section 3. Effects of bluestain on pulp and paper properties

142. Araki, D.; Lee, C.L. 1991. Brightening of thermomechanical pulp produced from sound and stained aspen logs. Forest Engineering Research Institute of Canada, Pointe Claire, QC. Technical Note TN 177. 6 pp.

Sound and sap stained wood from aspen (*Populus tremuloides*) was pulped by thermomechanical pulping (TMP). The percentage of acceptable chips and the brightness were both less for stained wood than for sound wood. Brightness was poor for both types of raw material. A market pulp of uniform quality could probably be produced by sorting the stained and sound wood, mixing them in a controlled ratio, and then increasing the brightness with chemicals.

143. Behrendt, C.J.; Blanchette, R.A. 1997. Biological processing of pine logs for pulp and paper production with *Phlebiopsis gigantea*. Applied and Environmental Microbiology 63(5): 1995–2000.

Phlebiopsis gigantea (*Phanerochaete gigantean*) is a white rot fungus that rapidly colonizes cut stumps, stems, and branches of pine. Two laboratory and several field studies showed that inoculation of red pine logs, *Pinus resinosa*, with *Phlepiopsis gigantea* reduced the pitch content of wood, facilitated bark removal, modified wood cells, and controlled detrimental sap stain. Isolations from inoculated logs revealed up to 100% and 80% colonization of the sapwood by *P. gigantea* after eight weeks in the field and 32 days in the laboratory, respectively. Logs colonized by *P. gigantea* in both the laboratory and field showed a 9% to 71% reduction in pitch content, as well as a significant enhancement of bark removal. Examination with Simons' stain of refined wood fibres from inoculated logs revealed an increase in cell-wall porosity. Blue-stain fungi that cause dark discoloration of the sapwood were inhibited by inoculation with *P. gigantea*. These studies demonstrated that biological processing of logs with *P. gigantea* could result in substantial benefits to the pulp and papermaking process.

Note: This paper is primarily focused on the inhibition of blue-stain and the prevention of pitch problems, and is not centered around the effects of bluestain on pulp quality.

144. Blanchette, R.A.; Farrell, R.L.; Burnes, T.A.; Wendler, P.A.; Zimmerman, W.; Brush, T.S.; Snyder, R.A. 1992. Biological control of pitch in pulp and paper production by *Ophiostoma piliferum*. Tappi 75(12): 102–106.

The bluestain fungus, *Ophiostoma piliferum*, in addition to being an important agent of damage to felled softwood timber, has been found to be able to degrade pitch in large concentrations. A non-pigmented isolate has been developed which grows rapidly and is capable of degrading large quantities of pitch. Heavily stained wood chips of loblolly pine (*Pinus taeda*) were examined for presence of pitch and bluestain fungi. *O. piliferum* was the most frequently isolated bluestain fungus; it grew preferentially in resin canals and ray parenchyma cells, removing resin and causing some damage to surrounding thin-walled epithelial cells. Freshly cut loblolly pine wood chips were inoculated with the colourless isolate of *O. piliferum* in laboratory and pulping mill studies. Colonization of the chips was rapid and concentrated in areas where pitch accumulates. There was a 40% reduction in dichloromethane extractives after 12 to 14 days exposure to the colourless isolate and no discoloration of the chips. Results were similar in wood chips exposed to wild-type isolates, but discoloration was severe. Treating wood chips with the colourless isolate appeared to prevent colonization by wild-type isolates of bluestain fungi.

Note: The effect of bluestain on pulp quality is not examined in this paper.

145. Bryukhanov, V.A.; Malysheva, O.N.; Solov'ev, V.A. 1975. Storage of chips in the timberyard of the Krasnoyarsk combine. [In Russian]. Bumazhnaya Promyshlennost 9: 11–12.

Describes studies on the storage of pulp chips in the open [cf. FA 35, 5635, 6518; 36, 2379], giving comparative data on rates of self-heating and spread of bluestain and other fungal conditions for five-metre piles of two different kinds of chips stored for five months (July-Nov.): (1) Aspen/coniferous chips prepared from freshly felled timber delivered by road; and (2) coniferous chips (spruce, pine, and fir) prepared from floated timber. Laboratory sulphite cooks showed that summer storage of softwood chips did not affect the strength properties of the pulp.

146. Chidester, G.H.; Bray, M.W.; Curran, C.E. 1938. Characteristics of sulphite and kraft pulps from blue-stained southern pine. Technical Association of the Pulp and Paper Industry. Technical Association Papers 21(1): 137–140.

Sulphite and sulphate pulping experiments were conducted to determine the effect of the bluestain produced in loblolly and shortleaf pines by inoculation of stored chips or by natural development in pulp logs under ordinary mill-yard storage conditions. The bluestained wood gave unbleached sulphite pulps that were darker in colour, had higher dirt content, and required more bleach than the pulps from the unstained wood, these differences being proportional to the percentage of stained wood used. No significant differences in the yield or strength properties of the pulps resulted from bluestain nor were any appreciable differences noticed in the results of inoculated and naturally infected wood. The unbleached sulphate pulps from the bluestained wood were also darker in colour, contained more specks, required from 2.5 to 5 % more bleach than the pulps from the unstained wood. As in the case of the sulphite pulps, no difference in yield was attributable to bluestain. Likewise, no appreciable differences were noticed in the effects of staining in field and in the laboratory.

147. Dorado, J.; Claassen, F.W.; Lenon, G.; Beek, T.A. van; Wijnberg, J.B.P.A.; Sierra-Alvarez, R. 2000. Degradation and detoxification of softwood extractives by sap stain fungi. Bioresource Technology 71(1): 13–20.

Wood extractives (resin) cause pitch deposition problems and effluent toxicity in pulp and papermaking. The ability of six sap staining fungi to degrade and detoxify extractive constituents in Scots pine (*Pinus sylvestris*) sapwood was examined, and the results were compared with those obtained with the commercial depitching fungus Cartapip (*Ophiostoma piliferum*). *Pestalotiopsis crassiuscula* and *O. piliferum* were the best strains, and they provided high reductions of total resin (50-60% in six weeks). Both strains were highly effective in the degradation of individual extractive components including triglycerides, diglycerides, and free fatty acids. Although all strains displayed moderate to high pitch degradation, their detoxifying capacity was limited. Two important exceptions were *Ceratocystis deltoideospora* and *O. piliferum* that caused a 11- to 14-fold decrease in toxicity (Microtox bioassay). These results indicate the potential of wood pre-treatment with the selected sap stain fungi for minimizing pitch problems and decreasing effluent toxicity in pulping.

148. .Dorado, J.; Martinez Inigo, M.J.; Beek, T.A. van; Claassen, F.W.; Wijnberg, J.B.P.A.; Sierra-Alvarez, R. 1998. Screening of fungal strains for wood extractive degradation. The 20th Annual Meeting of the International Research Group on Wood Preservation held June 14–19, 1998 in Maastricht, Netherlands. IRG Secretariat, Stockholm, Sweden. IRG-WP-98-10254 . 11 pp.

Fungal strains were screened for their ability to degrade apolar extractives in wood from Scots pine (*Pinus sylvestris*). The degradation of total wood extractives by 91 different strains was monitored in stationary batch assays incubated for six weeks. The results obtained show that the ability of wood-inhabiting fungi to use wood extractives varied greatly, even for different isolates of the same species. Fungal pre-treatment provided up to 70% total resin reduction. Outstanding strains included mainly white rot fungi. Several sap stain strains were also efficient extractive degraders. Apolar extractives are well known for their inhibitory effect to fungal growth. However, these findings show that wood extractives can serve as a carbon source for numerous wood-inhabiting fungi. Furthermore, these results indicate the potentials of wood-inhabiting fungi in biotechnological processes for pulp and paper manufacturing, i.e. wood-chip depitching and biodetoxification.

149. Farrell, R.L.; Blanchette, R.A.; Brush, T.S.; Hadar, Y.; Iverson, S.; Krisa, K.; Wendler, P.A.; Zimmerman, W. 1993. CartapipTM: a biopulping product for control of pitch and resin acid problems in pulp mills. Journal of Biotechnology 30(1): 115–122.

A biological treatment of wood chips using specific isolates of the ascomycete, *Ophiostoma piliferum*, which results in a reduced extractive content, specifically pitch (resin), of the wood chips is described. Natural isolates of the fungus cause bluestain in the sapwood of conifers. Colourless isolates isolated in the lab, marketed as CartapipTM, have been shown not to cause discoloration of wood. Hyphae preferentially colonize ray parenchyma cells and resin canals. Studies have shown that not only does overall pitch content decrease with treatment of wood chips by the *O. piliferum* strains tested, but also many free resin acids and fatty acids are significantly reduced. Additionally, treatment of wood chips with the colourless strains of *O. piliferum* results in biocontrol since other microorganisms including staining organisms have significantly reduced growth on the wood chips. Therefore bleach chemicals can be saved in the processing of mechanical pulp to give paper of a greater brightness.

150. Gee, W.; Johal, S.; Hussein, A.; Yuen, B.; Watson, P. 2003. The pulping properties of mountain pine beetle-killed lodgepole pine. Paprican Research Report (available upon request).

Thermomechanical and kraft pulps were prepared and tested from current, 1-year, 2-year, and 3-year mountain pine beetle-infested lodgepole pine trees from Williams Lake. There was a significant increase in fine and pin chip content with increasing time since beetle infestation because reduced moisture content and incipient decay increased the susceptibility to mechanical damage during the chipping process. In thermomechanical pulping there was no well-defined relationship between energy consumption and length of time since beetle infestation. However, the results indicated that up to 2-year beetle-infested lodgepole pine trees can be used in thermomechanical pulping process without any significant detrimental effects on either mechanical or optical properties. Currently-infested trees had a significantly lower kraft pulp yield and required more alkali to pulp to a given kappa number than those from 1, 2, and 3-year beetle infested trees.

151. Hitchings, R.G.; Levi, M.P. 1981. Southern pine beetle-killed trees can be salvaged by kraft pulping. Pulp and Paper 55(10): 156–159.

The influence of beetle-killed southern pine on kraft pulps prepared from mixtures of fresh green trees and two classes of recently killed material (dead for three months) and long-killed (dead for about 30 months) trees was determined. A decrease in specific gravity was observed in comparing of healthy wood to the recently killed wood (4.3% loss) and long-killed wood (10.9% loss). The loss of wood yield is expected as this generally occurs when pulpwood has been subjected to insect and microorganism attack over the periods of time represented. An amount of fines material also increased with length of time the beetle-killed pine trees remained in the forest before harvesting. The kraft pulping results indicated that the pulp yields for the sound and beetle-killed trees were similar, however the percentage of rejects constituted almost one-half of the total pulp yield for the beetle-killed material. More alkali was required by the beetle-killed wood to reach the same screened yield and kappa number as healthy wood. Handsheet strength properties from the kraft pulps indicated that the recently-killed and long-killed wood as well as their mixtures with healthy wood all exhibited poorer burst, tear, and tensile strengths than the healthy wood pulp. The lower specific gravity of the beetle-killed wood would also have its proportional influence on volume yield.

Note: Reference was included as the implication is that freshly killed pine would contain bluestain.

152. Ifju, G.; Oderwald, R.G.; Ferguson, P.C.; Heikkenen, H.J. 1979. Evaluation of beetle-killed southern pine as a raw material for pulp and paper. Tappi 62(2): 77–80.

Southern pine trees left dead on the stump for up to three years following southern pine bark beetle infestations in the Virginia piedmont and coastal regions were felled, chipped, and pulped in an experimental kraft digester. The trees included in the study were stratified according to the length of time they had been standing dead after infestation. Chips from each tree were cooked, the yield was determined, and handsheets were prepared and tested for tear and breaking length after five different beating periods. Despite apparent decay, no drop in kraft pulp yield was found compared with green control material. However, tearing resistance of the handsheets decreased after 0-6 months following death. Paper tensile strength increased slightly after six months following death and then increased to a small loss after 24 months. Dead southern pine trees left on the stump for as long as two years after a beetle attack may be safely used as raw material by kraft mills without affecting yield and with only a slight effect on paper properties. However, quick removal of the dead material is recommended because of easy breakage of branches and tops of dead trees.

Note: Although this is clearly one of the most comprehensive reports on the effect of beetle attack on pulping and pulp quality, the conclusions drawn regarding pulp strength are not valid. The pulps were not compared at the same kappa number, therefore the initial increase in pulp strength can be attributed to a milder treatment of the fibres (kappa 40 versus 36). If all pulps had been cooked to a constant H-factor, it is likely that decreases in pulp strength would have been observed over the range of the samples evaluated.

153. Ince, P.J. 1982. Economic perspective on harvesting and physical constraints on utilizing small, dead lodgepole pine. Forest Products Journal 32(11-12): 61–66.

Costs, energy requirements, and physical characteristics of the wood were investigated for small dead lodgepole pine harvested from the Umatilla National Forest in eastern Oregon during a three-month demonstration harvest. An informal market survey of several dozen local timber buyers was conducted in order to ascertain the current problems and potential in use. Results showed that the cost of producing chips alone was lower and less variable than the cost of producing roundwood and chips. Market prices of both roundwood and chips varied considerably with time. Harvesting presented no major difficulties and small dead lodgepole pine wood was generally acceptable to buyers and used for a variety of products. Energy inputs to harvesting were small (6-7%) relative to the recoverable heat if the deadwood is used as fuel. The cost-to-energy-value ratio of delivered dead lodgepole pine chips was less than the price-to-energy-value ratio of oil and gas, but not coal. However, the price-to-energy-value ratio of dead lodgepole pine chips is likely to be higher and more variable than the cost ratio, due to alternative and competing end uses and variable market prices.

Note: The current economics in British Columbia of dead wood chips as a fuel source suggests $80/bdt at $0 stumpage. The fuel value is approximately 20GJ/bdt, which equates to fuel costs of $4/GJ: this is barely competitive with natural gas (at current prices).

154. Ince, P.J.; Henley, J.W.; Grantham, J.B.; Hunt, D.L. 1984. Costs of harvesting beetle-killed lodgepole pine in eastern Oregon. Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, Portland, OR, USA. General Technical Report PNW-165. 26 pp.

The costs (1979) were assessed of harvesting roundwood and whole-tree chips of lodgepole pine infested with *Dendroctonus sp*. Mechanized harvesting was conducted on six sites covering 134 acres. The average cost per ton of producing chips was $31.30, wet, delivered 50 miles from the harvesting site. The average cost per ton of logs was $50.28. Gross energy required for harvesting was about 3.4% of the gross energy content of the delivered products.

155. Kayama, T. 1955. Pulping of blue-stained pinewood. I. Sulfate Process. [In Japanese] Mokuzai Gakkai shi = Journal of the Japan Wood Research Society 1(1): 1–5.

Sapwood chips of *Pinus densiflora* were exposed to *Ophiostoma ips, O. pini*, and *Leptographium* species for 60 days at 20-25°C, and the bluestained wood was analyzed and compared with sound wood. The results for bluestained and control wood were respectively, ash content 0.55-0.65% and 0.41%, hot water extractives 2.34-4.18% and 3.56%, ethanol/benzene extractives 2.02-2.29% and 3.42%, pentosans 12.39-12.58% and 11.49%, crude cellulose 52.64-56.76% and 57.69%, and lignin 26.74-28.16% and 25.62%. Bluestained and control wood did not show a significant difference in yield and Roe number of their unbleached and bleached sulfate pulps. However, in proportion to the degree of bluestaining of wood, the colour of the unbleached pulp was darker and the brightness of the bleached pulp was lower. There was no significant difference in strength of the unbleached and bleached pulp between bluestained and control, but the folding endurance was very weak for the pulp obtained from bluestained.

156. Kayama, T.; Yonezawa, Y. 1958. Pulping of blue-stained pinewood. II. Sulfite Process. [In Japanese] Mokuzai Gakkai shi = Journal of the Japan Wood Research Society 4: 243–247.

Paper pulp and dissolving pulps were prepared from a bluestained pinewood and sound wood by the sulfite method. Pulp from bluestained pinewood was more difficult to bleach than was pulp from sound wood. Even the pulp from the former could be purified up to the standards required of dissolving pulp by the usual multistage bleaching, but the filtration of viscose from pulp from bluestained wood was difficult.

157. Komarov, F.; Nagrodskii, I.; Belyaev, I. 1936. Production of sulfite pulp from spruce damaged by sap rot and by blue stain. [In Russian]. Bumazhnaya Promyshlennost 15(5): 33–38.

The results of comparative laboratory sulfite pulping of spruce – normal and damaged by bluestain and by destructive sap rot – are described. The bluestained spruce gave a greater yield of pulp by weight and volume than the normal wood. The bluish pulp is completely decolorized in bleaching. The sap-rotted wood gave a greater pulp yield by weight; the product is somewhat inferior in mechanical properties.

158. Lougheed, M.; Dutton, B.; Huang, Q. 2003. Suitability of bluestained chips for the production of high yield market pulp. Pages 287–292 *in* International Mechanical Pulping Conference held June 2–5, 2003 in Quebec City, QC. Pulp and Paper Technical Association of Canada, Montreal, QC.

Quesnel River Pulp is a market pulp mill that use fibre from local sawmill residual chips. A significant component of the chip mix is lodgepole pine, *Pinus contorta,* from beetle-killed stands. A lab-scale study was conducted to investigate the effects of bluestain chips on refining energy, bleach consumption, and final pulp quality. This paper presents the methodology and findings of the study that determined these chips to be highly appropriate for the thermomechanical (TMP) and bleached chemithermomechanical (BCTMP) processes.

159. Löyttyniemi, K.; Uusvaara. O. 1972. Effect on the quality of pulp of blueing in pine pulpwood caused by fungi associated with insects. [In Finnish]. Paperi ja Puu 54(8): 472–474.

This study examined the effects of the blueing of conifer pulpwood caused by fungi associated with bark beetles on the quality and properties of bisulfite pulp. Degraded pine (*Pine silvestris* L.) pulpwood, blued by *Blastophagus minor* Hart. (*Col., Scolytidae*), and control material from the same logs were processed in the laboratory by the Mg bisulfite method. The brightness of the pulp processed from blued wood was low before bleaching, and even after bleaching it remained much darker than pulp from the control. However, the consumption of bleaching chemicals was 16.5% higher than that in bleaching control pulp. The pulp yield of blued logs was slightly lower, but the strength properties were better than those of the pulp processed from prime wood.

160. Lowery, D.P.; Hillstrom, H.A.; Elert, E.E. 1977. Chipping and pulping dead trees of four rocky mountain timber species. Intermountain Forest and Range Experiment Station, USDA Forest Service, Missoula, MT, USA. Research Paper INT-193. 12 pp.

The vast quantity of dead down and standing timber in the Rocky Mountains is a potential resource for the pulp and paper industry. Pulpwood bolts of dead Engelmann spruce, Douglas-fir, western larch, and lodgepole pine were experimentally chipped and evaluated as pulp material. Samples from dead bolts and green bolts indicated that the dead wood was sound (specific gravities were essentially the same) and that the dead tree bolts had much lower percent moisture content than the green bolts. As a result of the lower moisture content, 14 to 30 percent more power was required to chip the dead trees than to chip the green trees. Also, chipping the dead wood produced a slightly larger percentage of fines than the chipping of green wood. No problems were encountered in separating the bark from the wood chips. Test runs made with dead insect-killed lodgepole pine chips indicated that the pulp should be suitable for a variety of paper and board products.

161. McGovern, J.N. 1951. Pulping of lodgepole pine. Forest Products Laboratory, USDA Forest Service, Madison, WI, USA. Report R1792. 11 pp.

Several types of green and insect-killed lodgepole pine (*Pinus contorta*) from Montana were evaluated by physical and chemical tests in connection with groundwood, sulfite, and sulfate pulping experiments. The insect-killed down wood contained considerable visible decay (mostly in an incipient stage). Except for somewhat lower holocellulose and alpha cellulose contents, the dead wood did not differ appreciably in chemical composition from the green wood. Sulfate pulping tests were made on younger- and older- growth green-cut woods; on older-growth insect-killed woods of the following types: dead standing, dead down, selected sound wood, and wood with 28% advanced decay; and on a typical woods-available mixture of dead material from predominantly green stands. The green and the sound dead woods showed similar pulping characteristics and gave nearly the same pulp yields and pulp strengths. The dead wood with decay showed a slight tendency to pulp more rapidly and to give lower permanganate numbers, lower pulp yields, and lower pulp strengths. The difference in yield was, however, only 5%, and in pulp strength, only 10%, between green wood and dead wood with 28.6% advanced decay. Groundwood pulping tests were also made on the sound and dead lodgepole pine. The tests showed that pulps of good brightness and strength could be obtained from both materials with moderate energy consumptions. The pulps from green wood were slightly brighter, stronger, and longer in fiber, and had a wider freeness range than the pulp from the dead wood pulped under comparable grinding conditions.

Note: It is not evident as to which fungal species are involved.

162. Merlin, E.; Nannfeldt, J.A. 1934. Research into the blueing of ground wood-pulp. [In Swedish]. Svenska Skogsvards-foereningens Tidskrift 32: 397–616.

The blueing of wood and groundwood pulp is caused by certain fungi with dark-coloured hyphae, which occur in many groundwood mills. They form round, oval or irregular spots in the finished sheet, 1-3 cm in diameter, one sheet being capable of infecting a number of others. Samples from 17 Swedish groundwood mills were studied. The main sources of infection were found to be the pulpwood, the fresh water and especially the factory air. Grinding at high temperatures kills the fungi (70-80°C). The spore content in fresh water is considerably lower than in the back water, but despite all spores being killed during the hot grinding process, infection from the stored pulpwood spreads continuously to the air and from there is passed on to the white water and pulp, regardless of whether the hot or cold grinding process has been employed. Borax, sodium fluoride, sodium bichromate, and other chemicals can be added to the water or pulp for combating the fungi. They are also killed by chlorine, but much larger quantities are required than for bacteria, so that the process is no longer economical. Treatment with SO_2 has successfully reduced the trouble. A biological method also is recommended.

Note: This paper is specific to environmental effects rather than pulp quality.

163. Mroz, W.; Surewicz, W. 1986. Effect of microbiological defects of pinewood on the yield of byproducts from kraft mills. [In Polish]. Przeglad Papier 42(10): 359–360.

This report examined the tall oil yield, acid number, pulp yield, and turpentine yield from kraft pulping of pinewood (*Pinus*) afflicted with bluestain or hard and soft rot and classified as respectively somewhat decayed or extremely decayed. Also determined was the content of methanol/benzene extractives in the decayed wood, which, however, was found to have no correlation with tall oil or turpentine yields. The somewhat decayed pinewood gave a similar pulp yield and only slightly lower tall oil yield than those of nondecayed wood. The acid number was the same. The extremely decayed pinewood gave a two point lower pulp yield, 8% lower tall oil yield, and 6% lower acid number. Turpentine yield from the somewhat decayed and the extremely decayed pinewood was 30% and 40% lower.

Note: For tall oil production, one would expect a higher extractives content in early attacked trees. Once bluestained, the extractives content of the sapwood is reduced, which affects tall oil yield.

164. Okladnikova, T.G.; Razumovskaya, M.P.; Mitkalinnyi, V.V. 1992. Possibility of using discarded wood at [pulp and paper] mills. [In Russian]. Tsellyuloza Bumaga Karton 3: 16–17.

More than 500 000 m^3 of discarded pinewood (*Pinus*) have accumulated on the shores of Russia's Bratsk water reservoir. Bluestain has afflicted 20% of the wood, while rot has attacked 3-

10%. Laboratory kraft cooks showed that this wood would be suitable for pulping. However, wood consumption per ton of pulp increased, while pulp breaking length was reduced by 600-1000 m. Pulp yield and alpha-cellulose content were lowered by 2.5 and 1.6% respectively. A 0.7% higher alkali consumption and a 30-minute-longer cook time were needed to obtain a pulp equal to that of pulp from undamaged roundwood.

165. Pekkala, O.; Uusvaara, O. 1980. Storage of pulpwood in the forest and its effect on the yield and quality of pulp. [In Finnish]. Metsantutkimuslaitoksen Julkaisuja 96(4). 24 pp.

Scots pine, Norway spruce, birch (*Betula pubescens*) and aspen trees were felled in spring, cut into 2.5 m bolts, and stored in stacks in the forest over three growing seasons. Bluestain, decay, and insect damage were recorded, and wood samples were taken at the end of each summer. After three summers, decay and bluestain in pine and spruce had penetrated to the heartwood, and in birch and aspen both sapwood and heartwood were affected. Storage did not affect basic density during the first summer, but after three years, the decrease was 15-25 kg/m^3. The reduction in pulp yield was 0.5, 3.0 and 2.5 percentage units respectively for pine, spruce and birch stored in Southern Finland, whereas with pine stored in Northern Finland, and with aspen, storage slightly increased percentage pulp yield. Storage increased wood consumption per tonne of bleached pulp by 10-15% for pine, 5% for spruce and 20-35% for birch and aspen. The paper-technical properties of bleached pulp changed relatively little. Strength expressed as the product of tensile strength and tear strength decreased by 5% for pine and spruce, and 20% for birch, but increased by 5% for aspen.

166. Persson, E.; Bergquist, J.; Elowson, T.; Jakara, J.; Lonnberg, B. 2002. Brightness, bleachability and colour reversion of groundwood made of wet- and dry-stored Norway spruce (*Picea abies*) pulpwood. Paperi ja Puu 84(6): 411–415.

The brightness, bleachability, and colour reversion of groundwood prepared from dry-stored wood and wood stored and kept wet by water sprinklers were evaluated. Pulpwood stored for 0, 1, and 3 months was debarked at atmospheric conditions and bleached by hydrogen peroxide. The effects of tannin damage and bluestain on these optical properties were also examined. Storage was negative with respect to brightness, especially wet storage with the high-sprinkling intensity. After bleaching, most of the brightness losses were regained with the exception of the high-intensity-sprinkled wood. The high-intensity sprinkling also gave poorer brightness stability. Pulp made from bluestained wood suffered from decreased brightness compared with corresponding non-infected wood. The brightness was recovered after bleaching and bluestained wood did not affect brightness stability. Pulp made from tannin-damaged wood suffered from decreased brightness, even after bleaching, and had lower brightness stability.

Note: Aerobic wet storage (sprinkling) will increase the level of fungal darkening (sap stain) versus anaerobic (water) storage.

167. Roberson, T. 2000. Southern pine beetles wreak havoc on southern pulp operations. Pulp & Paper 74(10): 13.

The southern pine beetle (*Dendroctonus frontalis*) is the most destructive insect that kills pine in the Southeastern U.S. In addition to feeding on tissue under the bark, the beetles carry bluestain fungi on their bodies, which colonizes the sapwood and disrupts the flow of water to the tree crown. The bluestain fungi are also detrimental to certain pulping processes, requiring more bleach to obtain the desired brightness level.

Note: The pulping process (chemical vs. mechanical) most affected was not defined but it is likely mechanical.

168. Schafer, E.R.; Pew, J.C.; Curran, C.E. 1938. Grinding loblolly pine. Relation of wood properties and grinding conditions to pulp and paper quality. Technical Association of the Pulp and Paper Industry. Technical Association of the Pulp and Paper Industry. Technical Association Papers 21: 449–456.

In the production of mechanical pulp for newsprint from loblolly pine, wood having a relatively wide range of properties can be used, but the range of grinding conditions is closely limited. Green wood yielded better pulp than seasoned wood. Knotty wood required more power than clear wood to produce an equivalent product. Bluestained wood can be used to a limited extent without much detriment to brightness. Compression wood lowered the strength and colour of the pulp in proportion to the amount present. The experiments confirm the feasibility of making satisfactory ground wood from southern pine if the wood is properly selected and grinding conditions carefully controlled.

169. Scheffer, T.C. 1940. Stains of sapwood and sapwood products and their control. U.S. Department of Agriculture, Washington, D.C., USA. Technical Bulletin 714. 124 pp.

Same as reference # 107. Results indicate that unbleached sulfite pulps made from bluestained southern pine chips were substantially darker than those made from non-stained wood.

Note: The conclusions drawn here are supported by the majority of subsequent work and Paprican's pilot plant studies.

170. Scott, G.M; Bormett, D.W.; Sutherland, N.R.; Abubakr, S.; Lowell, E. 1996. Pulpability of beetle-killed spruce. Forest Products Laboratory, USDA Forest Service, Madison, WI, USA. Research Paper FPL-RP-557. 8 pp.

Infestation of the *Dendroctonus rufipennis* beetle has resulted in large stands of dead and dying timber on the Kenai Peninsula in Alaska. Tests were conducted to evaluate the value of beetle-killed spruce as pulpwood. The results showed that live and dead spruce wood can be pulped effectively. The two least deteriorated classes and the most deteriorated class of logs had similar characteristics when pulped; the remaining class had somewhat poorer pulpability. The more deteriorated wood required the same or slightly less refining energy to achieve a certain level of freeness. The presence of sap rot decay was found to be an important indicator of pulping efficiency and resultant pulp quality. Log deterioration had mixed effects on paper properties. Results indicated that the presence of sap rot increased the Kappa number of the pulp and decreased the pulp yield.

Note: Kraft pulping of insect-killed lodgepole pine is reviewed in this paper.

171. Surma-Slusarska, B.; Surewicz, W. 1986. Suitability of microbiologically damaged wood for production of kraft pulp. [In Russian]. Khimiya Drevesiny (Riga) 2: 12–18 (March/April).

A study was made of the anatomical structure, chemical composition, and suitability for kraft pulping of pinewood and beechwood, as well as yields and strength properties of pulp from wood affected by common forms of decay. Suitability for kraft pulping depends on the nature of the microbiological damage. Pinewood moderately infected with bluestain still remains highly suitable for production of bleached kraft pulp. The pulpability of pinewood and beechwood containing more than 15% hard brownrot declines rapidly with increasing amounts of decay. For the production of bleached kraft pulp from pinewood or beechwood, the hard brownrot content of the wood should not exceed 20%.

172. Surewicz, W.; Surma-Slusarska, B.; Mroz, W. 1985. Effect of microbiological defects of pinewood and beechwood on their suitability for kraft pulp manufacture. [In Polish]. Przeglad Papier 41(6): 205–208

Kraft cooks were conducted of healthy pinewood and beechwood, and of the same woods affected to different degrees by bluestain, brown rot, and white rot. The conditions of the cooks were: active alkali, 20%; sulfidity, 25 and 28%; maximum temperature, 170°C and 172°C for pine and 165°C for beech, cooking time at the maximum temperature, 80 and 120 minutes. Prior to the cooks, the chips were analyzed for density, fibre length, and chemical composition. The pulps were beaten to 25 and 40 Schopler-Rieger or 50 Schopler-Rieger (beech), and determinations were made of their yield, content of undercook kappa number, and mechanical-strength properties. The woods were evaluated by their "relative pulping value", defined as the product of two partial indicators: the specific yield of pulp from 1 m^3 wood, and the strength indicator (product of tensile strength and tear resistance). The pulping value of healthy wood was taken as 100%. On this basis, it is concluded that pinewood affected by bluestain only has a nearly 100% value; the value of pinewood with up to 20% brown rot is 90-95%, and of beechwood 80-85%. The value of wood with 25% or more decay is about 65%. Such wood should not be used for pulping; it could possibly be used in small amounts such as a component of bleached pulp.

173. Thomas, P.R. 1986. Infestation by pine and spruce bark beetles in British Columbia and its effect on kraft and mechanical pulping. Pages 35–47 *in* R.W. Nielson, ed. Harvesting and Processing of Beetle-Killed Timber: proceedings of a seminar sponsored by Forintek Canada Corp. and COFI, Northern Interior Lumber Sector held May 10, 1985 in Prince George, B.C. Forintek Canada Corp., Western Division, Vancouver, B.C. Special Publication 26.

Samples of pine beetle- and spruce beetle-killed wood were collected at various stages of time since attack. Wood characteristics, debarking wood losses, and chip quality were measured. The furnishes were kraft cooked, and pulping characteristics were determined. Kraft pulp quality, drainage, drying and bleaching characteristics were assessed. Bluestain, which occurs in beetle-attacked wood, was evaluated for its effect on kraft and mechanical pulp quality and bleachability. Kraft pulping alkali requirement was almost constant with the different categories of pine and increased slightly with the spruce. Pulp viscosity was reduced for the oldest categories of spruce and for the oldest whole-log pine pulp. The whole-log and slab pine and spruce samples showed an increasing loss in kraft pulp yield with time after attack. Black liquor tall oil content increased significantly with beetle attack and then decreased as time after attack increased. Beetle attack caused no significant differences in the bleachability of kraft pulps. Beetle-attacked wood pulp showed poor pressing/drainage characteristics as well. Chemithermomechanical pulping and bleaching were carried out on both the spruce and pine, and the results indicated that tear strength usually decreased with increased time after attack and showed poorer bleaching response became poorer with increased time after attack. The effect of including beetle-killed wood chips with unattacked wood on chip-pile deterioration was also assessed, and is not likely to increase deterioration and wood loss.

174. Trevelyan, B.J. 1969. Mechanical pulping of southern pine wood. Forest Products Journal 19(1): 29–38.

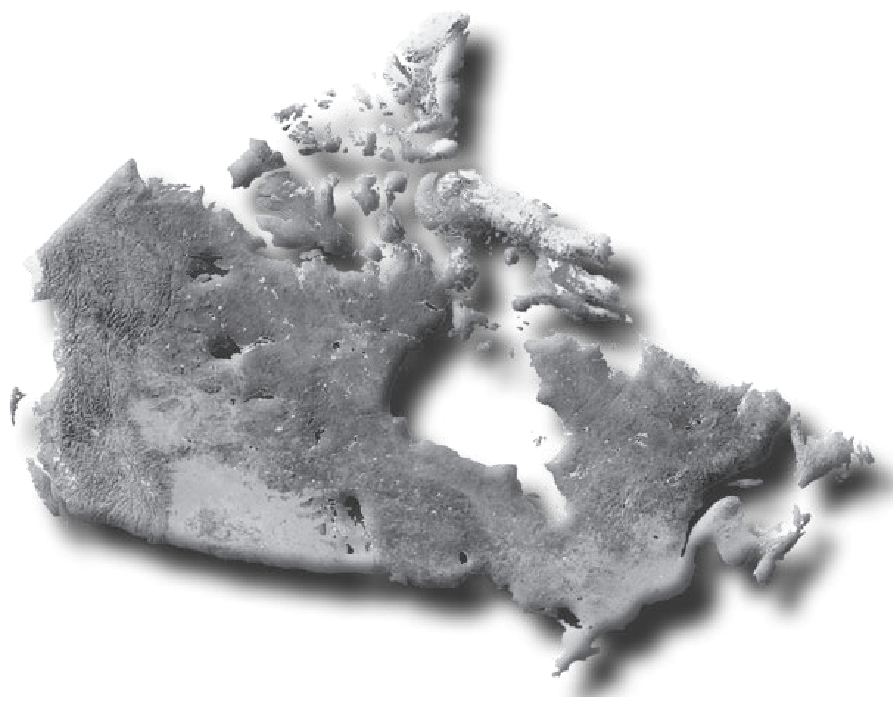
The high summerwood content, high resin content and susceptibility to attack by fungi causing bluestain are the source of major difficulties in attempts to produce satisfactory groundwood pulp from southern pines. The author reviews the history of the newsprint industry in the South, emphasizing the techniques employed by the industry to overcome these problems. Modern operating practices and equipment used in groundwood pulp production are discussed, and areas for future improvements are presented. The author also summarizes some findings from other studies performed on bluestain fungi. Other studies concluded that strength properties of bluestained pulp were unaffected and that power consumption for the bluestained and healthy material was similar. Approximately, 10% stained wood showed no loss of whiteness, however, greater than 20% stained wood caused a distinct loss of whiteness.

This publication is funded by the Government of Canada through the Mountain Pine Beetle Initiative, a program administered by Natural Resources Canada, Canadian Forest Service (web site: mpb.cfs.nrcan.gc.ca).

Contact:

For more information on the Canadian Forest Service, visit our web site at:
www.nrcan.gc.ca/cfs-scf

or contact the Pacific Forestry Centre
506 West Burnside Road
Victoria, BC V8Z 1M5
Tel: (250) 363-0600 Fax: (250) 363-0775
www.pfc.cfs.nrcan.gc.ca



To order publications on-line, visit the Canadian Forest Service Bookstore at:
bookstore.cfs.nrcan.gc.ca