Cryptococcus fagisuga **System:** Terrestrial

Kingdom	Phylum	Class	Order	Family
Animalia	Arthropoda	Insecta	Hemiptera	Eriococcidae

Common name felted beech coccus (English), woolly beech scale insect (English), felted beech scale (English), beech scale insect (English), beech scale (English), woolly beech scale (English)

Synonym *Cryptococcus fagi* , Baer.

Similar species

Summary The beech scale insect (*Cryptococcus fagisuga*), along with *Neonectria* ascomycete fungi form the disease-complex responsible for beech bark disease (BBD) of American and European beech. Beech scale infests mainly larger sized beech trees, feeding on host tissues and causing small fissures on the bark. This initial damage to the tree allows *Neonectria* to enter the tree, which kills host tissue and eventually girdles the tree causing it to die. In North America the main fungi involved are *N. faginata* and N. ditissima, whereas in Europe *N. ditissima* and *N. coccinea* are responsible for the disease. BBD can dramatically alter forest stand composition and structure, through loss of large trees and proliferation of smaller trees that originate from root sprouting. Reduction of beech nut production and loss of large trees in infected stands may affect mammals and birds that use beech nuts as important food source and old trees as habitat. Around 1% of American beech is estimated to be resistant to BBD. Research is currently focused on modes of inheritance and propagation methods.

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Species Description
Beech scales (*Cryptococcus fagisuga*) are yellow, soft bodied scale insects measuring 0.5 to 1.0 mm long as adults. Female adults (no males of this species are known) are legless, wingless and have only rudimentary antennae. They attach to trees only by their 2 mm long stylets. Nymphs possess glands that secrete a white, woolly wax that covers their bodies (McCullough *et al*., 2003), and causes heavily infested trees to heavily appear as though they are covered by white wool (McCullough *et al*., 2003). Unlike some scale insects *C. fagisuga* has no filament (Kosztarab, 1996 in Wiggins *et al*., 2004).

Lifecycle Stages
Cryptococcus fagisuga has one generation per year. Adults lay pale yellow eggs on the bark of beech trees in midsummer (June to September) before they die. Eggs are attached end to end in strings of four to seven eggs. First instar, mobile crawlers hatch from eggs 25 days later in late summer to early winter. These immature scales are unlike adults in having legs and functional antennae. They are able to move about in order to find a suitable location. Once located they force their long, tube-like stylet into the bark to suck the sap. Once a nymph has begun to feed it moults to the second instar which have no legs and are immobile. They produce the white wax that eventually covers their bodies. Second instars overwinter and moult to the adult stage the following spring (McCullough *et al*., 2003; Houston, 1994a).

Habitat Description
Cryptococcus fagisuga infects American beech (*Fagus gradifolia* Ehrh) and European beech (*F. sylvatica*) trees. Trees around 25 years old appear to be particularly susceptible to attack (Wainhouse, 1980), whereas smaller, younger trees (3-10 and 11-17 cm classes) may be a less suitable habitat (Fernandez & Boyer, 1988; Houston, 1988). Larger trees may be more susceptible to scale infestation due to more suitable spatial habitat and more nutritious bark. Larger trees have high nitrogen concentration, which is known to influence scale insect growth and development. Greater scale fecundity on larger trees yields higher infestation and, greater fungal infection and more severe disease development (Latty *et al*., 2003).
Nymphs prefer to colonise areas of the tree where the bark is rough. Infestations often start near old branch stubs, under large branches or sometimes beneath moss or lichens (Houston, 1979; McCullough *et al*., 2003).
The ability of the beech scale to establish itself of individual trees varies widely and is influenced by host resistance, bark epiphytes and possibly by predators and pathogens (Houston, 1994a). The beech scale prefers moist and shaded habitats (Gavin & Peart, 1993), although high rainfall is thought to be detrimental to scale populations and BBD as it may wash crawlers from trees and affect *Neonectria* spore production and dissemination (Houston, 1988).
Cold temperatures reduce the overwintering second-instar scale populations in the winter. Thus heavy rainfall and cold temperatures reduce scale infestation, and hence infection levels of *Neonectria* and subsequent cankering of trees (Houston, 1988).There appears to be a direct connection between climate and beech scale insect populations. In northern latitudes beech scale is limited by low winter temperature; minimum daily temperatures of -34 °C or below correlate with scale population dieback (Houston & Valentine, 1988 in Dukes *et al*., 2009).
Neonectria appear to only be limited geographically by the current distribution of beech scale, suggesting that they are not constrained by climate. In fact, perithecium production may be highest in winter as host dormancy reduces the capacity of trees to resist infection (Gove & Houston, 1996 in Dukes *et al*., 2009). The effect of future climate change scenarios of disease dynamics is unknown, but increased CO2 may enhance tree growth and thus increase susceptibility. Alternatively, increases in CO2 tend to decrease tissue nitrogen concentration, possibly decreasing bark nitrogen and thus susceptibility to scale attack. Increases in the frequency and severity of storms may influence the longevity of infected trees which are highly vulnerable to windthrow (Dukes *et al*., 2009).

Reproduction
Scale insects reproduce asexually by parthenogenesis. Thus all beech scales are females and no mating occurs. This form of reproduction allows the insects to rapidly build populations when suitable hosts are present (McCullough *et al*., 2003).

Nutrition
Cryptococcus fagisuga feeds on American (*Fagus grandifolia*) and European beech (*F. sylvatica*). This insect initiates feeding by inserting its long stylet through the bark tissue and into the cortex and phloem to feed on the vascular fluid of trees (Ehrlich, 1934 in Wiggins *et al*., 2004).
Acquisition of nitrogen is important for scale insects, and affects their growth and development. Larger trees are more susceptible to scale infestation in part because they have higher nitrogen levels, and thus more nutritious bark. Similarly, old growth forests generally have higher than secondary growth forests, and are thus more susceptible to beech scale infestation and BBD (Latty *et al*., 2003).

General Impacts
Beech bark disease (BBD) is caused by the combined impacts of beech scale insect (*Cryptococcus fagisuga*) and several species of ascomycete fungi in the genus *Neonectria*. BBD affects American (*Fagus grandifolia*) and European beech (*F. sylvatica*). Two principal species of *Neonectria fungi* are associated with BBD in North America. The probably introduced *Neonectria faginata* only infects F. grandifolia and is the main species involved with the disease. Native *N. ditissima* (*N. galligena*) affects a range of tree species, including beech (Houston, 1994a). In many cases *N. faginata* spreads to stands infected with *N. ditissima* and replaces this species as the dominant pathogen (Houston, 1994b; Kasson *et al*., 2009). A third species *N. ochroleuca* (now named *Bionectria ochroleuca*) has been found in association with BBD in some regions of the United States (Houston, 2005). In Europe the fungi associated with BBD are *N. ditissima* and *N. coccinea* (Twery & Patterson, 1984; Castlebury *et al*., 2006).
The beech scale insect feeds on host parenchyma cells which collapse and die, resulting in small fissures on the bark that allow *Neonectria* to enter the tree. Heavy infestations of scale allow *Neonectria* to spread rapidly within the bark (Houston, 1994a). As the fungal mycelia grow, large areas of tissues become weakened and die, sometimes causing cankers on the trunk and branches. Sometimes red-brown liquid oozes from the bark tissues killed by the fungi, and the foliage of severely affected trees may become sparse and turn yellow (LeGuerrier *et al*., 2003). If enough tissue is killed the tree will be girdled and die (Koch *et al*., 2010). The course of the disease may take as little as two years, but other trees may linger for several years.
Much research has suggested that BBD mainly affects large, older trees, and may cause up to 80% mortality of beech within a stand (Houston, 1994a). Death of older trees leads to gradual gaps in the canopy. This gives the opportunity for other tree species to take over, sometimes leading to drastic changes in the composition and structure of stands (Twery & Patterson, 1984; Runkle, 1990; Wiggins *et al*., 2004). Particularly in stands dominated by BBD-tolerant species such as eastern hemlock (*Tsuga canadensis*) and sugar maple (*Acer saccharum*); these species dominate and American beech may become a minor component of the stand (Twery & Patterson, 1984).
However in most forest stands BBD favours the development of dense beech thickets that interfere with the regeneration of other trees (Houston, 1994a; Garnas *et al*., 2011), due to beech's propensity to reproduce vegetatively via adventitious root sprouts, especially from damaged root sprouts (Garnas *et al*., 2011). Thus in many forests there is actually an increase in beech volume accumulation, particularly 10-20 years after BBD invasion (Morin *et al*., 2007).
Beech is a highly important tree for many birds and mammals due to the habitat large old trees provide and for the beechnuts produced during mast years. Loss of larger trees may reduce food and habitat and have negative impacts for animals, which may ramify through the ecosystem (Lovett *et al*., 2006; Wiggins *et al*., 2004).
Diseased trees are more prone to "beech snap" during high wind events. This poses a threat to people and personal property where trees occur in campgrounds, recreation areas or near homes (McCullough *et al*., 2003; Heyd, 2005). Alteration to beech composition may also have economic impacts, both negative and positive (Garnas *et al*., 2011).
For a detailed account of the impacts of beech bark disease please read Impacts of Beech Bark Disease

Management Info
Most control methods focus on reducing populations of the beech scale, as *Neonectria* are unable to colonise trees that have not been previously infested with the scale. Thus control of *Cryptococcus fagisuga* is likely to slow the spread of BBD (Wiggins *et al*., 2004).
Cultural: Thinning and removal of infected or susceptible trees, while retaining resistant trees is a commonly used management strategy. This is important for decreasing long-term susceptibility and vulnerability of forests to beech bark disease. Potentially resistant trees can be identified by smooth bark and vigour. In contrast, large overmature trees, trees with rough bark, and trees with wounds, broken tops or other obvious problems are most likely to be infested by beech scale and most vulnerable to *Neonectria* infection (McCullough *et al*., 2003). However such practices not feasible in large areas of natural forest due to labour, financial and practical constraints (Wiggins *et al*., 2004).
Physical: Physical removal of scale insects by scrubbing trees, high pressure water, or use of petroleum-based oils, which cover and suffocate scale insects may be used on individual high-value ornamental or yard trees (McCullough *et al*., 2003).
Chemical: There is no practical chemical control for beech scale (Pond, 2008), although insecticides may be used for individual high-value ornamental or yard trees (McCullough *et al*., 2003). Herbicides may be used in some cases to control beech regeneration, in order to minimise root sprouting and the creation of dense beech thickets (McCullough *et al*., 2003). Pesticides are not acceptable control options in large natural areas because of labour, financial, environmental and practical constraints (Wiggins *et al*., 2004).
Biological: The most desirable option for control of BBD is a biological control agent of *C. fagisuga* (Wiggins *et al*., 2004). A number of natural predators and pathogens of *C. fagisuga* have been identified including coccinellids, mites, gall gnats and a fungus (Shingo, 1964 in Houston, 1994a; Wiggins *et al*., 2004; Dukes *et al*., 2009). However none are effective in stopping its spread to date (Pond, 2008), and much further research is required (Wiggins *et al*., 2004).
Genetic: An estimated 1% of American beech trees are resistant to scale insect infestation, and thus BBD. The cause of resistance to BBD remains unidentified (Koch *et al*., 2007), although in European beech resistance appears to be due to anatomical features that act as barriers to infestation (Lonsdale, 1983a in Houston, 2005), whereas in American beech resistance may be associated with less total and amino nitrogen concentration (Wargo, 1988 in Houston, 2005). Recent findings suggest that resistance to BBD ranges from partial to total resistance (Ramirez *et al*., 2007).
Currently the only known method to identify resistant trees is the artificial infestation method developed by Houston (1982). Drawbacks to this method include the minimum 1-year wait for results and the reliance on live scale eggs which could result in spread of the insect. Thus much research is focused on identification of genetic markers for resistance, trials to clarify modes of inheritance via cross-breeding resistant and susceptible individuals, and methods of propagation via somatic embryogenesis (Koch & Carey, 2005; Loo *et al*. 2005; Pond, 2008).
For a detailed account of management options for beech bark disease please read Management of Beech Bark Disease

Pathway
Beech scale has may be transported on beech specimens shipped by plant collectors (Gwiazdowski *et al*., 2006). Beech scale is thought to have been introduced to Canada from Europe in an infested beech shipment (McCullough *et al*., 2003). Beech scale infestations in Michigan, West Virginia and Ohio are all centered on campgrounds or scenic areas, suggesting that humans likely play a role in moving scales long distances, e.g. by moving firewood.

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