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BEETLE-FUNGUS ASSOCIATIONS

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Introduction

Various insect genera may visit, breed and feed on the same woody material in which fungi and other microorganisms are also encountered. It is in this environment that the insects and fungi interact. These interactions occur spatially (across large geographic areas) and temporary (over periods of time). They may occur anywhere in the wood processing chain starting with standing trees, harvesting, transport and storage of logs, processing into wood products, green and dry lumber storage, transport of wood products, site storage and construction and in the wood in service. Interest in the role of insects in bluestain transmission and in the potential for outbreaks of insects vectoring plant disease organisms has resulted in a large volume of literature on insect-fungi relationships. This presentation summarized the major aspects of the intricate connections between beetles, fungi and the host (substrate) using historical and more current, still unpublished, information and in the context of modern forestry, global climate changes and international trade with wood products.

Beetles, Fungi and Mites

Beetles are hard bodied insects from the order Coleoptera with sclerotized bodies and sheathed front wings that cover more fragile wings underneath. They are found in almost all habitats and include following subgroups: Buprestidae (flat headed wood borers, jewel/metallic beetles), Cerambycidae (longhorn beetles, round headed borers), Curculionidae (snout beetles, weevils), Platypodinae (ambrosia beetles) and Scolytidae (ambrosia beetles, bark beetles, engravers). Fungi were also found associated with other beetles e.g. insect predators (e.g. Cleridae, Rhyzophagidae, Trogossitidae), scavengers that are associated with bark beetles habitats e.g. Staphylinidae (rove beetles), seed and pith feeders, Nitidulidae (sap beetles) and others. Little is known about their fungal associates of beetles from Botrichidae (powder post beetles or branch, twig and grain borers). The bark and ambrosia beetles have been most extensively studied for fungal associates followed by root infesting weevils. In general most other beetles are not commonly studied in depth with respect to the fungi they may carry so it is not clear in many cases if reported fungal associations are specific or casual.

Fungi encountered on the beetles and in the beetle habitats are numerous and belong to different fungal groups. The majority of them, especially those shown to be closely associated with bark and ambrosia beetles, belong to ophiostomatoid fungi. They typically produce slimy masses of spores at the tops of long stalks and include classical genera of *Ceratocystis*, and *Ophiostoma*. *Grosmannia* has recently been resurrected to accommodate species with *Leptographium* anamorph. *Ceratocystiopsis* typically have *Hyalorhinocladiella* anamorph while *Ophiostoma* (that comprise largest number of species) typically have *Pesotum* and/or *Sporothrix* anamorph. The purely asexual complex of *Ambrosiella* fungi is known to form close, mutualistic associations with ambrosia beetles. It includes genera of *Ambrosiella*, *Dryadomyces* and *Raffaelea* that are found to have taxonomic affiliation either with *Ophiostoma* or *Ceratocystis.* Yeasts and bacteria are also very common microorgnisms in the system and especially in the guts but have not been studied as extensively as fungi with more clear morphology. The yeast most commonly belong to genera of *Candida*, *Pichia*, *Hansenula*, *Saccharomyces* and *Cryptococcus*. Basidiomycetous fungi are also encountered although far less frequently than yeasts or ascomycetous fungi. In a few cases are shown to be closely associated with the beetles e.g. *Entomocorticium* sp with *Dendroctonus frontalis*. There are also other anamorphic fungi that can be casually or, in some cases, more closely associated with beetles such as *Geosmithia*.

In some beetle systems (e.g. *Dendroctonus frontalis* or *Ips typographus*) mites have been shown to be an important factor in spore transmission. Phoretic mites are clearly adopted for phoresy on beetles and they appeared to be very site specific, one species occurring consistently at different parts of a beetle body. Some mites have these special structures that protect and prevent washing of the attached spores. More recently some other systems like Dutch elm disease vector *Scolytus multistriatus* have been examined and significance of mites were confirmed there as well. In general the ecology of mites associated with bark beetles remains poorly understood and there are number of unanswered question regarding to link between mites beetles and fungi in the same system.

Associations

There are several recently published syntheses of research on insect-fungi associations. Ophiostomatoid fungi in particular are well adapted to dispersal by arthropods and their spores are coated with an adhesive material to help them adhere to the insect. The most highly developed relationships exist between bark and ambrosia beetles, and ophiostomatoid fungi where associated fungi are carried and maintained in special pouches (mycangia). Mycangia that have glands secret nutrients and chemicals that enhance growth of mycelial fungi while suppress growth of contaminant fungi.

There is substantial debate on the evolution of these associations and on when they began. Fungi may use the insect transport to move around and get to new substrates and food and

sometimes get food directly from the association (e.g. special carrying pouches in insects provide food for associated fungi). Insects also bring different fungal genotypes together ensuring gene flow within their population, hybridisation, diversification and evolution of associated fungi. On the other hand there are several paradigms attempting to explain why insects associated with fungi. These include the pathogenicity (fungi helping a beetle to overwhelm healthy host resistance mechanisms), nutritional supplement (fungi used as a food source for a beetle or assist beetles with cellulose digestion), mycological competition (some fungi may be important for the beetle to defend the gallery system from other more aggressive opportunistic fungi) and pheromone production paradigm (some fungi are indicated as being involved in chemical reactions that produce pheromones).

The research on the association between insects and fungi is challenging as these associations may be complex, go well beyond the casual relationship, and can be mutualistic, neutral or competitive or perhaps even change the nature of this relationship at different times. The degree of partner's dependency also may vary. Typically it is not one beetle-one fungus associations, but rather there are several consistent associates of one beetle species. Number of parameters may significantly influence the results of the association studies. First, this is a dynamic system and there is a possibility of natural variety of fungi in it at any given time as there is a constant competition among microorganisms found there. A state of the substrate, identity and abundance of competing organisms and environmental factors (e.g. temperature, water potential) can influence a shift of one organism over the other. When investigating fungal associates one needs to assess the level of intimacy and consistency of microorganisms in the system as well as the consistency of the association itself. Is this association been repeatedly found spatially (in different geographical locations) as well as temporally (in different seasons of or over several years)? Are these associations obligate, where partners would not survive without each other, or consistently casual? Human factors have also been shown to influence the results as different research methodologies and different experience and skills may produce different results within the same system.

Concluding remarks

There are a number of examples where insect-fungi combinations have caused major economic losses. Introduced secondary insects and fungi may cause havoc in importing countries either due to higher susceptibility of novel hosts or through novel combinations of associated fungi and insects in the importing country. The vector-fungus relationship is a strategy that makes both groups ecologically effective and often quite destructive to the crops. Together they spread fast, have high plasticity and ability to be destructive and cause plant diseases, invade new territories and explore new crops on a global scale. There are a number of ongoing new introductions to areas with novel host and indigenous insects and fungi. This creates overlap between introduced and existing insects and fungi and allows host switching (both insect and trees for fungi) and explorations of new hosts.

Current ongoing research concentrates on further surveys, pest risk assessments and work on detection methods using modern tools. These will assist with timely prevention, eradication and control of these movements.