MOULD AND STAIN: BIODETERIORATION OF WOOD - KNOW YOUR ENEMIES

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1. Introduction

Mould and bluestain fungi as well as other non-microbial factors may cause discolorations (stain) of wood products that may significantly affect wood marketability. Some of these fungi are the early part of a succession of microbes that cause biodeterioration of wood, provided there is fluctuating or continuous presence of the moisture required for the biodeterioration process. Some can also cause biodegradation of preservatives and coatings. Customers do not like the appearance of discoloured wood, nor do they appreciate premature failures of coatings and the industry has been in a constant battle and faced challenges in controlling wood/coatings discolorations and biodeterioration. This paper reviews the biology and control of mould and stain fungi, highlighting new trends and research needs.

Common questions when customers see the discoloured wood and coatings are: Is it is mouldy? Is it health risk? Is it affecting the wood or the coating? Is it the first stage of decay? Will wood rot faster? Is there a better material choice than wood for this particular use? Is there a better performing and longer lasting coating? There are also biosecurity related questions with more recent focus on fungi in international trade and questions as to whether live fungi found on imported wood products pose a phytosanitary risk.

Discolorations of wood can occur at any step of the wood processing chain including in standing trees in the forest, harvesting, forest storage, transportation and yard storage of logs, debarking, milling, green storage of lumber, drying, dry storage and transport, at the distributor's storage, construction site storage, during construction and while wood is in service with or without coatings and preservatives for different uses and under different hazards. This clearly represents a plethora of possible scenarios and a huge variety of substrates requiring protection, including logs, lumber, plywood, OSB, particleboard and CLT composed of variety of wood species and other materials such as glues, resins, and paint films, all with or without additional chemical preservatives. Different substrates have different moisture gaining, retaining, and drying properties, have variable amounts of nutrients available to discolouring fungi, and contain other substances that may affect fungal growth. The substrates are subjected to a variety of micro climates and environmental conditions indoors, and in outdoor exposures, subjected to various infection sources and other particular scenarios or combinations of factors that affect what type of discoloration/biodeterioration occurs and how it could be managed and prevented.

2. Types of Enemies, Terminology and Definitions

We define wood discolorations as deep or shallow change in colour that diverges from the natural wood colour. There are discolorations that are not caused by microorganisms (non-microbial discolorations) and those caused by the actions of microbes (microbial discoloration). The later are much more prevalent and this paper focuses on microbial discolorations. However, non-microbial discolorations can be economically significant and some are challenging to control. These include burn marks, dirt and other deposits on wood, mineral/metallic discoloration, hemlock brown stain, enzymatic discolorations, sticker stain, water stain, etc. Control options of some of these may include different chemistries alone or in combination with specific management practices (Uzunovic et al. 2008)

Microbial discolorations are caused by variety of organisms that are conveniently grouped based on general human perception of fungi and their effects on our daily lives as **bluestain**, **mould** and **decay** fungi, and **bacteria.** Discolorations caused by bluestain fungi are the most prevalent. **Sapstain** (although used as synonym for bluestain by some) to us indicates any microbial discoloration of sapwood and may be caused by all of the microbial organisms mentioned, where one can predominate, or there is a mix of different organisms.

Fungi in general pose a challenge when it comes to their control and prevention of undesired outcomes. Fungi are neither plants nor animals and have evolved a lifestyle of using extracellular enzymes and chemistry to digest food outside their mycelial body and then assimilating digested food through their cell walls. There is a huge variety of fungi with their different biology and physiology and potential. Some are tree pathogens and able to effectively resist and overcome host defence mechanisms causing tree disease and death or are early colonisers of freshly felled logs. Others are opportunistic pathogens while many are saprotrophs and composters that live on dead organic matter and utilize simple or more complex and not easily available food sources.

In the process of developing strategies to digest and obtain food they developed amazing survival capabilities developing complex biochemical processes that help them to break down complex carbohydrates such as lignin and cellulose and other organic materials. They can tolerate high salt and sugar concentrations and also some tolerate wood preservatives and can detoxify a wide range of compounds. Some fungi produce complex chemistries (alcohols, ketones, esters, toxins etc.) where composition and quantities and types of compounds may change with changing conditions and with the presence of competing microflora. With this degree of variety, fungi pose a significant control challenge. There is no panacea to control all fungi, and the actives currently available are greatly restricted by health and environmental regulations. Only a few new actives are likely to come to market given the high cost of developing, testing, and obtaining regulatory approvals for new biocides (Stirling and Temiz, 2014).

2.1 Bluestain

Blue stain is the most common microbial discoloration on wood. It is caused by a specific group of fungi that have evolved to attack fresh, or dried and rewetted, sapwood. These fungi synthesise a pigment called melanin that is deposited within hyphae and/or sporing structures. The abundance of growth of the hyphae and sporing structures in or on the wood visually shows as pronounced and very dark wood discoloration. Melanins are pigments of high molecular weight formed by oxidative polymerization of phenolic compounds and are among the most stable, insoluble, and resistant of biochemical materials. They have important functions in fungi and are being linked with virulence. They protects fungi from UV light, give the fungal structures rigidity, prevent insect grazing, protect against a broad range of toxic chemistries, enhance pathogenicity and in general promote survival in the environment (Jacobson 2000, Gómez and Nosanchuk 2003).

The most common group of fungi causing bluestain are the Ophiostomatoid fungi. These include the genera *Ophiostoma, Cerotocystis, Grosmannina,* and *Leptographium*. There are also non-ophiostomatoid genera *Sphaeropsis (Diplodia)* and *Lasiodiplodia* that cause bluestain in warmer climates (Uzunovic and Byrne 2013). Some of species are more pathogenic in nature and are able to colonise standing trees and fresh logs with very high moisture content and active host resistance mechanisms, while others range from opportunistic pathogens to pure saprotrophs. Those species primarily attacking trees and fresh logs are called **deep bluestain** as they grow deep inside the sapwood and cause deeply penetrating discoloration. Species that attack lumber, which are called **surface bluestain**, rarely penetrate much below a few millimetres inside the wood, and are most prevalent on the surface. Because of the niche where they grow and their overall appearance, they are often confused with darker moulds. An expert eye and the aid of magnifying glass or a microscope is needed to distinguish the two.

There is also a group called **Black-Stain** or **Bluestain in service** which have different biology and include genera of *Aureobasidion/Hormonema and Epicoccum*. They are common on wood in service both interior (saunas, bathrooms) and exterior and are one of the key causes of coatings and paint films failures and greying of UV-bleached wood (See section 2.3).

Some authors classify bluestain fungi (*sensu lato*) as: **Primary blue stain** (which corresponds here to deep bluestain blue stain of trees and logs), **Secondary bluestain** (surface bluestain-blue stain of sawn timber) and **Tertiary bluestain** (black-stain/bluestain in service) (Schmidt 2006; Pfeffer et al 2011).

2.1.1 Control and management of bluestain

Where bluestain has already occurred and could not be prevented (e.g. with the attack of aggressive bark beetles such as Mountain pine beetle (*Dendroctonus ponderosae*) where sapwood could fully discolor while trees are still standing) there are ways of partially bleaching it based on the use of oxalic acid, sodium hypochlorite or sodium hydroxide/hydrogen peroxide (Evans et al. 2007). Combinations of bleaching agents with UV light and with plasma have also been shown to remove bluestain from the surface of wood (Stirling and Morris 2009; Jamali and Evans 2013). The practical management practices to control deep bluestain in logs include prompt log processing, chemical control where appropriate, freezing and snow storage, controlled log drying, oxygen-less storage (water storage or storage under elevated CO_2), reduction of mechanical damage, control of significant insect vectors and available nutrient reduction e.g. sour felling, or biological control (Uzunovic et al. 2008).

In the 1960s and 70s some coastal BC logs were sprayed with lindane to prevent beetle attack (beetles commonly carrybluestain fungi) but otherwise Canada has not traditionally used chemical pesticides for log protection. Currently there are no available registered chemical pesticides for use on fresh logs in Canada or USA. Due to environmental concerns and registration requirements for industrial pesticides it is unlikely that any chemical will be registered for use on logs. An exception is that some mould/stain preventative chemicals may be used on logs in a controlled mill situation especially for debarked logs destined for the log-home industry where a clean bright surface is an advantage. Log home treatments need to comply with the Pest Management Regulatory Agency (PMRA) regulations and registered products applied according to the approved label. Protection is most efficient if applied immediately after debarking. Newly-treated logs should be protected from rain to prevent leaching of chemical into the environment (Uzunovic et al 2008).

Lumber protection is best handled through storage practices that focus on reduction and maintenance of low moisture content, as this controls both surface bluestain and mould. Promotion of air drying by specifically storing the lumber to encourage drying is good practice. Chemical control of surface bluestain is commonly used on green lumber. To be effective, chemical protection, which is often confined to the surface, should be applied to green lumber without much delay following manufacture. Chemicals are applied by spraying, brushing, or dipping (in–line bulk dipping) lumber. Suppliers recommend treatment levels, target application rates and provide technical information on their products based on the material being treated and storage conditions. The antimicrobial products currently used for treatments generally have a narrower spectrum activity, and a improved environmental performance compared to some of the broader spectrum chemicals that were used in past (Byrne 1998a, 1998b).

Current commonly used actives include propiconazole, didecyldimethylammonium chloride, 3-iodo-2-propynyl butyl carbamate (IPBC), and diiodomethyl p-tolyl sulfone (Schauwecker and Morrell 2008). They are mixed in different formulations with various non-active compounds to improve efficacy and cost effectiveness. They are used to control sapstain that includes bluestain and moulds. Because most actives are carbon-based molecules that are subject to breakdown, their duration of protection on green lumber is limited. They are meant to give a few months protection to cover the time from manufacture to export, shipping, and receipt of the wood at a building site or other end use. They do not replace wood preservatives which give greater and longer resistance to fungal attack, especially to decay (Schauwecker and Morrell 2008). Apart from possibility of breakdown of actives, the biggest challenge in the industry is preinfection (fungal infection/colonisation that existed prior to chemical treatment) which is often a cause of treatment failure.

Research has confirmed that several types of chemistries were most effective against spores, less so against approaching established mycelium, and least effective against live mycelia already present in wood prior to treatment. Field tests also confirmed that sapstain was more difficult to control on wood preinfected with bluestain and mould (Uzunovic et al 2013). Although short periods of exposure prior to treatment may not affect efficacy, any delays between manufacture and treatment increase the risk of preinfection and should be avoided.

FPInnovations (former Forintek Canada Corp.) and other laboratories have extensively tested sapstain control products to protect green lumber. Various test methods have been used, ranging from laboratory to field to shipping trials and different methods may produce different results so it is very important to include test methods that are representative of situation to which lumber may be exposed in real life. Most developed and commercial products were designed to prevent bluestain rather than mould and a number of formulations have traditionally been less effective against moulds. New formulations intended to better control moulds are being evaluated, and some show promise.

2.2. Mould

Mould is a convenient but artificial category of fungi, based on general human perception of fungi and their effects on our daily lives. The most obvious attribute of mould is its visual appearance. It typically appears as smudges or fuzzy growth observed on various substrates including food, building materials, clothes etc. Taxonomically mould fungi fit into several fungal groups within the large fungal kingdom with many genera and species involved. Some “moulds” may also be classified by their niche, for example as, plant pathogens, human pathogens, food contaminants and spoilage organisms, biological control agents, sapstaining fungi etc. The fuzzy surface growth is a fungal body consisting of a mat (termed mycelium) of thread like structures (termed hyphae) bearing spores and spore producing structures primarily on the surface of the substrate. We define mould as surface-growing, micro fungus with pigmented filamentous networks (hyphae) typically bearing dry spores that are typically easily carried by air currents; appear on the surface as smudges of white or coloured fluffy or powdery masses.

Compared to bluestain the individual microscopic hyphae are often colourless and not easily seen even though they can sometimes penetrate deeper into wood or other organic substrates. Sporulating surface structures are often pigmented and can range from light to very dark in almost any colour. Discoloration of wood is caused by growth of coloured mould hyphae or structures and sometimes is due to pigment diffusion released by mould (Eaton and Hale 1993, Uzunovic et al 2008).

Growth of mould is usually associated with moisture and nutrients, so when mould grows on wood it is predominantly found on moist sapwood, but may also occur on the moist heartwood of some wood species. Mould is commonly encountered on stored green lumber but can also be found on kiln dried and rewetted lumber. Moulds may grow on dry substrates (e.g kiln dried lumber in transport or storage or in servce if the ambient humidity is high enough (above about 80% RH) to enable absorption of the necessary moisture out of the air or where surface moisture is present . That is why some prefer to use Water activity (aw) as a better measure to define conditions for mould growth where aw is numerically 1/100th of RH of the air in equilibrium with material. Aw describes available water in the substrate and is widely used in soil science and the food industry. Water availability to microbes was found to be specific to each food product (Scott 1953, Flannigan and Miller 2001) and aw, not water content, correlated with bacterial (microbial) growth. Thus a material with a water activity (aw) of 0.8 would produce an equilibrium relative humidity (ERH of 80%).

Under steady state conditions, prolific mould growth does not occur when RH is maintained below 75-80%, as most fungi do not germinate and grow below this level. Small amounts of growth of some xerophilic (dry-loving) fungi may occur on some susceptible materials below 80% RH, but growth is extremely slow. Virtually no moulds are able to grow below aw 0.65. Generally, above ~80% RH the rate of mould proliferation progressively increases (Flannigan and Miller 2001). Laboratory work generally indicates that if susceptible surfaces can be kept below aw of 0.80 by manipulating temperature and humidity, mould growth will essentially be stopped

Little work has been reported on the effects of the fluctuating humidity that occurs in real-life. The fluctuating moisture and temperature conditions that occur in service are difficult to monitor or to simulate, but, together with the properties of the substrate, fluctuations affect the state and survival of mould. Fluctuating moisture conditions appear to lengthen the time for spore germination and fungal proliferation and the growth rate is therefore less (Rautiala et al. 1999). The range and frequency of fluctuations undoubtedly affect fungal vigour and rate of growth. Some moulds tend to tolerate these fluctuating conditions better than others, so species composition may be linked with fluctuating moisture conditions.

Compared to bluestain fungi that produce wet slimy spores, moulds typically produce dry spores that are easily carried by air. Air dissemination is the major form of mould spore transmission, and apart from allowing them to easily colonise susceptible substrates, this also makes them easily inhaled and, in large amounts, potentially associated with health problems. Some moulds can also disperse over surfaces through water films.

Moulds typically do not cause physical damage to solid wood but can visibly degrade its value. However, continued mould growth can indicate moist conditions favourable for growth of other fungi that eventually may cause wood rot and structural damage. Some mould and bluestain species are implicated in soft rot under conditions which favour decay but are unfavourable to wood-rotting basidiomycetes, particularly in hardwoods (Duncan 1960, Goodell et al. 2008).

2.2.1. Mould control challenges

Regardless of the nutrient status of any material, the key determining factor whether mould will grow or not is the availability of water in or around the material. Moisture control is the most practical method for limiting mould growth. “Keep it Dry” is the simplest and the most significant action that will prevent mould growth.

Where moisture control is not possible (e.g. preffered trading of green lumber) or where moisture ingress cannot be predicted or ruled out, other options need to be considered. In addition some moulds are common and occur frequently on different materials, while others occur only under very specific situations where they are able to outcompete other organisms. Many aspects of controlling surface bluestain on lumber using chemicals apply here as bluestain and mould cause sapstain and sapstain control aims at both of these groups of organisms. Even with applied control, green lumber treated with sapstain control products can still develop mould, particularly in the fall months in coastal BC when conditions are supportive of mould growth. Occasionally the same retentions may allow significant mould growth under suitable conditions or successfully control mould under different conditions. Failure to control mould could be due to wood being treated with sub-optimal chemical retentions, unequal coverage, lower level of active substances, inappropriate mix of actives for particular challenge mould, dilution of actives due to heavy rain and outside exposure etc.

Best practices for chemical treatments of green lumber are important and play a role in successful mould control, but details are beyond the scope of this document. In general they include: Minimizing pre-infection of logs being sawn into lumber and being aware that obviously pre-infected wood or particular hazards (e.g. in the fall mould season) require special diligence; Selecting the most environmentally acceptable or lowest toxicity chemical products that do the protection job required; Combining narrower spectrum chemicals, with adjuvants where appropriate, in mixtures that optimize the cost/efficacy benefit ratio from the chemicals; applying the chemical through a well-designed system that is set up and well maintained to apply a uniform treatment at target applications; Ensuring that treatment liquids are fresh and there is no build-up of contaminants such as iron-stain precursors; having a quality control program that periodically verifies that lumber target chemical retention rates are being met, usually by chemical analysis; and protecting treated lumber from the weather and minimising dilution and impact of leached chemicals on the environment (Uzunovic et al 2001).

Where moisture control is an option in general, drying of wood to reduce the moisture content below 19% is recommended and dried wood should not be allowed to get rewetted. Best practices for different commodities therefore aim to reduce and maintain moisture below a critical level. Moisture control includes reducing wood moisture content through air- or kiln-drying, and/or reducing exposure to high humidity and liquid water. An increasing amount of lumber is now kiln dried and, as mentioned earlier, wood which is properly dried and kept dry will not generally be susceptible to fungal growth. Handling and storage of dried lumber is also important to prevent rewetting and subsequent bluestain and mould problems (http://cwc.ca/design-with-wood/durability/durability-solutions/on-site-moisture-management/). However, after the wood leaves the sawmill various factors that are not under the control of the producer may cause it to arrive physically or biologically damaged after a long open railcar, truck and/or ship voyage. Package handling at multiple transfer points, mishandling the lumber and severe weather exposure conditions can impact negatively on a small proportion of the delivered product.

To control mould on dried wood the reduction of ambient humidity and prevention of condensation on the wood surface is the most common way used to minimize mould growth under such circumstances. Wood does not conduct heat readily so it is rarely the coldest surface available. Typically other building materials are more prone to condensation than wood.

Our field tests confirmed that sapstain (mould and bluestain) was more difficult to control on wood preinfected with sapstain and mould. Short periods of exposure prior to treatment may not affect efficacy, nevertheless any delays between manufacture and treatment increase the risk of preinfection and should be avoided. Preinfection is another big issue. Lab experiments found that CMIT, MIT, IPBC, and propiconazole applied prior to exposure to seven mould fungi were most effective against spores, less so against approaching mycelium, and least effective against live mycelia already present in wood prior to treatment (Uzunovic et al 2013). As with bluestain, different test methods can lead to different results, so it is important to select methods that closely represent the intended use environment. For example AWPA E24-12 Standard method for evaluating the resistance of wood products surfaces to mould growth uses high humidity conditions compared to a variant AWPA E24-12 test method (currently developed at FPInnovations) where intentionally moisture is forced to condense on the surface of test samples to mimic some situations found in real life (e.g. roof attics). Although these tests are in essence similar, the mould ratings and results are different for both treated and untreated test materials (controls) as were moisture and wetting events of different test materials. Similarly, antisapstain field tests, such as AWPA E29-13, are highly dependent on the environment in which they are located, and can produce different results during different seasons.

2.3 Black-Stain (Bluestain in Service)

Black-stain (often referred to as bluestain in service) is caused by a group of fungi capable of producing both highly-melanised yeasty forms and mycelial colonies. The stain sometimes appears as slimy black streaks when wet or as black dots or small streaks when dry and often does not have observable fuzzy growth unless grown in pure culture. As mentioned under bluestain categories in the section 2.1. they are common on wood in service in interior and exterior situations associated with prolonged elevated moisture content that alternate with dry periods. These fungi are also key causes of the failure of coatings and paint filmsand greying of UV-bleachedwood and are very adaptable to, and tolerant of, harsh and fluctuating environmental conditions. Apart from causing unsightly discoloration, they can penetrate intact coatings and weaken adhesion to wood (Sharpe and Dickinson 1992, Bardage and Bjurman 1998).

Their resilience and capabilities can certainly be linked to melanin which may play crucial and specific roles in aiding their survival under high UV exposure, resilience in fluctuating harsh environments, against a broad range of toxic chemistries (Jacobson 2000, Gómez and Nosanchuk 2003). In addition these highly-melanised fungi directly penetrate coatings creating cracking in coatings (melanin provides rigidity when penetrating and weakening coating adhesion). They utilise simple sugars and proteins from woody substrates, but also are known to use lignin breakdown products on weathered wood (Sharpe and Dickinson 1993) so the same UV exposure provides them with food at the same time may break down incorporated biocides and weaken coatings. In addition these fungi may also detoxify naturally occurring phenolic compounds and allow earlier colonization by decay fungi (Bjurman 1988).

Typical black stain genera that occur on wood in service or wood finishes include *Aureobasidium*, *Hormonema*, and *Epicoccum* that are cosmopolitan and common genera in outdoor and indoor environments worldwide (Ray et al. 2004, Gobakken and Westin 2008, Pfeffer et al. 2010. In our studies they have been found in a variety of locations and substrates (including all parts of trees, bark, stems, leaves) and were also sampled from collected rain and snow (Uzunovic, 2005).

2.3.1 Black-stain control challenges

These fungi are very difficult to control and different strategies have been described that include both moisture control and biocidal treatments, without consistent success. Stirling et al. (2011) recently summarized some of the approaches to control black-stain fungi. Some studies indicated that polyurethane semi-transparent water-based coatings were more resistant to black-stain fungi than acrylic and alkyd acrylic formulations. The type of resin may be more important than the solvent. Alkyd formulations have been shown to be more resistant to *Aureobasidium pullulans* than acrylic formulations in some studies while a waterborne stain with an acrylic top coat was associated with significantly better performance in a field test than a solvent-borne semi-transparent alkyd paint and a white paint system with a solvent borne primer and a waterborne acrylic top coat. Opaque systems are generally more resistant to black stain fungi and pigments present in opaque coatings may have activity against fungi. The poorer resistance of transparent and semi-transparent coatings to UV and visible light can lead to weakened or degraded coatings that provide pathways for colonization and poor wood coating adhesion, providing ideal habitat for black-stain fungi.

Biocides added to coatings can provide some protection against black-stain fungi but optimal solutions have not yet been found. Carbendazim, diuron, and 2-n-octyl-4-isothiazolin-3- one were reported to provide effective dry-film protection (Gillat 1996). On painted surfaces, combinations of IPBC in the top coat and IPBC plus triazoles in the primer were best able to resist mould growth at two Norwegian sites (Gobakken and Jensen 2007); In laboratory tests, IPBC and an isothiazolone were most effective in controlling the growth of mould on paint films where propaconazole did not perform well (Viitanen and Ahola 1997). Combinations of propiconazole and IPBC and propiconazole and isothiazolone in both primer and top coat were most effective against mould fungi, including *A. pullulans* (Stirling et al. 2011).

Stirling et al. (2011) also developed methods to test additional combinations of compounds against several types of freshly isolated challenge black stain fungi. Selected biocides and biocide combinations formulated in a semi-transparent coating were evaluated and included IPBC, propiconazole, tebuconazole, thiabendazole, fludioxonil, chlorothalonil, oxine copper, copper metal, and naphthoquinone. Combinations of propiconazole with IPBC and propiconazole with IPBC and thiabendazole were most effective in the test. Despite some success, the study recognized it was difficult to control black-stain fungi with the biocides in the coatings tested and concluded that further work is needed to evaluate the use of other coatings and test fungi with the laboratory test method and to evaluate the performance of the best-performing biocides in field exposures. In the lab test unweathered samples performed better than weathered samples in almost all groups confirming that weathering is a critical component in black-stain colonization.

Apart from generatinglignin breakdown products that serve as a nutrient source for *A. pullulans*, it is also hypothesized that weathering creates cracks in the coating, which provide openings for germinating spores. *A. pullulans* is capable of penetrating very small pores with thin hyphae entering cracks in the coating or by penetration of the intact coating (Bardage and Daniel 1997, Sharpe and Dickinson 1992).

Additional management strategies may need to be considered including combined techniques and/or wood modification where attempts to keep the wood moisture content bellow fibre saturation are combined with UV protection and successful biocidal treatments (Pfeffer et al. 2011). Successful approaches may also include pre-treatments to protect or stabilize the wood surface itself, methods of restricting nutrients on the wood surface, or use of thicker, more weather-resistant films that would resist the penetration of hyphae. In additional alternative or specific options may need to be developed for different challenge scenarios for wood use and hazard class. Further testing of biocide combinations, particularly in the field tests, is needed to optimize performance against variety of common black-stain fungi.

2.4 Bacteria

Bacteria often do not cause discoloration directly in wood, apart from some specific scenarios e.g. in tropical hardwoods where bacterial metabolites are found associated with severe discolorations of logs after felling and lumber of Ilomba (Pycnanthus angolensis Exell) during drying (Yazaki et al 1985), or the watery, transparent discoloration to an orange-brown staining associated with water mark disease in willows caused by *Brenneria salicis* (Maes et al. 2002).

Typically after colonizing the wood under conditions of prolonged moisture, and when developed in excess there is no change in colour but bacteria may affect the permeability of the wood. This can lead to uneven uptake of later applied wood stains which often manifest as unsightly streaks (Daniel et al. 1993). Bacteria are commonly associated with logs although they only sometimes stain sawn wood. Bacterial counts can be up to 80 times greater in water-stored logs than in fresh green logs (Powell and Eaton 1993). Permanent brown stains on the surface of water stored radiata pine logs were identified as tannin-like compounds derived from bacterial breakdown of flavonoid glucosides that oxidize and concentrate on the surface during drying (Hedley and Meder 1992). Some conifers and hardwoods have wet pockets that are linked to bacterial activity and pose a challenge during the drying process (Powell and Eaton 1993; Webber and Gibbs 1996). Wet pockets may appear as translucent, watery stains often associated with a sour or rancid odour.

2.4.1 Control challenges for bacteria

Reducing wood moisture helps prevent bacterial growth. Nothing much can be done for bacterial damage that occurred in the log stage and logs should be processed as rapidly as feasible. Bacterial stain may not be obvious until a wood finish is applied.

3. Conclusions

Bluestain, black-stain and mould fungi present significant challenges for wood products at all stages of the value chain. The wide variety of these microorganisms and their abilities make chemical control challenging. Effective control strategies have been developed for many situations, but no one treatment if effective in all circumstances. Instead a systems approach that attempts to reduce risk of colonization at each step, and by different means, is preferable. Current work at FPInnovations is investigating such approaches for the control of black-stain fungi on wood coated with transparent finishes and used in exterior environments.

4. Literature

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