The North Carolina Forest Service

Forest Health Handbook

3rd Edition

September 2011

Updated August 2013

by Ryan A. Blaedow

Acknowledgment

The 3rd edition of the North Carolina Forest Service Forest Health Handbook is a revised version of the original Pest Control Handbook authored by Boe Green in 1952 and the second edition authored by Coleman Doggett, Don Rogers, Thomas Smith, and Jim Smith in 1990. The first two editions have been utilized for more than 60 years, both as a field reference and training manual, and have served as the foundation for the 3rd edition. The contributions of the original authors are deeply appreciated. In addition, we would like to acknowledge the unnumbered scientists and foresters who contributed to the information contained within this handbook. Far too little gratitude is paid to those who devoted their careers to protecting the forests of our state.

Contributors

Ryan Blaedow

Brian Heath

Wayne Langston

Craig Lawing

Jason Moan

Rob Trickel

Kelly Oten

TABLE OF CONTENTS

Forest Health Handbook, 3rd Edition

The North Carolina Forest Service Forest Health Handbook describes some of the most important and/or common forest insects and diseases that damage trees in North Carolina. The main purpose of this manual is to provide basic information on threats to forest health, guidance in diagnosing tree disorders, and pest management recommendations. It is not intended as a final reference when dealing with any of the pests described. Rather, it should serve as a training aid and introductory text for those unfamiliar with the forest entomology and pathology fields, and as a quick reference guide for specific insect and diseases problems. **The information provided is specific to North Carolina.**

The **3rd Edition of the Forest Health Handbook** provides much of the same information as its predecessors. Insects and diseases are divided into sections based on the type of damage caused. For each specific stress agent, a brief overview is provided followed by information on the causal agent, hosts, symptoms and signs, life cycle or disease cycle, importance, management recommendations, seasonal timelines, and distribution information. This edition also features color photographs to supplement descriptions of symptoms/signs, to assist with diagnoses in the field, and to illustrate concepts or examples. Introductory material on forest protection, forest health, pathology, and entomology are provided to introduce readers to the terms and concepts used in these forestry sub-disciplines. Finally, a set of appendices is provided at the end of the manual with additional information on tree physiology and anatomy, non-native invasive organisms, diagnosing tree disorders, sample collection and submission guidelines, plant disease/insect management, additional resources and references, and Forest Health Branch contact information.

Time-sensitive information was excluded from this handbook (when possible) to prolong its relevance and usefulness. Therefore, information on the distribution of non-native invasives, laws and regulations, and pesticide use information may be found lacking or over-generalized in this manual. Readers are encouraged to consult the list of additional resources at the end of the handbook for current, time-sensitive information on these topics.

An effort was made to utilize (to the greatest extent possible) images from ForestryImages.org, an online source for forest health, natural resources, and silviculture-related images. This was done so that the reader can access original, high-quality images from the manual online for the purposes of study or diagnosis. Commercial use of these images has not been authorized. Image citations are provided at the end of the handbook; images from Forestry Images are available at: http://www.forestryimages.org/.

Introduction to Forest Protection

Forest protection is the scientific branch of forestry concerned with the study and control of ***biotic*** (living) and ***abiotic*** (non-living) stress agents that affect the health and/or integrity of trees, forest communities, and wood products. Stress agents are destructive and their effects must be limited to protect and conserve our forest resources, maintain tree health, and provide forest products for current and future generations. Historically, forest protection has primarily been concerned with fire science and fire control. Biotic stress agents have been the focus of two major branches of forest protection: ***forest entomology*** (the study of insects) and ***forest pathology*** (the study of pathogens and disease). The study and control of other abiotic stress agents has traditionally been shared by forest protection and silviculture.

This book will focus primarily on the biotic forest stress agents (primarily insects and diseases), though brief consideration will be given to abiotic stress agents with the notable exception of fire. The reason for this exclusion is two-fold. First, the science of fire and fire control are sufficiently different from other aspects of forest protection; consideration of fire and fire control is provided elsewhere in far more detail than can be provided here. Second, while fire is a major concern because of its destructive potential and threat to human safety, its negative impact on forest health is relatively minor in comparison to the other stress agents. For instance, in one of the few studies of its kind, the U.S. Forest Service estimated that in 1952, losses in forest productivity (tree mortality and reduced tree growth) due to forest stress agents in the U.S. equaled approximately 90% of the sawtimber volume cut in the same year. Of this staggering loss, 45% was due to disease, 20% due to insects, 18% due to abiotic factors such as weather, and only 17% due to fire.

Forest protection is a scientific discipline that requires an understanding and utilization of the principles and practices of not only forest pathology and forest entomology, but also forest ecology, forest management, silviculture, tree physiology, tree anatomy, soil science, physics, chemistry, and general biology. Likewise, forest protection is a critical component of ***silviculture*** which is the science of forest establishment, growth, and composition. In addition, stress agents (particularly insects and microorganisms) play a critical role in determining the health and diversity of forest communities; therefore, an understanding of forest protection is necessary for proper forest management and the science of forest ecology. Forestry as we know it would not be possible without an understanding and appreciation for the principles and practices of forest protection and its inter-related disciplines. The ultimate goal of forest protection is to minimize tree mortality and growth loss due to forest stress agents, and thereby protect and preserve healthy forest communities. But what exactly is a healthy forest?

Forest Health

Forests are tree-dominated communities of plants, animals, and microorganisms that interact with each other and the forest's abiotic components including soil, water, landform, and climate. A simplified example of a forest community would be a typical food web which includes producers, consumers, and decomposers: each organism in the food web is eaten by or eats other organisms. The totality of these interactions forms a network (or web) with connections present between all members of the community. In reality, the interactions and connections in a forest community are vast and complex, although the basic idea holds true: each component of the forest has an effect on and is affected by the others. Trees affect which plants and animals reside in the forest, protect soil from erosion, reduce runoff, improve water quality, and clean and cool the air. Likewise, the forest's abiotic components and organisms determine what tree species are found in a forest. Humans, for better or worse, are also an important constituent of forest communities because of our influence and reliance upon them. We rely upon our forests for a wide variety of resources, we value them for a range of social and cultural reasons, and they are an essential component of a healthy planet. Many forests are managed or protected to meet the goals and objectives of those who utilize and rely upon them; or are altered in ways that are damaging to the forest community.

A ***healthy forest*** is a forest that possesses the ability to sustain the unique species, interactions, and processes that exist within it and that can meet the present and future needs of people for a variety of values, products, and services. There are many types of forests found in North Carolina, each with a unique set of species, interactions, and processes. The health of our forests must be maintained to ensure the survival of plant and animal species that make the forest their home and to protect those processes that sustain a healthy environment.

A healthy forest can have unhealthy trees, just as an unhealthy forest can have healthy trees. Forest health can be determined on a variety of scales ranging from an entire forest ecosystem to an individual shade tree. A single dead tree in a large forested tract can provide wildlife habitat, may be an essential component of natural stand thinning or succession, or may create a gap in the canopy for a diversity of other plant species. However, a single dead tree in an urban forest might mean the loss of a high-value and prized shade tree, could represent years of lost revenue from a fruit tree that has taken years to bring to maturity, or may pose a hazard to people or structures nearby. Alternatively, the loss of many trees in a forest may not significantly impact forest health if other individuals of the same or similar species are able to support the community. But complete eradication of a single tree species by an insect or disease could have catastrophic consequences for a forest ecosystem. Defoliating insects and cosmetic diseases that are of little concern in forested situations may be intolerable afflictions to shade trees or ornamentals in a home owner's front yard. Annual growth losses due to poor soil conditions or drought may be of little concern in a park or on a tree-lined street, but could mean the loss of profitability over the course of a thirty year rotation in a pine plantation. The determination of forest health must be made relative to the species, processes, or resources of interest, and the stress agents present in the forest community.

Stress Agents

Tree health is threatened by ***stress agents*** that cause a sustained disruption of the normal physiological processes or structural functioning of a tree. Physiological processes include photosynthesis, respiration, transpiration, translocation of photosynthetic products and nutrients, growth, reproduction, mychorrizal associations, compartmentalization, and defensive responses. Structural functioning of the tree is dependent on anatomical features such as the roots and root hairs, root crown, stem, branches, buds, flowers, seeds, leaves, bark, and the vascular system. If a disruption in physiology or structure is sustained over a long enough period of time, or if it is severe enough, a tree can be harmed or killed. ***Primary stress agents*** are capable of attacking and injuring or killing otherwise healthy trees. A ***secondary stress agent*** can only attack a tree that has been weakened by primary stress agents or predisposing factors. ***Predisposing factors***, such as drought, extreme temperatures, nutrient deficiency, and fire, are most often abiotic stress agents.

Physiological or structural damage to trees due to non-living entities or ***abiotic stress agents*** are not considered to be diseases (diseases are caused by pathogens), but are more commonly referred to as abiotic disorders or abiotic injuries. Examples of abiotic stress agents include nutrient imbalances, improper soil pH, soil compaction, grade changes, hardpan, drought, flood, saltwater intrusion, lightning, frost, heat scorch, hail, sun scald, storm damage, mechanical injuries, herbicide damage, and air pollutants. Abiotic disorders are generally not species specific, meaning that most tree species are susceptible to most abiotic stress agents. Some tree species are more tolerant of abiotic stress agents or may have slightly different environmental preferences, but in general, an abiotic stress agent will affect most or all tree species to some degree. This can be particularly destructive when the stress agent is severe and widespread; entire forest communities can be severely damaged by a hurricane, drought, or environmental pollutants for instance. However, most abiotic disorders are relatively localized and they cannot spread from tree to tree. Management of acute injuries (e.g. mechanical damage and fire) emphasizes prevention prior to being damaged and possible treatments after the damage has occurred. Chronic disorders (e.g. drought and nutrient deficiencies) are less likely to be preventable, but may be treatable.

Biotic stress agents are living organisms including plants, animals, and disease-causing microorganisms such as fungi, bacteria, viruses, and nematodes. Most biotic stress agents are known as ***pests*** because they interfere with the intended use of a forest, a tree, or wood products. Some pests only inflict mechanical damage (e.g. a deer rubbing its antlers on the stem and damaging the bark) while others damage forest productivity through competition (e.g. weeds). The most important biotic stress agents are either predators or parasites; both attack trees to feed on or within them to obtain nutrients. ***Predators*** (in this case known as herbivores) are free-living organisms that usually feed on more than one individual host to reach maturity. ***Parasites*** on the other hand, live on or within a tree (usually one individual tree is sufficient to reach maturity) to obtain nutrients, and in the process they cause injury (*see* insects) or disease (*see* pathogens).

Biotic stress agents, specifically insects and pathogens, are transmissible; meaning that they can spread from one host tree to another. Although this may at first seem obvious, it is an important distinction for several reasons. First, the transmissibility of pests means that the disease or injury caused by them can also spread. When managing biotic stress agents that can spread, one needs to take into consideration movement of the pests across the landscape and through time. Simply controlling the pest at the site where damage or disease is occurring may not be adequate. Secondly, insect and pathogen populations have the potential to grow exponentially over time as they spread. This can result in outbreaks (insects) or epidemics (pathogens) capable of severe and widespread impacts on forest health. Third, biotic stress agents can only be transmitted to suitable hosts. Therefore, when monitoring, diagnosing, and managing biotic stress agents, one needs to take into consideration only the suitable host species.


Tree Stress Agents
Biotic
Abiotic
Microorganisms
Viroids
Phytoplasmas
Viruses
Myxomycetes
Bacteria
Nematodes
Oomycetes
Fungi
Plants
Alternate Hosts
Competitors
Parasites
Animals
Mammals
Meristem Feeders
Defoliators
Borers
Phloem Feeders
Insects
Birds
Disorders
Genetic Disorders
Girdling Roots
Deep Planting
Sun Scald
Weak Wood
Included Bark
Rubbing Branches
Wetwood
Frost Cracks
Soil
Grade Change
Compaction
Saltwater Intrusion
Drought
Slope
pH
Flooding
Nutrient Excess
Nutrient Deficiency
Micronutrients
Macronutrients
Texture
Hard Pan
Allelopathic Compounds
Toxins
Pesticides
Radiation
Air Pollution
Heavy Metals
Natural Gas
Misc. Toxins
Injury
Root Damage
Storm Damage
Pruning
Fire
Mechanical Damage
Girdling
Weather
Snow
Hail
Heat
Frost
Ice
Rain
Lightning
Wind

Hosts

A tree attacked by an insect or pathogen is called a ***host***. Most parasites have only one or a few tree species that act as suitable hosts, but a few parasites have a wider host range. This is because pests and trees have co-evolved over millions of years together and are engaged in an eternal "arms race" for superiority. Trees have evolved very powerful defensive responses to ward off attacks by potential parasites. Some of these defense responses are quite obvious (e.g. toxic chemicals, thick bark, leaf shedding, resin production, etc.) while others occur at a microscopic, chemical, or genetic level. In response, parasites have had to develop an arsenal of weapons (e.g. modified mouthparts, specialized digestive systems, toxins, enzymes, and even chemicals that shut off host defense responses) to survive. Because there are hundreds of thousands of plant species, insects and pathogens have evolved over time to "battle" just one or a few tree species; they could not possibly overcome the wide variety of defense adaptations found in all plant species. This means that most parasites are very host specific (i.e. they are very picky eaters). Some insects or pathogens can only complete their life cycle on a single tree species, or even on a single tree cultivar. The fact that most parasites are so extremely host specific has given rise to the saying: "resistance is the rule, susceptibility is the exception."

In general, a tree species is said to be ***resistant*** if it is capable of preventing or overcoming an attack by a specific parasite, but is said to be ***susceptible*** if that parasite can successfully attack, obtain nutrients, and disease or injury results. A tree can be resistant to one parasite, but susceptible to another. Resistance can be complete, meaning that the tree is not a host and can completely prevent a parasite from causing injury or disease; or it can be incomplete, meaning that the tree is susceptible to attack, but the severity of disease or injury is less than what would be observed in a less resistant (or more susceptible) species.

Forest Insects

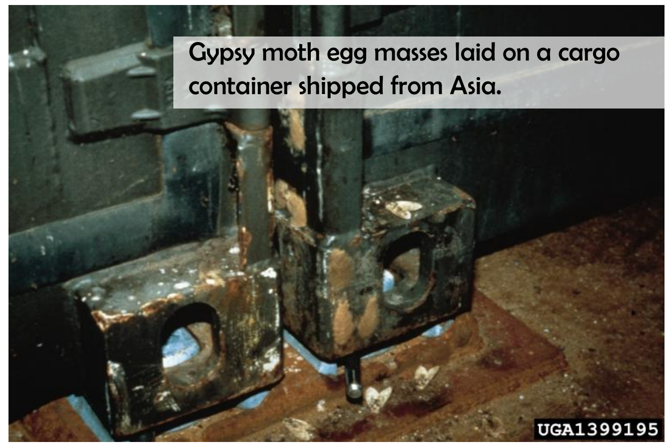
Forest Entomology

Insects kill more trees in the U.S. each year than any other forest stress agent. In addition, they can cause significant growth loss, degrade lumber, make trees vulnerable to attack by secondary insects and diseases, spread tree pathogens, and can be a serious nuisance. However, most insects that feed on trees do not cause serious harm. For instance, many of our native moths and butterflies feed on tree foliage in their larval stage. Trees have evolved along with these insects and under normal circumstances are tolerant of such activity. Many insects play important roles in the forest ecosystem including pollination, nutrient cycling, eliminating sick or weakened trees from the forest, and are even an important food source for many animals, especially birds. Many insects found in our forests are predatory and feed on some of our more serious forest insect pests and keep their populations in check.

Predatory insects such as the clerid beetle keep forest pest populations suppressed

Under normal circumstances, insect populations are highly suppressed by predators and disease. In addition, trees have evolved effective defense mechanisms against insect pests, and therefore serious or widespread damage or mortality caused by insects is rare. However, when trees become stressed or when predators fail to keep insect populations under control, the tremendous reproductive potential of insects can lead to large outbreaks and serious infestations resulting in tree damage or death. When outbreaks occur, they are often difficult or impossible to control. Therefore proper forest management, early detection of infestations, and practices that promote predatory populations are key components of minimizing the impact of serious forest insect pests.

During the last few decades, there have been dozens of introductions of exotic insects from other countries. Because our tree species have not adapted defense mechanisms against these insects, and predators adapted to feed on these exotic species are often lacking, exotic insect populations have the potential to increase rapidly and cause serious damage to the forest ecosystem. The first serious exotic forest insect to arrive in the U.S. was the gypsy moth (*Lymantria dispar*). Since its introduction in Massachusetts in the late 1860's, the gypsy moth has defoliated and killed millions of acres of



Gypsy moth egg masses laid on a cargo container shipped from Asia.

hardwood trees. Since that time, other insects such as the European elm bark beetle, hemlock woolly adelgid, beech scale, balsam woolly adelgid, Asian longhorned beetle, emerald ash borer, and the redbay ambrosia beetle, along with many others, have done serious and irreparable damage to our nation's forests. Exotic insects are now some of the biggest and most serious threats to our forest ecosystems.

Entomology is the study of insects, and ***forest entomology*** is the study of forest insects, particularly those insects which feed on or do damage to trees or lumber. Forest entomologists study insect biology, life cycles, classification, interactions with their host plants and other organisms, and control/management strategies.

The first insects appeared around 340 million years ago. Since that time, they have spread across our planet to occupy virtually every habitat imaginable. Their adaptations and modifications are nearly endless and often bizarre. The smallest insects are some species of parasitic wasps that are less than 1/16 inch long; the largest include moths with 12 inch wingspans, giant walkingsticks almost a foot and a half long, and goliath beetles that are 3 inches wide! Scientists predict that there are at least 10 million different species of insects worldwide, of which only about 1 million are currently known to science. Insects are so plentiful, in fact, that they represent approximately 85% of all known animal

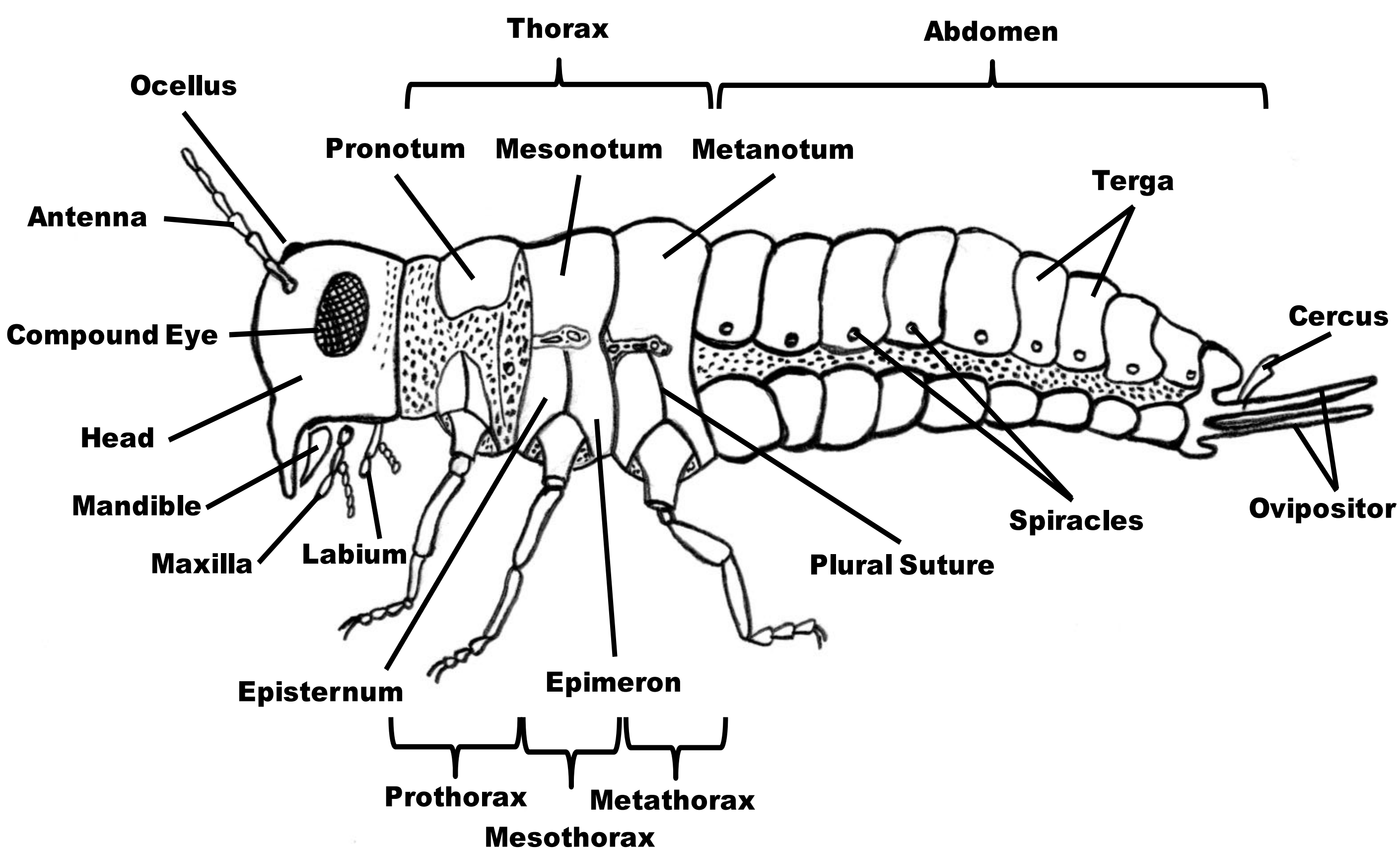
species on the planet. In the U.S. there are about 92,000 described insect species and an estimated 73,000 yet to be described. World-wide, there are more beetles than any other insect.

Insects are in the phylum Arthropoda which includes all animals with ***exoskeletons*** and segmented bodies. Entomology typically encompasses the study of two classes of arthropods: Class Insecta which are of course the insects; and Class Arachnida which includes the spiders, mites, scorpions, and ticks. There are approximately 30 insect orders, however not all orders include forest pests. The most common insect orders encountered in forest entomology include:

Coleoptera……. ………….	Beetles
Diptera………...................	Flies
Hymenoptera……………..	Ants, Bees, Wasps
Lepidoptera……………….	Moths and Butterflies
Orthoptera…………………	Grasshoppers, Katydids, Crickets
Phasmida……………..…..	Walkingsticks
Isoptera……………………	Termites
Hemiptera…………………	Cicadas, Leafhoppers, Aphids, Scales

All adult insects (with only a few exceptions) have the following characteristics: 1) a hardened external skeleton; 2) three distinct body regions (head, thorax, and abdomen); 3) one pair of segmented antennae; 4) one pair of compound eyes; 5) three pairs of segmented legs; and 6) one or two pairs of wings. Immature insects may resemble miniature adults or may have a completely different body shape and appearance. Arachnids differ from insects in that they have only two body segments and eight legs.

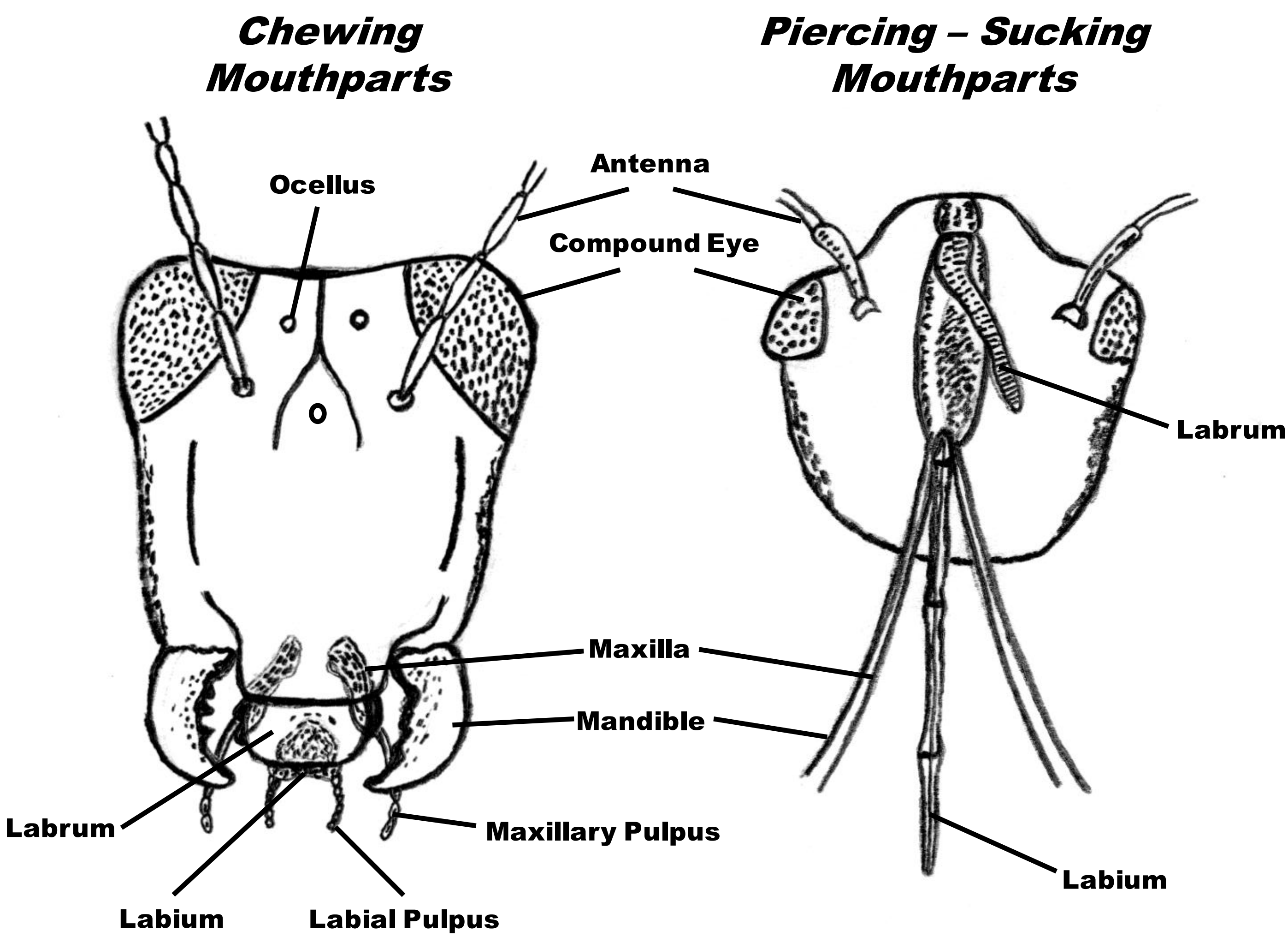
The ***head*** is the hardened region of the insect body that bears sensory organs such as eyes and antennae, and the mouthparts used for feeding. The large eyes that occur in most adult insects are called ***compound eyes***

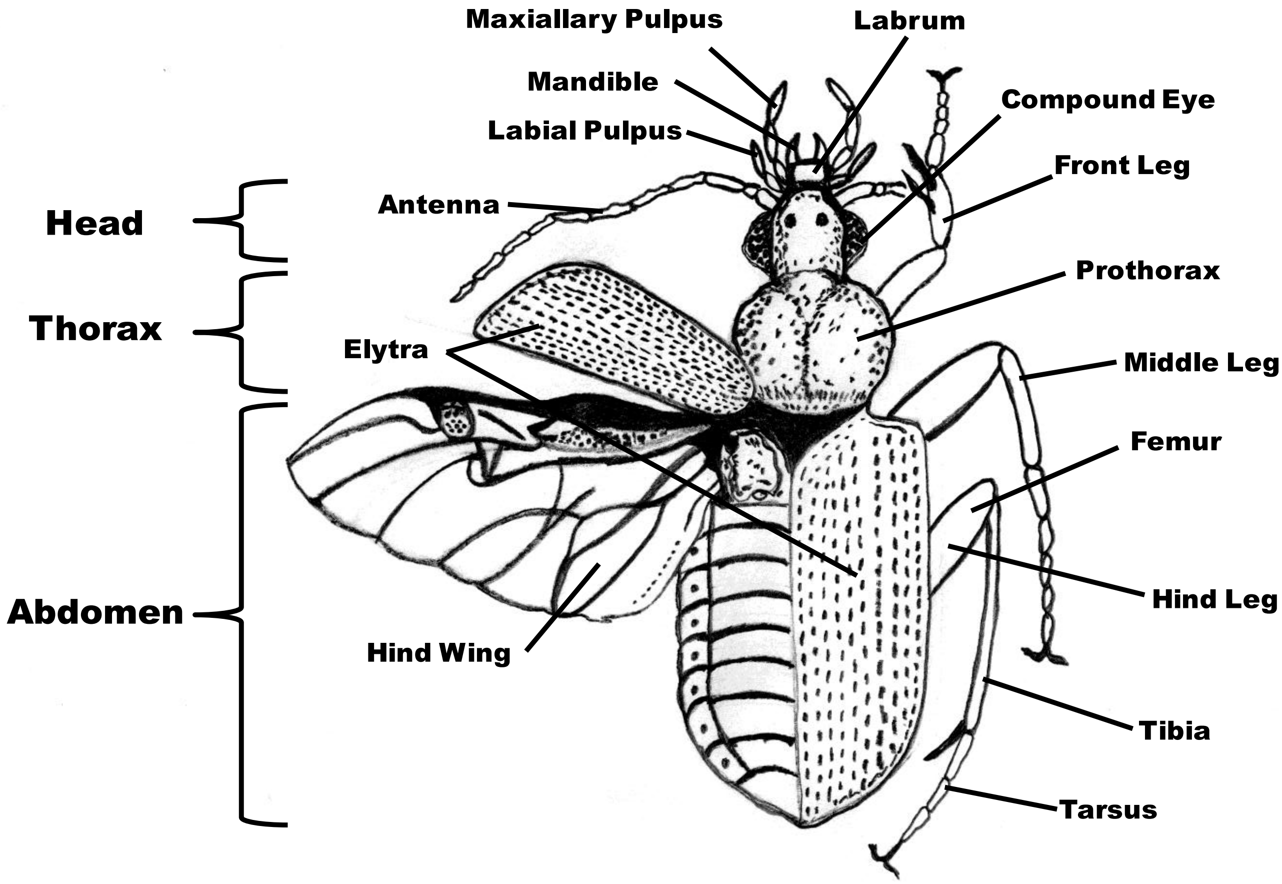


because they are made up of many individual light sensing units (up to several thousand per eye). Most adult insects also have three ***ocelli*** (simple eyes) located on the top of the head. ***Antennae*** are long, segmented sensory appendages that can be used to detect odors and sounds and to touch and taste objects. The function and appearance of the antennae varies with the insect species and can be useful for identification purposes.

The mouthparts are among the most varied of insect body parts and are specially adapted to accommodate their diverse diets. Therefore, mouthparts are often critical to classifying insect species. Mouthparts consist of an upper lip called a ***labrum***, a pair of jaw-like ***mandibles***, sometimes a tongue-like organ called a ***hypopharynx***, and a lower lip or ***labium***. In addition, the mouthparts contain a pair of elongated organs called maxillae that serve as sensory organs or are modified for piercing/sucking purposes. In general, insect mouthparts can be classified by their function: either ***chewing***, ***piercing-sucking***, or some other variation of these two categories including rasping-sucking, sponging, siphoning, etc. In chewing insects, the mandibles may be stout, curved, and toothed with special adaptations for cutting, crushing, or grinding. The labium and labrum are used to guide food into the mouth, and the maxillae have antenna-like appendages that touch and taste the food. In piercing-sucking insects, the mandibles and/or maxillae are modified into long, needle-like appendages; the labium/labrum may be somewhat flattened and elongated to surround, guide, and protect the mandibles/maxillae. In piercing-sucking insects, the elongated mouthparts are also known as the ***beak*** or ***proboscis***.

The ***thorax*** is the second body segment (located between the head and abdomen) and is made up of three individual segments known as the ***prothorax***, ***mesothorax***, and ***metathorax***. The segments of the thorax often contain grooves and ridges, and in addition to the arrangement of hardened scale-like plates that cover the thorax, can be useful for identification purposes. Each of the three segments of the thorax has a pair of segmented legs that may be specially adapted for

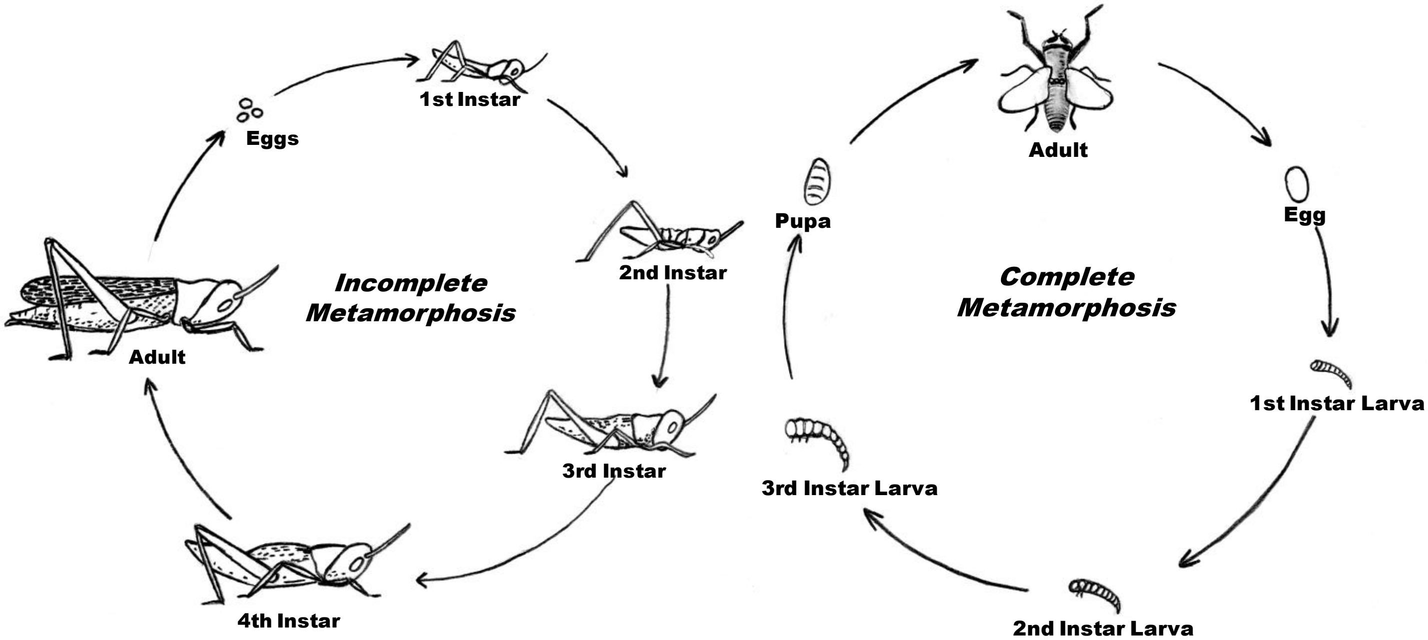




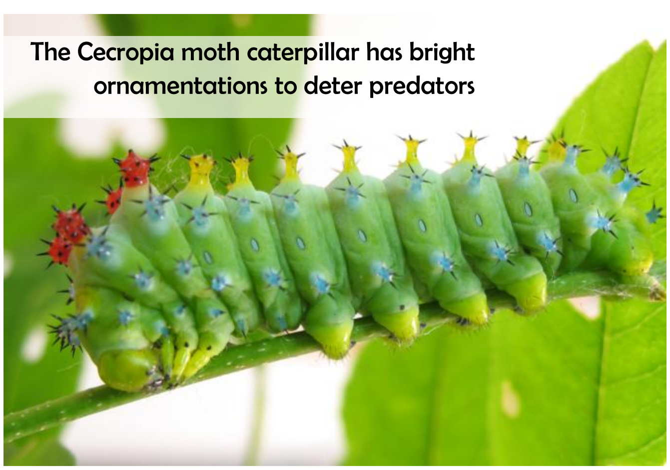
running, jumping, grasping, swimming, etc., depending on the insect. Each leg is made up of six segments, the last of which is a pair of claws. Insect larvae such as caterpillars may have additional pairs of fleshy legs on the abdomen known as ***prolegs***, but these legs do not have six segments and disappear in the adult stage of the insect. Most adult insects also have one or two pairs of wings that reside on the thorax, although some insects lack wings altogether. The wings vary in shape, color, size, thickness, texture, and even function. Beetles for instance, have two pairs of wings: one pair is elongated, thin, transparent, and often used for flight; the other pair known as ***elytra*** are thicker and hardened, and serve as protective covers for the underwings.

The last body segment, which tends to be softer and more flexible than the head and thorax, is the ***abdomen***. The abdomen contains most of the insect's internal organs, and usually consists of eleven distinct segments. Most adult insects lack any appendages on the abdomen, but exceptions include some male genitalia and the female ***ovipositor*** which can be specially adapted for egg laying, digging, sawing, piercing, or stinging. The abdomen of larvae may contain prolegs or ornamentations (that may be hairy, spiked, colorful, or even toxic) to deter predators.

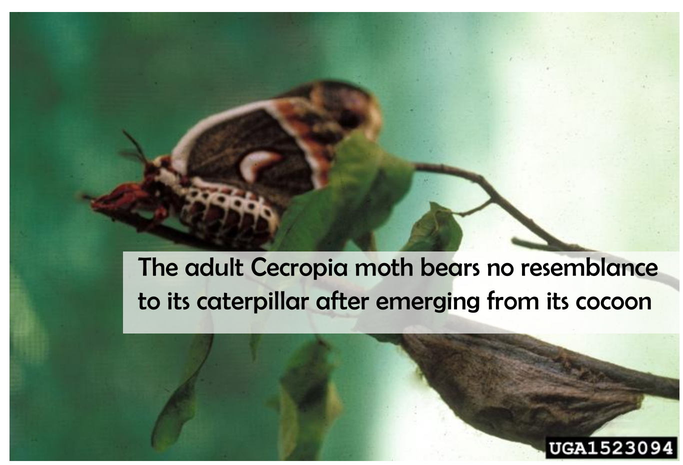
Insects undergo dramatic changes in appearance and behavior during the course of their lives. Immature forms may differ so significantly from adults that they may not even be recognized as the same species. During their development, insects undergo a drastic change in form known as ***metamorphosis***. There are two basic types of metamorphosis: incomplete and complete. ***Incomplete metamorphosis*** is characterized by immature insects that resemble adults and change mostly in size and the development of wings and genitalia. Immature life-stages typically have compound eyes and mouthparts; they generally have the same feeding habits as adults. Insects that undergo ***complete metamorphosis*** have immature life stages that do not resemble the adults, are generally worm like, have simple eyes, no visible wings, short antennae, and mouthparts that often differ greatly from the adult stage.



All insects begin their life as an egg. Immature insects which hatch from eggs are known as ***nymphs*** (incomplete metamorphosis) or ***larvae*** (complete metamorphosis). All immature insects grow in size by a process known as ***molting***, which is periodic shedding of the skin and expansion of tissues before the new underlying skin hardens. The number of times an immature insect molts before becoming an adult ranges from four to eight and varies with species and even gender. Between molts, the immatures are known as ***instars***. Insect development is often monitored by knowing what stage or instar the insect is currently in. Management recommendations such as pesticide applications are often timed to target certain instar stages (e.g. an insecticide must be sprayed before the 3rd instar).


The Cecropia moth caterpillar has bright ornamentations to deter predators

Following the final instar stage, insects that undergo incomplete metamorphosis become adults. For insects that undergo complete metamorphosis, the final instar stage is followed by an additional life stage known as the ***pupa***. The pupa does not feed nor move, and is usually covered in a protective coating that may be silken, hairy, or hardened. During ***pupation***, the structure of the insect completely changes from the larval form to the adult. In the pupal stage, the insect's tissues are broken down, reorganized, grow, and differentiate into their adult form. New mouthparts, digestive systems, reproductive organs, wings, compound eyes, and other dramatic additions and changes take place.



The adult Cecropia moth bears no resemblance to its caterpillar after emerging from its cocoon

The pupal stage may last for days, weeks, or even months. When the fully formed adult is ready, it emerges from the pupal skin and its new body begins to quickly dry, harden, and develop pigmentation. Some adults feed on completely different hosts or host tissues than their larvae; others do not feed at all and may only live for a few hours or days: just long enough to mate and lay eggs.

Many insects feed on and breed within trees and other forest plants. Forest insects cannot attack any plant species; instead, insects tend to be host-specific. A ***host*** is a plant that can be utilized for an insect to complete its life cycle. Most insects have only one or a few suitable host species; however some insects can attack a wide range of host plants. The mechanisms that determine which insects can attack which plants are very complicated and result from complex interactions and signals between the two organisms.

Trees have evolved structural and chemical defenses such as thick bark, waxy leaf coatings, root secretions, and even toxins that prevent or deter insect attacks. A plant that possesses the ability to prevent attack is completely ***resistant*** to that insect. Some plants may be attacked by insects, but because of defensive adaptations they are able to limit damage and are considered to be resistant compared to more susceptible plants. ***Susceptible*** plants are vulnerable to insect attacks that result in severe damage or death. Resistance and susceptibility form a continuum that ranges from completely resistant to highly susceptible. A plant can be resistant to one insect, but susceptible to another: each interaction is unique.

Forest insect pests are generally grouped by the type of damage they cause to their hosts. These insects fall into one of five categories: defoliators, bark beetles, wood borers, sapsucking insects, and meristem feeders.

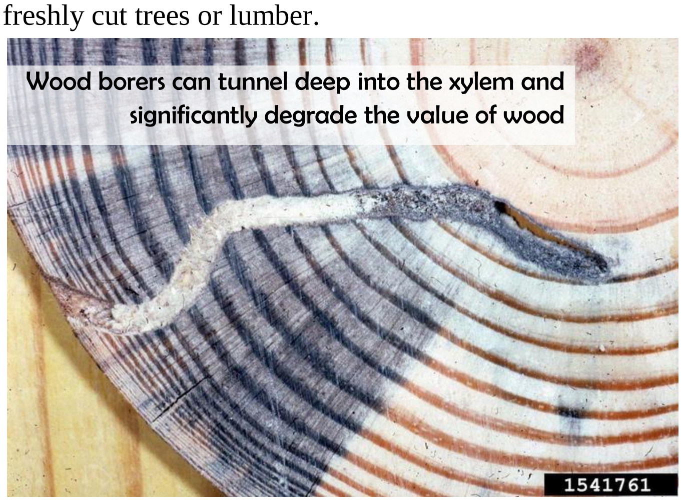
Defoliating insects feed on the foliage of trees, which are the main tissues responsible for photosynthesis. Although most defoliating insects are harmless or tend to be merely a nuisance, when outbreaks occur they can become highly destructive. For example, the gypsy moth is a highly damaging defoliator because its populations can grow rapidly, each larva can eat over a square foot of leaf surface per year, and a heavily infested tree can be completely defoliated year after year. Most other defoliating insects do not have such destructive potential. For instance, many of our native moth and butterfly larvae feed on tree leaves. Because only a few larvae feed on any given tree, little or no damage occurs. Any time a tree is partially or completely defoliated during the growing season there is a general decline in the health of that tree. This decline can cause the tree to grow slower, make the tree more susceptible to secondary pests, and can even cause tree mortality in some cases. If a tree is defoliated early in the growing season, it may refoliate, but this dramatically decreases the tree's energy reserves. Defoliation that occurs later in the growing season typically does less harm to the tree because the tree has already had ample time to build up energy reserves before the onset of winter.

Eastern tent caterpillars feed on the foliage of a variety of hardwoods during the spring

Bark beetles are a highly destructive group of forest pests. The southern pine beetle, the most destructive forest insect in the South, falls into this group, as do the *Ips* engraver beetles. Adult bark beetles bore into the inner bark of susceptible host trees to lay eggs in long tunnels known as ***egg galleries***. When larvae hatch from these eggs, they begin to bore through the inner bark and

Galleries formed by southern pine beetle adults and larvae girdle a tree's vascular system feed on the nutrient-rich cambium and phloem tissues, and even the outer sapwood. The tunnels created by feeding larvae are known as ***larval galleries***. If a tree is heavily infested by bark beetles, the cumulative effect of the galleries is ***girdling***, which occurs when the nutrient conducting tissues of the phloem are completely severed and destroyed. In addition, if the outer sapwood is damaged, the tree may be unable to transport water and will wilt. Healthy trees resist attack by bark beetles by producing sap or pitch to push adult beetles out of entrance holes. When trees are in a weakened state or are attacked by large populations of beetles, they may be unable to generate enough sap to prevent beetles from entering. Therefore, when bark beetles do gain entrance to a tree, the most common result is tree mortality. Many of the bark beetles carry fungi, such as blue stain fungi, that can degrade wood quality and plug the tree's vascular tissue accelerating the host's decline.

Wood borers differ slightly from bark beetles in that their activity is not strictly confined to the cambium and phloem tissues of the inner bark. Wood borers will also bore into and feed on the sapwood. Damage from wood borers includes girdling of the water and nutrient conducting tissues of the vascular system, and usually results in death. Many devastating non-native invasive insects, such as the emerald ash borer, redbay ambrosia beetle, and Asian longhorned beetle belong to this group. Many secondary insect pests also fall into this group, including the twolined chestnut borer and the southern pine sawyer. Wood borers that feed on dead or dying trees require sufficient wood moisture; trees that have been dead for a prolonged period of time (e.g. when the bark falls off) are no longer suitable for wood borer activity. However, as long as wood moisture remains sufficient, wood is susceptible to attack. Therefore, many wood boring insects are a significant threat to freshly cut trees or lumber.

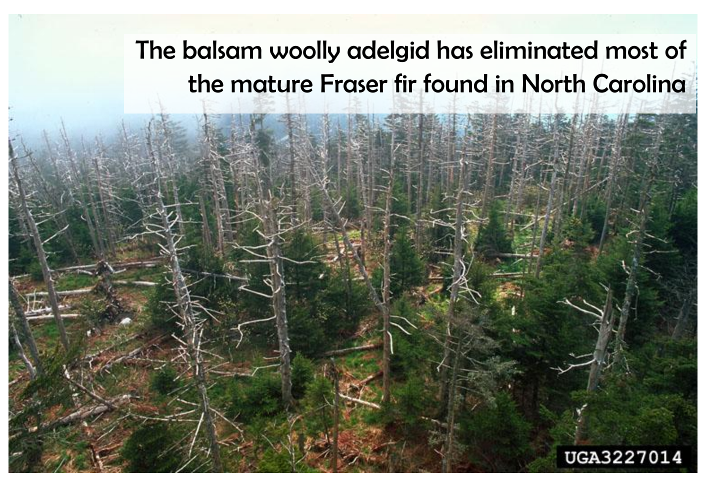


Wood borers can tunnel deep into the xylem and significantly degrade the value of wood

Sap-sucking insects are those insects that possess piercing-sucking mouthparts and are able to penetrate the nutrient conducting tissues to feed on the plant's sap. Most sap-sucking insects are only able to feed on soft, succulent tissues where the vascular system is close to the plant surface; others possess mouthparts which can penetrate tree bark. Though most are not, piercing-sucking insects can be highly damaging to trees. For instance, the hemlock woolly adelgid is a sap-

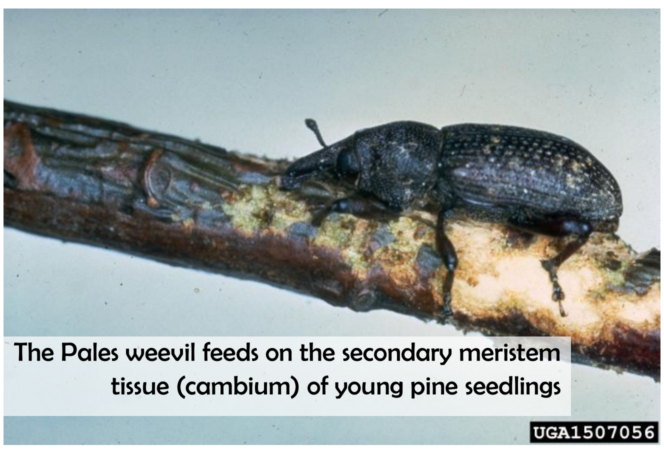
Aphids are sap-sucking insects that are commonly found on both conifers and hardwoods

sucking insect that feeds at the base of hemlock needles and is responsible for nearly wiping out both eastern and Carolina hemlocks in North Carolina. The balsam woolly adelgid, which created the ghost forests of high elevation Fraser fir in North Carolina, also are highly destructive. Piercing-sucking pests include scales, aphids, adelgids, pysillids, leafhoppers, and related species such as mites. Under the right conditions, piercing-sucking insects can cause serious damage resulting in tree decline or mortality. Some of these insects, such as aphids, can also cause a distortion of plant parts and unsightly galls.



The balsam woolly adelgid has eliminated most of the mature Fraser fir found in North Carolina

Meristem-feeding insects feed on those tissues of a plant known as ***meristems***, which are responsible for plant growth. Meristems include shoot tips (which account for increases in tree height and branch length) and the cambium (which accounts for increasing tree diameter). An example of a meristem feeder would be the Nantucket pine tip moth which lays its eggs on the shoots of young pines. Upon hatching, larvae bore into the young, rapidly growing shoots to eat the nutrient rich tissue. When populations are high enough, meristem feeders can kill trees (especially seedlings and young trees), but more often they only disfigure trees or cause reduced growth. Feeding by these insects can cause the terminal shoots to die, resulting in increased lateral branch growth that gives rise to trees with poor form and multiple stems. Damage from these insects also reduces tree growth and vigor, and may make them more susceptible to secondary pests.



The Pales weevil feeds on the secondary meristem tissue (cambium) of young pine seedlings

The Nantucket pine tip moth feeds on the primary meristem tissue (growing shoots) of young pines

Scale Insects

Overview: Scale insects are some of the most destructive pests of shade trees and ornamentals, but few are serious forest pests. All scale insects pierce plant tissues and obtain nutrients by the ingestion of large amounts of plant sap. Localized injury may occur around feeding sites and serious damage or death may occur in heavily infested trees. All adult scales produce a waxy or shell-like covering. Many scale insects are often very inconspicuous (some scale coverings act as camouflage) making diagnosis of an infestation difficult (Fig 5). Others may produce an obvious waxy coating that is easily visible. There are hundreds of species of scale insects that feed on North Carolina trees and shrubs. However, each scale species usually infests only one (or a few) host species. Therefore, many scales are named for the specific host species on which they feed.

Causal Agent: Scale insects: Order Hemiptera, Suborder Sternorryncha, Superfamily Coccoidea

Hosts: Many species of conifers and hardwoods. Scale insects are usually very host specific.

Symptoms / Signs: Symptoms vary widely with the scale species, host, and host tissue attacked. The most common symptoms observed may include foliage spotting, speckling, chlorosis, curling, and/or wilting; as well as galls, distorted growth patterns, bark swelling, twig dieback, branch dieback, decline, and mortality.

Adult females are sedentary, wingless, and may lack distinctive divisions between the head, thorax, and abdomen. They are covered with a hard scale or waxy secretion, and can range from $^{1}/_{50}$ inch to ¼ inch long. Scale coverings can be flattened and shield-like (Fig. 3), spherical (Fig. 8), or anywhere in between. Wax coatings (frequently white) (Fig. 6) may simply be a thin transparent film (Fig. 7), but some species produce powdery bloom-like secretions. Adult males usually have wings, lack mouthparts, and are very active flying insects but are rarely observed. Nymphs are nearly microscopic and only mobile for a few days to a couple of weeks. After their first molt, they lose their legs, become sedentary, and begin to form a scale or wax covering. The best way to detect crawlers is to hold a white sheet of paper under an infested branch. Shaking the branch will cause the crawlers to fall onto the paper, where they may be visible as small moving dark specks.

In addition, like many other sap-sucking insects, some scales produce large amounts of honeydew (waste and excess plant sap that could not be processed by the digestive system) that drips down onto lower surfaces. Specialized fungi known as “sooty molds” grow on the honeydew, turning those surfaces dark gray or black (Fig. 2). Other insects, such as ants and wasps, may also invade the area to feed on fresh honeydew.

Life Cycle: Life cycles vary by scale species. Usually there are 1-4 generations per year in North Carolina. Most scales overwinter as late-stage nymphs. In the spring after maturation is complete, the eggs inside the adult female’s body mature within one to several weeks after fertilization. When the eggs hatch, the first stage nymphs (known as “crawlers”) search for feeding sites, or may spread to neighboring trees on the wind or by animal vectors such as birds and small mammals. Once a feeding site is located, the crawlers molt and become sedentary. Their long piercing-sucking mouthparts may penetrate deep into the plant to reach nutrient-rich sap. Feeding sites may be leaves, buds, twigs, or main stems depending on the scale species. It may take 2-8 weeks for nymphs to transform into fully mature adults. Populations can grow exponentially, resulting in heavy infestations in short periods of time, and are frequently cyclical.

Importance: Moderate. Most scales pose no serious threats to tree health. However, scales can be a serious nuisance on landscape trees and ornamentals. Gloomy scale can cause serious dieback or even death in many maple species. The tuliptree scale (Fig. 1) is a serious pest of yellow poplar that can cause branch dieback or death. The beech bark scale releases a potent toxin and carries a pathogen that threatens the survival of American beech. Lecanium scales are a very common pest of hardwoods, but rarely require control measures (Fig. 4).

Management: Chemical control options are available for high-value trees. Treatments are usually ineffective against adults. Therefore, applications of insecticides or horticultural oils must target crawlers when they are active. Close monitoring of crawler activity and repeated chemical applications are usually necessary for successful control.

Timeline: Species dependent. Life stages may overlap significantly. Crawlers are most active in the spring and fall.

Range: Statewide.


Fig. 1 Tuliptree scales

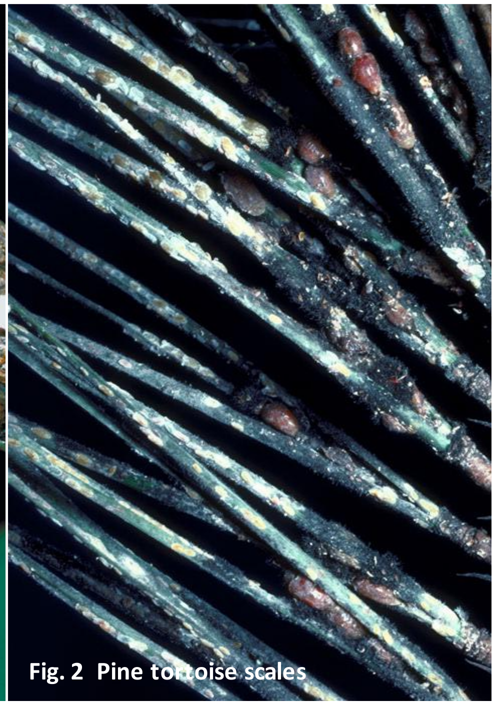


Fig. 2 Pine tortoise scales

Fig. 3 Obscure scale

Fig. 4 Lecanium scales

Fig. 5 Black scale

Fig. 6 Wax scales

Fig. 7 Green scales

Fig. 8 Soft scale

Aphids

Overview: Aphids are usually minor pests of hardwoods and conifers, however, a few can cause serious harm to landscape trees and ornamentals, while others can be serious pests in seedling nurseries. Some aphids act as vectors for viral or bacterial diseases, and most have the potential to become persistent and troublesome pests. All aphids pierce plant tissues and obtain nutrients by the ingestion of large amounts of plant sap. Localized injury may occur around feeding sites, and serious damage or death may occur in seedlings or young trees. Usually natural predators keep aphid populations under control, therefore, serious infestations are often observed following insecticide applications that adversely affect predatory insects. Aphids can feed on almost any plant tissue, but are most common on foliage and new growth. Aphids produce large amounts of honeydew resulting in sooty mold that can damage or degrade the beauty of ornamentals. Some aphids produce a woolly or waxy material that covers their body; others induce gall formation at the feeding site. There are hundreds of species of aphids, most of which are named for their host plants.

Causal Agent: Scale insects: Order Hemiptera, Suborder Sternorryncha, Superfamily Aphidoidea

Hosts: Conifers and hardwoods. Aphids are usually host specific; almost all plant species are attacked by one or more species of aphid.

Symptoms / Signs: Aphids weaken a plant by feeding on sap, or may transmit plant pathogens. Symptoms vary widely with the aphid species, host, and host tissue attacked. The most common symptoms observed may include foliage spotting, speckling, chlorosis, curling, and/or wilting; as well as distorted growth patterns (Fig. 6), galls (Fig. 7), bark swelling, twig dieback, branch dieback, decline, and mortality.

Aphids are small (1/64 - 1/4 inch long) pear-shaped insects (Fig. 1) that live in colonies (Fig. 2 & 5) on the leaves and new growth. They may be winged (Fig. 3 & 4) or wingless and vary widely in color, shape, and size. Some aphids produce alarm pheromones when threatened or disturbed, stimulating defensive responses (e.g. dropping to the ground, shaking aggressively) in their neighbors. Other aphids have wax glands in their abdomen that produce a woolly or waxy coating that may cover their entire body (Fig. 9).

Like many other sap-sucking insects, aphids produce honeydew (waste and excess plant sap that could not be processed by the digestive system) that drips down onto lower surfaces. Fungi known as "sooty molds" grow on the honeydew, turning those surfaces dark gray or black. Other insects such as ants and wasps may also invade the area to feed on fresh honeydew, and some ant species "farm" aphids for honeydew (Fig. 8).

Life Cycle: Life cycles vary considerably in different aphid species. Usually, aphids overwinter in the egg stage and hatch in early spring as plant growth resumes. Only wingless females are produced at first, which feed and reproduce without mating, resulting in a growing population of more wingless females. When the colony gets big enough, winged females are produced that fly to an alternate host plant species to feed and continue to reproduce without mating. Late in the season, winged forms return to the original host plant species where a generation of both males and females is produced; they mate and lay eggs before the onset of winter. Numerous overlapping life-stages can be found throughout the growing season.

Importance: Moderate. Most aphids cause little or no serious harm to host plants; however, large infestations can cause damage. Generally, aphids are a serious nuisance that degrade the appearance of landscape trees and ornamentals.

Management: Chemical control options are available and infested plants must be thoroughly treated. Contact insecticides and horticultural oils are usually ineffective against aphids with waxy protective coatings; systemic insecticides are sometimes effective in these cases. Aphids are notoriously difficult to control and nearly impossible to eradicate completely. An integrated pest management approach is usually the most effective. Predatory/parasitic insect populations usually keep aphid populations in check; insecticide applications that kill beneficial insects may result in aphid outbreaks.

Timeline: Species dependent. Life stages may overlap significantly. Active throughout the growing season.

Range: Statewide.

Fig. 1 Tobacco aphid

Fig. 2 Aphid colony

Fig. 3 Green peach aphid

Fig. 4 Giant bark aphid

Fig. 5 Black cherry aphid

Fig. 6 Leaf curl ash aphid

Fig. 7 Woolly apple gall aphid

Fig. 8 Ant feeding on honeydew

Fig. 9 Woolly alder aphid

Gall-forming Insects

Overview: Many insects induce hypertrophies (a condition of abnormal rapid cell division and cell enlargement) in host tissues during feeding or to complete their life cycle. These hypertrophies are generally referred to as galls, and are caused by a wide variety of insects. Gall-forming insects release plant growth-regulating chemicals that alter normal plant growth and development. Most gall-forming insects are host species-specific and are often named for their host. Galls can be formed on virtually any host tissue including leaves, buds, flowers, cones, shoots, twigs, branches, and main stems. There are hundreds of gall-forming insects, most of which cause little if any serious harm to their host plants. However, because galls may be large and conspicuous, they often cause concern.

Causal Agent: Gall-forming insects include a number of insect and arachnid orders and families including aphids, phylloxerans, midges, adelgids, mites, psyillids, beetles, moths, sawflies, and wasps. Most often it is the immature stage of the insect that is responsible for gall production. Galls formed by gall wasps are among the most common galls observed.

Hosts: Most common in hardwoods. Most hardwood species serve as hosts to one or more gall-forming insects; galls are particularly common in oaks. Some conifers including pines, fir, spruce, and baldcypress (Fig. 9) are hosts to gall-forming midges and adelgids.

Symptoms / Signs: The causal agents of galls are usually not observed; larvae inside of galls are difficult to identify. Diagnosis is usually based on the gall symptoms and host species. Galls vary widely in size, shape, color, texture, and longevity and are determined by the host species, host tissue, and the causal agent. In general, galls are tissue swellings caused by rapid cell division and enlargement (gall midges in conifers also cause resin accumulation at their feeding sites, which contribute to gall swelling). Galls can be small leaf spots or bumps (e.g. eyespot galls on maple, dogwood, and yellow poplar (Fig. 1)), soft and fruit-like (e.g. oak apple galls (Fig. 2)), carpet-like (e.g. eriophyid galls (Fig. 4)), woody (e.g. many oak galls), ornamented (e.g. horned oak galls (Fig. 3)), spiny rose galls), fuzzy (e.g. hedgehog gall, woolly rose gall (Fig. 5)), cone-like (e.g. eastern spruce gall (Fig. 6)), well defined (e.g. nipple galls (Fig. 7)), deformed (e.g. many psyllid galls), or abnormal clusters of buds, shoots, or leaves (e.g. witches brooms (Fig. 8)). The variations are nearly endless.

Life Cycle: Life cycles vary considerably. Galls are produced by plant growth-regulating compounds (sometimes called plant hormones) released by larvae, but a few galls are caused by adult life stages (e.g. sawfly-induced galls). Additional resources should be consulted for specific information on gall-forming insects. The life cycle of a typical oak gall caused by a gall wasp is given below as an example.

Each gall-making wasp species utilizes only one or a few closely related tree species as a host; each gall maker creates a distinctive gall on its host. An interesting characteristic of many gall wasps is that they are heterogamous: the offspring differ significantly from their parents, but are identical to their grandparents. This is also referred to as alternating generations. The galls formed by alternating generations may be formed on different host tissues and look completely unlike those caused by the parent (Fig. 10 & 11). In fact, the offspring and their galls may look so unlike their parents that in many cases, entomologists have unknowingly described them as separate species. Many gall wasps overwinter as mature adults inside their galls. In the spring they emerge and lay eggs in suitable host tissue. Larvae rapidly develop; the plant growth-inducing chemicals they release cause rapid multiplication and growth of nutrient-rich cells surrounding the larval chamber on which they feed. Adults of the second generation emerge and lay eggs on the same host (but often different tissue). Larvae formed during this generation mature during the summer and fall but will not emerge until the following spring.

Importance: Low. Galls usually cause little if any serious harm to their hosts.

Management: Usually not required.

Timeline: Species dependent; active throughout the growing season.

Range: Statewide.

Fig. 1 Eyespot galls

Fig. 2 Oak apple galls

Fig. 3 Horned oak gall

Fig. 4 Eriophyid mite gall

Fig. 5 Mossyrose gall

Fig. 6 Eastern spruce gall

Fig. 7 Nipple galls

Fig. 8 Witches brooms

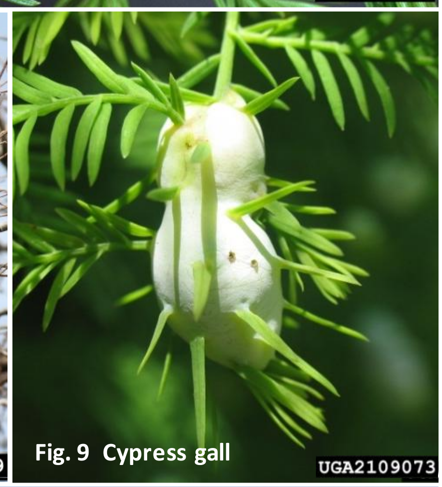


Fig. 9 Cypress gall

Fig. 10 Cynipid gall wasp (Generation 1)

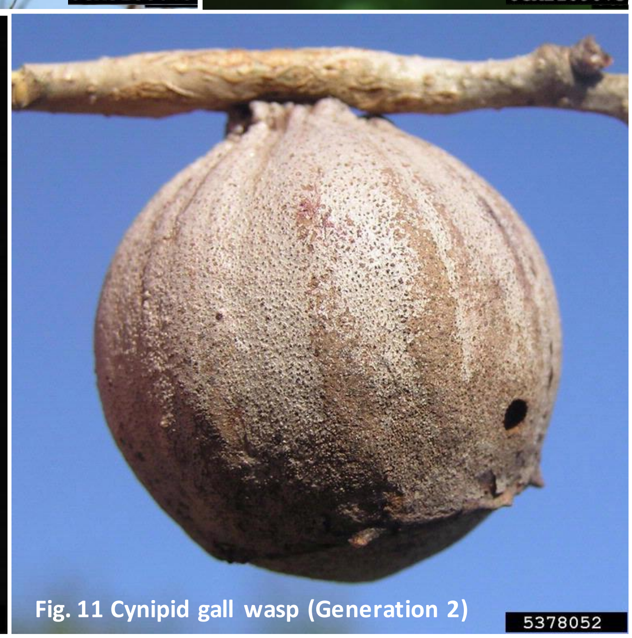


Fig. 11 Cynipid gall wasp (Generation 2)

Hemlock Woolly Adelgid

Overview: The hemlock woolly adelgid was first introduced to the eastern United States in the early 1950's from Asia. Since that time, it has spread throughout much of the natural range of our native hemlocks and threatens to eradicate virtually all hemlocks from our forests. The hemlock woolly adelgid is an aphid-like insect that feeds on nutrient-rich sap; large populations of the insect that heavily infest trees cause decline and eventually death over a period of three to seven years. There are many potentially disastrous consequences of losing mature hemlocks from our forests as they are critical for water and soil quality preservation, and are depended upon by many plant and wildlife species.

Causal Agent: Hemlock woolly adelgid (*Adelges tsugae*)

Hosts: Eastern and Carolina hemlocks; also hundreds of ornamental hemlock cultivars.

Symptoms / Signs: Symptoms develop gradually over a period of several years. The foliage on infested branches will begin to pale in color, often turning from dark green to grayish-green or gray. Needles will dry out and may fall off the tree within a few months. A new flush of needles may occur on some infested trees, but this is not necessarily an indicator of improving tree health. Infested trees put on little if any new shoot growth. Crowns will appear thin and individual branches may be killed starting in the bottom of the crown and spreading upwards (Fig. 3). Trees will usually die within 3-7 years of becoming heavily infested. In areas where the adelgid front has already passed through, large numbers of pale-gray snags line watersheds (Fig. 7).

Sedentary adult adelgids will be located on the undersides of branches (Fig. 1). Adults (< 1/16 inches long) (Fig. 8) are covered by a white woolly coating and are usually attached at the base of needles (Fig. 4). Heavily infested branches will look as if they have been sprinkled with snow (Fig. 2). The juvenile crawlers are nearly microscopic, but can be seen (when present) by shaking an infested branch over a white piece of paper; crawlers will appear as small black dots moving on the paper surface.

Life Cycle: The hemlock woolly adelgid has a complex life cycle that involves a number of life stages and an alternate host (spruce) in Asia. The life-cycle here in the U.S. is not as complex because our native spruce species are not suitable for the production/survival of certain life-stages of the insect. In spring, two life stages are produced at the same time: winged sexuparae and non-winged progrediens. *Note: Sexuparae do not survive or reproduce in North America.* Progrediens hatch as crawlers from late March through early May. Crawlers are mobile for several weeks and can be dispersed to new trees by wind, people, and animals (particularly birds). Crawlers quickly settle down and attach themselves to a feeding site at the base of a needle where they remain attached for the rest of their life. The adelgids have a long stylet (3 times the length of the insect) that penetrates deep into plant tissues and obtains nutrients from cells that store and deliver nutrient-rich sap to the rest of the tree. By June or July, the progrediens have developed into mature sedentary adults, and produce white cottony sacs of eggs that cover their bodies (Fig. 5). Another life-stage called sistens hatch from these progredien eggs in mid-summer. Sisten crawlers attach themselves to needle feeding sites within a few days of hatching. Sistens remain attached throughout the fall and winter; in February they produce white sacs of eggs that hatch into progrediens and sexuparae a few months later.

Importance: High. The hemlock woolly adelgid is a serious threat to our native hemlock species and ornamental varieties. There may be catastrophic consequences for ecosystems that depend on this important late-successional species.

Management: Chemical control options are available for high-value trees in early stages of decline. Insecticidal soaps and oils can be sprayed onto small trees, but coverage must be thorough and timed accordingly to target susceptible crawlers and nymphs. Systemic insecticides, which can be injected into the tree or applied as a soil drench, are effective for up to three years. Research to use predatory beetles introduced from Asia and the Pacific Northwest as biological control agents is currently underway.

Timeline: White and woolly adult adelgids first become visible in early spring. Crawlers are active in late spring and again for a short period during mid-summer. White woolly residue is usually visible year-round.

Range: Throughout the native range of hemlock in the state. (Fig. 6).

Fig. 1 Infested branch

Fig. 2 Infested branches

Fig. 3 Declining trees

Fig. 4 Adelgids on needles

Fig. 5 Eggs in egg sac

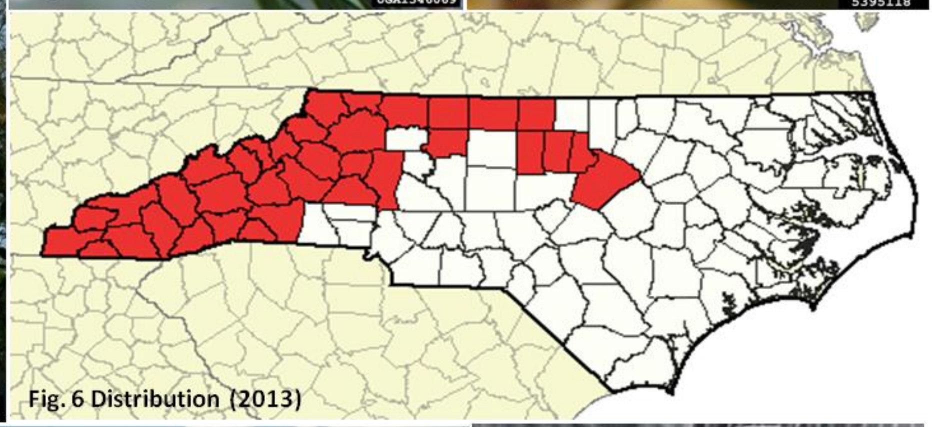


Fig. 6 Distribution (2013)

Fig. 7 Dying hemlocks

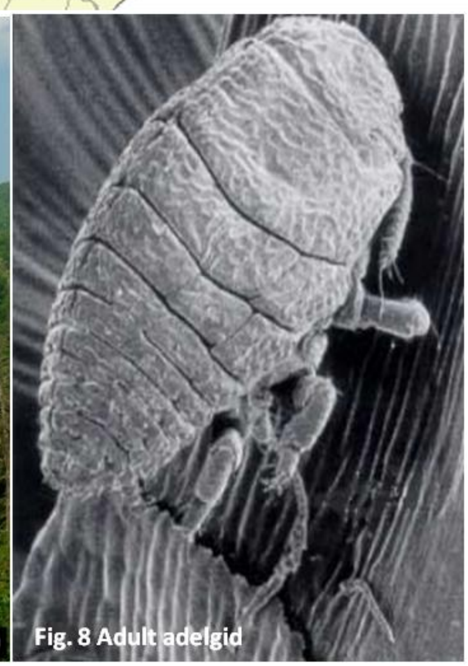


Fig. 8 Adult adelgid

Balsam Woolly Adelgid

Overview:	The balsam woolly adelgid was first introduced to the northeastern United States in the early 1900's from central Europe. In the 1950's, the insect was introduced to the southeast, and now all natural fir stands in North Carolina are thought to be infested (Fig. 6). The balsam wooly adelgid is considered to be a serious threat to Fraser firs in forests, Christmas tree plantations, and seedling nurseries. The insects attach themselves to the bark of stems and twigs to feed; abnormal cell growth and swelling follow and prevent water conduction in the sapwood. Trees decline and die within 2-3 years of being attacked. The long-term ecological consequences of this pest in fir-dominated ecosystems are unknown.
Causal Agent:	Balsam woolly adelgid (*Adelges piceae*)
Hosts:	All North American true firs; eastern U.S. species include balsam and Fraser fir.
Symptoms / Signs:	The most common symptom of trees attacked by the balsam woolly adelgid is abnormal swelling of infested tissues. This swelling is called "gouting" and is most common around buds, branch nodes, and on stunted shoots (Fig. 3 & 4). Gouting is most severe in trees that are only lightly infested for a prolonged period of time; the tops of these trees are usually killed first, and will often curl over. In more severe cases, adelgids will infest the main stem of the tree (Fig. 1); abnormal swellings resembling severely roughened bark may be present at feeding sites. When adelgids attack the main stem, trees are sometimes weakened to such a degree that gouting does not appear on other tissues. Foliage may become chlorotic, needles may fall off, and trees usually die within 2-3 years. Adult adelgids are very small (< 1/32 inch long) and are covered by a thick mass of white, woolly, and waxy coating that protects both the adult and its eggs. The adults are easiest to find where they gather in high densities around buds, branch and twig nodes, and on the main stem especially where bark is roughened. Juvenile crawlers are nearly microscopic, but can be seen (when present) by shaking an infested branch over a white piece of paper; crawlers will appear as small black dots moving on the paper surface. After crawlers attach and begin to feed, they become flattened and wax-fringed.
Life Cycle:	The balsam woolly adelgid has 2 ½ - 3 generations per year in North Carolina. Only female adelgids are present in North America, and they can reproduce without mating. Life stages widely overlap. Eggs hatch in spring and crawlers are mobile for several weeks; they are easily spread by wind and birds. Crawlers settle down and attach at feeding sites, such as bark lenticels and other natural openings. After the crawler's mouthparts pierce the bark and it begins to feed, the insect transforms (without molting) into an immature resting stage called a neosisten. Neosistens generally develop into adult sistens by the end of June, and for the next several weeks eggs are laid by the sedentary female adults. Eggs (Fig. 2) hatch within a few days, crawlers quickly attach to feeding sites, and transform from neosistens to adults in September and October. In warmer parts of the state, a partial third generation will develop. Neosistens are the only over-wintering stage.
Importance:	High. The balsam woolly adelgid is a serious threat to our native firs. The long term consequences of balsam woolly adelgid-caused mortality are unknown. When the insect first colonizes a new stand, populations grow exponentially and high rates of tree mortality are observed. Natural regeneration follows, however, successive cycles of regeneration and mortality may cause significantly declining populations of firs over time (Fig. 6).
Management:	Chemical control options are available for high-value trees (Fig. 5). Contact insecticides are most effective against the crawler stage in May-June or September-October. Insecticidal soaps and oils may be effective against wax-covered adults, but coverage must be thorough and timed to avoid burning the foliage. Chemical applications can reduce adelgid populations enough to allow natural tree defenses to overcome the remaining infestation. Many treated trees may remain free of adelgids for several years. Timeline: Crawlers are active in late spring and again for a short period during mid to late summer. Life stages overlap significantly, and evidence of white woolly adults can usually be seen year-round.
Range:	High elevations in western North Carolina.

Fig. 1 Infested stem

Fig. 2 Eggs laid around a bud

Fig. 3 Twig gouting

Fig. 4 Branch gouting

Fig. 5 Chemical treatment

Fig. 6 Mortality and regeneration

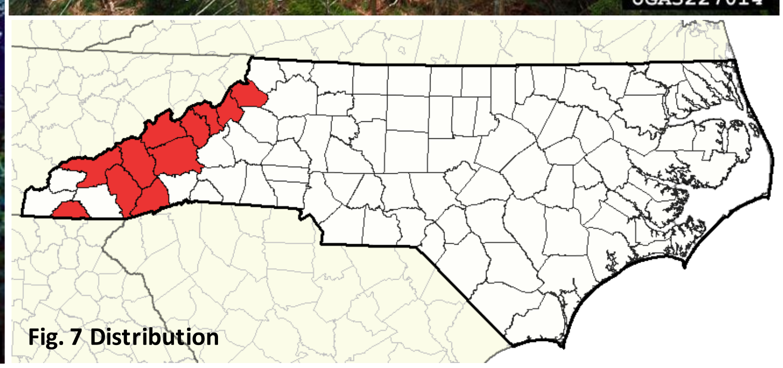


Fig. 7 Distribution

Pine Webworm

Overview: The pine webworm is considered to be a minor pest of southern pines. The pine webworm larvae primarily feed on young seedlings, but may attack larger saplings or even mature trees. Severe defoliation is uncommon; even heavy infestations of the pine webworm are not usually severe enough to kill the host, but heavily defoliated seedlings may have reduced growth and vigor. There are many species of web-spinning sawflies and pine false webworms similar in appearance and behavior; generally, the information provided below applies to all of these species.

Causal Agent: Pine webworm (*Tetralopha rubestella*).

Hosts: Southern pines including loblolly, longleaf, pitch, shortleaf, slash, Virginia, white pine, and others.

Symptoms / Signs: Symptoms include defoliation; early larval instars mine the needles whereas later instars clip and feed on the entire needle. Browning of mined/clipped needles may be observed. Growth reduction is possible when defoliation is severe.

Pine webworm infestations are unmistakable, but usually go unnoticed until after the larvae have disappeared and feeding is complete. Needle mining by early instars is difficult to detect. Larger larvae will form colonies within a silken web nest. As the larvae feed and mature, the nest becomes filled with small brown fecal pellets and clipped needles. The result is an unmistakable mass of frass and webbing wrapped around branches or clustered at branch crotches (Fig. 1 & 2). Nests range from less than 2 inches to more than 5 inches in diameter. The larvae when fully grown are approximately ¾ inches long, tan to yellow-brown or brown, with dark-brown longitudinal stripes (Fig. 3). Adult moths are rarely observed, but are drab or dark gray with darker forewings; wingspan is approximately 1 inch (Fig. 4).

Life Cycle: There are two generations per year in North Carolina. Pine webworms overwinter as pupae in the soil. The emergence of adult moths begins in May and continues throughout the summer. Adults mate and the females lay eggs in longitudinal rows on the needles of a suitable host; up to 20 eggs may be laid on a single needle. When larvae hatch, they spin a silken strand behind them, eventually entangling many needles. Young larvae mine the needles from within, but as they grow, they devour entire needles. Larger larvae will form colonies within a single silken nest; colonies may contain anywhere from two to more than 80 individuals. The feeding larvae fill the nest with frass and clipped needles. In September, the second generation of larvae drop to the ground and burrow into the soil to pupate.

Importance: Low. Pine webworms usually cause little if any significant damage. When severe infestations occur, young seedlings can be killed but usually growth reduction is the only result (Fig. 5).

Management: Usually not required. Pine webworm larvae are a preferred food of natural predators such as birds and rodents. There are also several species of parasitic wasps and flies that keep pine webworm populations in check.

Timeline: Emergence of first generation adults occurs in May. The first webs (from the current growing season) may be visible as early as June. Nest formation and feeding occurs throughout the summer. Pupation of the second generation occurs mid to late September. Nests from the previous growing season are persistent and may be visible year-round.

Range: Statewide.

Fig. 1 Pine webworm nest

Fig. 2 Pine webworm nest

Fig. 3 Pine webworm larvae

Fig. 5 Defoliated seedling

Fig. 4 Pine webworm adult

Pine Sawflies

Overview:	There are over 100 species of sawflies in the U.S. whose larvae feed on the foliage of conifers; several occur in North Carolina including the redheaded pine sawfly, blackheaded pine sawfly, introduced pine sawfly, and the loblolly pine sawfly. Sawflies are not actually flies (Order Diptera), but rather they are a type of non-stinging wasp (Order Hymenoptera). They are called sawflies because they resemble flies and have a saw-like appendage that protrudes from their abdomen which is used to insert eggs into pine needles. Sawfly larvae are potentially serious defoliators of many pine species in North Carolina; heavy defoliation can lead to growth loss or mortality. Outbreaks of this pest generally do not warrant control measures, but sawfly activity should be closely monitored to prevent serious damage. This pest is most common in young plantings, but trees of all ages may be attacked. All species of sawflies in North Carolina are similar in appearance and biology; the redheaded pine sawfly is discussed below as an example.
Causal Agent:	Redheaded pine sawfly (*Neodiprion lecontei*)
Hosts:	Loblolly and longleaf pine are the preferred hosts; all southern pine species are susceptible.
Symptoms / Signs:	Symptoms include defoliation. Early larval instars feed only on the outer edges of needles; partially consumed needles will turn brown and fall off and resemble fine straw hanging from the tree. Older larvae will consume the entire needle. Complete defoliation of pines is possible during severe outbreaks (Fig. 4 & 5). Fully grown larvae are easy to identify; the larvae is approximately 1 inch long, pale to bright yellow, have four to six rows of black spots on the body, and a prominent red head (Fig. 1). Larvae often cluster together to feed (Fig. 2). Adults are rarely seen and resemble flies that are approximately ¼ inch long with four clear wings.
Life Cycle:	There are usually two to three overlapping generations per year in North Carolina. Sawflies overwinter as pupae in the soil or leaf litter below the host tree. Emergence of adults occurs in the spring (emergence of some pupae is delayed for one to three years as a survival mechanism so that the population can survive should all larvae during a single growing season be killed). Females can lay eggs with or without mating (unmated females only lay eggs that produce males). Eggs are laid in rows of slits cut into needles; there may be more than a dozen eggs per needle and each female may lay more than 100 eggs in a cluster of needles (Fig. 3). Larvae hatch in approximately one month and begin to feed immediately. Feeding lasts for 3-5 weeks during which the larvae grow rapidly; larvae then drop to the ground and burrow into the soil to pupate.
Importance:	Moderate. While the redheaded pine sawfly is usually a minor pest, when conditions are suitable, populations can grow rapidly and severe defoliation can occur. Outbreaks are particularly common in plantation settings where many host trees are available in close proximity. Seedlings and saplings are most commonly attacked and most severely impacted by defoliation. Trees greater than 12-15 feet in height are rarely attacked.
Management:	Usually not required. Severe infestations usually subside naturally after 1 or 2 years, but populations of this pest should be monitored to avoid serious damage. Rapid population declines are usually due to predation by rodents, birds, and a viral disease that spreads rapidly through large populations. Chemical control options are available but are only effective against early instars. Because generations overlap considerably, larvae at all stages of development are usually present making successful treatment difficult. Often, by the time severe defoliation is detected it is too late to apply insecticides. The best option is to wait until the following year, monitor the new population, and treat early in the growing season if necessary.
Timeline:	Emergence of adults occurs in the spring. Defoliation is usually noticed mid to late summer. Insecticides should only be applied in the spring or early summer when only young instars are present.
Range:	Statewide.


Fig. 1 Redheaded pine sawfly larvae
UGA0284090b


Fig. 2 Redheaded pine sawfly larvae


Fig. 3 Adult sawfly laying eggs
UGA0284091a


Fig. 4 Defoliated pine plantation
UGA0010124


Fig. 5 Larvae on defoliated seedling
5383259

Eastern Tent Caterpillar

Overview: The eastern tent caterpillar is a common native defoliator in the eastern U.S. Normally, the eastern tent caterpillar is only a nuisance or an aesthetic problem, but populations are cyclical and outbreaks occur on average at ten year intervals. During outbreak years, individual trees can be heavily infested and defoliated. Control is usually not necessary because trees can survive these occasional attacks and caterpillar populations soon decline.

Causal Agent: Eastern tent caterpillar (*Malacosoma americanum*)

Hosts: Cherries, apples, and crabapples are the preferred hosts. Other host species include ash, birch, blackgum, willow, maple, oak, aspen, peach, and plum.

Symptoms / Signs: Eastern tent caterpillars are so named for the silken tents which colonies of larvae construct. Tents usually begin in a branch crotch, and grow in size along with the caterpillars (Fig. 5 & 6). During heavy infestations, entire trees can be covered with webbing and trees can be completely defoliated. Fully grown larvae have black heads, are lightly covered by brown or yellow hairs, and can be up to 2 ½ inches long. Wavy yellow and blue lines run down the sides of the caterpillar on a black background; a row of blue and black spots run between these stripes (Fig. 1). Eastern tent caterpillar larvae are easily confused with the forest tent caterpillars, but differ in that they have a solid white line that runs down their back (forest tent caterpillars have white spots running down their back) (Fig. 2). Adult moths have a 2 inch wingspan, are reddish-brown or yellow-brown, and have two narrow white stripes running across each forewing (Fig. 3). Eggs are brown or black in color, cup-shaped, and laid in masses of several hundred individuals that are covered in a varnish-like protective coating. Egg masses are spindle-shaped, less than 1 inch long, and completely encircle small twigs (Fig. 4).

Life Cycle: There is only one generation per year. Egg hatch in spring coincides with bud-break of suitable host species. Caterpillars group together in a nearby branch crotch and construct a small silken tent from which they venture out to feed on new leaves. Caterpillars do not feed during cool and/or wet weather; rather they cluster together in their tents for protection. As caterpillars move about, they spin a silken thread behind them, so tents grow in size as the larvae move about branches to feed. Almost the entire leaf is consumed; only the midrib is left behind. Caterpillars become fully grown by late spring or early summer and leave the crown in search of a suitable location to spin a cocoon (usually on the trunk or other nearby vertical object). Adults emerge by the end of June or early July and lay eggs by mid to late summer. Populations are cyclical and outbreaks occur approximately every ten years.

Importance: Low. Heavy defoliation only occurs during outbreak years and usually causes little long-term damage to trees. However, severe defoliation (especially if it occurs in consecutive years) can weaken trees and make them susceptible to secondary insects or diseases.

Management: Control is usually not necessary. Trees usually produce new leaves by early to mid-summer. Insecticides are available to protect valuable fruit trees and ornamentals. Caterpillars can be picked from small trees by hand. Tents can be clipped off or gathered up and destroyed on cool rainy days when larvae are inside. Egg masses can also be located and clipped off of trees during the winter months.

Timeline: Emergence occurs in early spring; feeding occurs through late spring or early summer. Adults are active for several weeks during the summer. Trees usually produce new leaves by early to mid summer, leaving little evidence of infestations or defoliation.

Range: Statewide.

Fig. 1 Eastern tent caterpillar

Fig. 2 Eastern tent caterpillar

Fig. 3 Eastern tent caterpillar adult

Fig. 4 Egg masses

Fig. 5 Defoliated tree

Fig. 6 Tent in branch crotch

Forest Tent Caterpillar

Overview: The forest tent caterpillar is one of the most important native defoliators of hardwoods in the eastern U.S. Its name is misleading because the larvae of this species do not form a true tent (as compared to the eastern tent caterpillar), rather they form a flattened silk mat on the trunk or large branches. Populations are somewhat cyclical and major outbreaks occur on fluctuating intervals of 5-20 years. Occasionally, large acreages of trees can be defoliated. Consecutive years of defoliation by this insect can cause growth loss, decline, or even isolated mortality. However, trees are seldom killed and populations of the forest tent caterpillar are usually kept in check by parasitic insects and diseases, therefore control options are usually unnecessary.

Causal Agent: Forest tent caterpillar (*Malacosoma disstria*)

Hosts: Bottomland hardwoods including water tupelo, sweetgum, birch, ash, silver maple, oak, elm, cherry, and basswood. Sycamore, red maple, and conifers are avoided. If trees are completely defoliated and food is scarce, the larvae may descend and feed on shrubs and even herbaceous plants.

Symptoms / Signs: The forest tent caterpillar does not construct an obvious silken tent like the eastern tent caterpillar; rather they form a silken mat on the main stem or on large branches where they gather to rest or molt. Fully grown larvae have black heads, are lightly covered by light brown or yellow hairs, and can be up to 2 ½ inches long. Wavy yellow, orange, and blue lines run down the sides of the caterpillar on a black background. Forest tent caterpillar larvae are easily confused with the eastern tent caterpillars, but differ in that they have white keyhole shaped spots running down their back (eastern tent caterpillars have a white stripe along their back) (Fig. 1 & 2). Adult moths have a 1½ - 2 inch wingspan, are tan or yellow-brown, have a short stocky body, and have one or two brown stripes on each forewing (Fig. 4). Egg masses, which can contain over 300 eggs, are tan in color, covered in a varnish-like protective coating, encircle small twigs, and are squared (rather than tapered) at their ends (Fig. 5).

Life Cycle: There is one generation per year. Egg hatch in spring coincides with, or even precedes, bud-break of suitable host species. Early instars feed on leaf and flower buds, and they may even mine unopened buds if foliage is not available. Once leaves expand, older instars consume the entire leaf except the midrib (Fig. 7). Larvae feed in colonies and travel from branch to branch in single file along a winding path of silk laid down by the leading individuals. Colonies of young instars tend to feed in the upper crown (Fig. 3); as they mature they are more frequently found in the lower crown or on the trunk. Pupation occurs in late spring or early summer. Larvae descend out of the crown and spin yellowish cocoons wrapped in a folded leaf (Fig. 8); adults emerge approximately two weeks later. Moths, which are active in the late afternoon and throughout the evening, are highly attracted to lights. Eggs are laid in masses of 300 or more individuals on small twigs by the end of summer. Outbreaks of the forest tent caterpillar occur every 5-20 years and defoliation can be severe (Fig. 6). However, parasitic insects and diseases usually cause drastic population declines soon after large outbreaks occur. Therefore outbreaks rarely last more than a couple of years and hosts are rarely killed.

Importance: Low. Heavy defoliation only occurs during outbreak years and usually causes little long-term damage to trees. However, severe defoliation (especially if it occurs for three or more consecutive years) can kill trees or increases their susceptibility to secondary insects or diseases. Widespread mortality is rare because outbreaks usually subside within a couple of years.

Management: Control is usually not necessary. Trees usually produce new leaves by mid-summer. Insecticides and biological control products are available to protect valuable landscape trees and ornamentals. Caterpillars can be picked from small trees by hand. Natural diseases and parasitic insects keep populations in check and infestations rarely occur for more than a few consecutive years.

Timeline: Larvae hatch in early spring; feeding occurs through late spring or early summer. Adults are active for several weeks during the summer. Trees usually produce new leaves by mid-summer, leaving little evidence of infestations or defoliation.

Range: Statewide.

Fig. 1 Forest tent caterpillar

Fig. 2 Forest tent caterpillar

Fig. 3 Young larvae

Fig. 4 Adult

Fig. 5 Egg masses

Fig. 6 Defoliation

Fig. 7 Defoliation

Fig. 8 Cocoon

Fall Webworm

Overview: The fall webworm is a native defoliating insect that feeds on a wide variety of hardwoods, particularly landscape trees and ornamentals. It is not considered to be a serious forest pest, but numerous silk nests and defoliation can detract from the aesthetics of landscape trees. Complete defoliation can occur in heavily infested trees by the end of growing season, but this results in little long-term damage to the tree. Interestingly, the fall webworm was accidentally introduced to Europe and parts of Asia where it has become a serious pest of hundreds of species of trees and shrubs. Its name comes from the fact that its web-like nests, which are spun at the ends of branches as opposed to branch crotches (eastern tent caterpillar), become prominent on heavily infested trees in the late summer and early fall.

Causal Agent: Fall webworm (*Hyphantria cunea*)

Hosts: The fall webworm is found throughout the U.S. and its host preferences vary by region. In North Carolina, many species of hardwoods can be attacked, but preferred hosts are persimmon, pecan, sourwood, black walnut, and sweetgum.

Symptoms / Signs: There are two races/forms of fall webworms which differ in appearance and biology: the "black-headed race" and "red-headed race" are named for the color of the caterpillar's head. Moths are white with a wingspan of approximately 1 inch. Larvae may exceed 1 inch in length when fully grown and are covered in silky hairs. Young black-headed larvae are yellow-green or pale yellow and have rows of black tubercles (raised dots) along their backs (Fig. 1). As they mature, their color darkens slightly to yellow or green, and they develop a dark stripe down their back. Larvae of the red-headed race tend to be tan or orange in color with red or orange tubercles (Fig. 2). While both races form silken nests at the ends of branches, the webs of the black-headed race are thin and provide less protection than the smaller, more compact webs of the red-headed race. The nests enlarge as caterpillars feed. When approached or when branches containing nests are disturbed, caterpillars in the nest will all wiggle to ward off predators. Complete defoliation by the end of the growing season can occur and may be observed in trees with many nests (Fig. 8).

Life Cycle: There are two to three generations of fall webworm per year in North Carolina. Fully formed adults overwinter in cocoons in a sheltered location or in leaf litter. Moths of the black-headed race may emerge up to a month earlier than the moths of the red-headed race. Eggs are laid on the underside of suitable host leaves (Fig. 5) and hatch two weeks later; larvae initially feed on the soft tissues between leaf veins (Fig. 6 & 7). Larvae are gregarious; dozens of caterpillars can be found feeding within a single nest (Fig. 3 & 4). As the caterpillars feed, they spin a silken strand which accounts for the ever-expanding web around infested leaves and branches. Larvae mature in 4-6 weeks and drop to the ground to pupate in the soil or leaf litter. Many species of parasitic insects, predators, and pathogens suppress fall webworm populations; severe infestations rarely last more than a few years in an individual tree.

Importance: Low. Severe defoliation occasionally occurs but has little serious impact on tree health. Defoliation and the webs in particular, detract from the aesthetics of landscape trees and ornamentals. The fall webworm is not considered to be a serious forest pest, but it is often a serious concern to homeowners.

Management: Control is usually not necessary. Trees will produce new leaves the following year. Many species of parasitic insects, predators, and pathogens suppress fall webworm populations. Insecticides are available for severe infestations, but should only be applied when larvae and webs are small during the summer. If webs can be reached, they can be removed by pruning or can be pulled off with a forked stick; removed webs should be destroyed.

Timeline: Emergence of adults from cocoons occurs in spring; larvae first appear in early summer. Feeding proceeds throughout the summer and into the fall. Webs and defoliation are most prominent in late summer and fall.

Range: Statewide.

Fig. 1 Fall webworm (black-headed race)

Fig. 2 Fall webworm (red-headed race)

Fig. 3 Gregarious larvae in nest

Fig. 4 Silken nest

Fig. 5 Adult laying eggs

Fig. 6 Skeletonized leaf

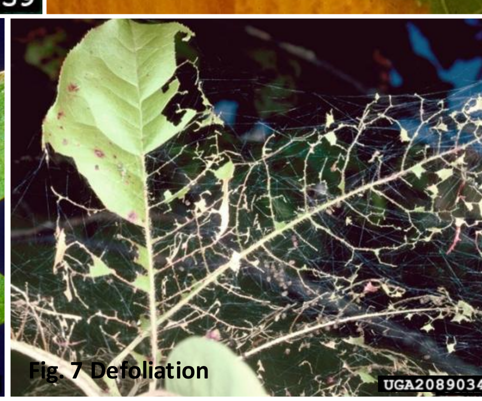


Fig. 7 Defoliation

Fig. 8 Infested tree

Orangestriped Oakworm

Overview: The orangestriped oakworm is one of several closely related native moths that are important defoliators of oaks and several other species of hardwoods. Outbreaks and complete defoliation by these caterpillars occurs occasionally, but because feeding occurs late in the growing season, trees are normally not adversely affected. While trees in forested situations tend to be attacked more frequently, severe defoliation can detract from the appearance of landscape trees. Natural predators and parasites keep populations in check; therefore control measures for these pests are usually not required.

Causal Agent: Orangestriped oakworm (*Anisota senatoria*) and related species including the pinkstriped oakworm (*Anisota virginiensis*), spiny oakworm (*Anisota stigma*), and the greenstriped mapleworm (*Dryocampa rubicunda*).

Hosts: The orangestriped oakworm prefers to feed on oak species; it is particularly common on white oaks, scrub oaks, willow oaks, and pin oaks. It may also feed on maple, hickory, cherry, and hazelnut. The pinkstriped and spiny oakworms also feed on species of the red and white oak groups, whereas the greenstriped mapleworm prefers maples but will also feed on oaks.

Symptoms / Signs: Larvae of fully grown orangestriped oakworms are 2 inches long; their bodies are black with eight orange or yellow stripes running lengthwise down their backs (Fig. 1). Pinkstriped oakworms are green to brown with four pink stripes (Fig. 4) and spiny oakworms are tan to pink in color but lack stripes (Fig. 2). The greenstriped mapleworm is slightly smaller than the oakworms; it is greenish-yellow, has a red or black head, and seven green to black stripes running down its back (Fig. 3). All of these species have a pair of "horns" near their head and are covered in spines of varying size, numbers, and arrangements. Adult oakworm moths are stout bodied and short haired, range in color from red, yellow, pink, or orange, and have a small but obvious white dot on their forewing (Fig. 5 & 6). The mapleworm moth, called the rosy maple moth, is woolly and cream colored with pink wings and a white band on the forewing (Fig. 7). All species consume the entire leaf with the exception of the largest veins (Fig. 8).

Life Cycle: Fully formed adult moths overwinter in cocoons formed in the soil or leaf litter. Adults emerge in early summer (usually June or July). Within a month after emerging, females will lay several clusters of a few dozen to a few hundred eggs on the underside of leaves on suitable host trees (Fig. 9). Larvae hatch and feed together in groups throughout the summer and into early fall; they usually feed on and defoliate one branch at a time. During outbreaks, entire trees may be defoliated and caterpillars may crawl to neighboring trees to feed. At the end of September, fully mature larvae drop to the ground to pupate in the soil or leaf litter. Usually, only one generation occurs per year in North Carolina, but two generations have been known to occur. Natural predators such as birds and rodents, and parasitic insects such as wasps, limit populations. Outbreaks tend to only last a couple of years before subsiding.

Importance: Low. Severe defoliation occasionally occurs, but because defoliation occurs late in the growing season, the impact on tree health is minimal. Even trees that are defoliated in several consecutive years show little growth loss or adverse affects. The aesthetics of landscape trees can be negatively impacted.

Management: Control is not necessary. Trees will produce new leaves the following year and outbreaks usually subside after a few years. Defoliation of landscape trees may be a concern to homeowners for aesthetic reasons, and insecticides and biological control agents are commercially available for small to medium sized trees. Chemical treatments are most effective against early instars. Caterpillars can be handpicked from small trees.

Timeline: Emergence of adults from cocoons occurs in early summer; larvae first appear in June or July. Feeding proceeds throughout the summer and into the fall. Defoliation becomes prominent in late summer and early fall.

Range: Statewide.

Fig. 1 Orangestriped oakworm larvae

Fig. 2 Spiny oakworm larvae

Fig. 3 Greenstriped mapleworm larvae

Fig. 4 Pinkstriped oakworm larvae

Fig. 5 Pinkstriped oakworm moth

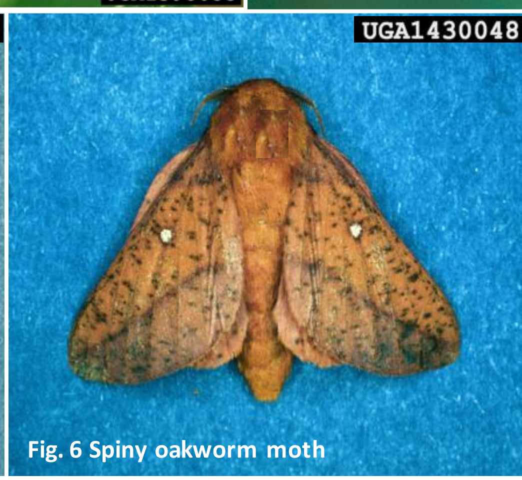


Fig. 6 Spiny oakworm moth

Fig. 7 Rosy maple moth

Fig. 8 Feeding caterpillars

Fig. 9 Eggs on underside of leaf

Pine Colaspis Beetle

Overview:	Pine colaspis beetles are not a serious forest pest, but the feeding activity of adult beetles causes needles to turn brown. Large populations of the beetle can result in a dramatic browning of entire trees, especially in young plantation settings, but little if any serious damage results. The beetles feed at night and are rarely observed; damage caused by this pest is frequently confused with Pales weevil, sawfly infestations, or needle cast disease.
Causal Agent:	Pine colaspis beetle (*Colaspis pini*)
Hosts:	Southern pines; especially slash pine, but also loblolly and longleaf pine. Occasionally baldcypress and ornamental spruces are attacked.
Symptoms / Signs:	Adult beetles are approximately ¼ inch long, rusty brown to brownish-yellow with metallic green highlights (Fig. 1). Adult beetles feed on the edges of needles, leaving a jagged saw-like edge (Fig. 2). Entire needles are not consumed, rather needles that have been fed on turn brown, die, and fall off (Fig. 3 & 4). Occasionally, entire trees may turn brown and may have a fire-scorched appearance. By late summer, brown needles fall off the tree and even heavily infested trees appear green and healthy again.
Life Cycle:	There is one generation per year in North Carolina. Eggs are laid on herbaceous plants in the understory during the summer. Larvae feed on the roots of herbaceous plants and grasses throughout the summer and fall. Larvae lie dormant in the soil through the winter and pupate in the spring. Adults emerge in early summer and begin to feed on pine for several weeks prior to laying eggs.
Importance:	Low. Tree health is not seriously impacted, but the appearance of infested trees may be a concern to landowners and forest managers. Heavy infestations are most common in young plantation settings.
Management:	Control measures are not necessary in forest or plantation settings. On landscape trees and ornamentals, chemical control options are commercially available to prevent unsightly damage.
Timeline:	Damage is most noticeable in early to mid-summer following emergence of adult beetles.
Range:	Statewide.

Fig. 1 Pine colaspis beetle adult

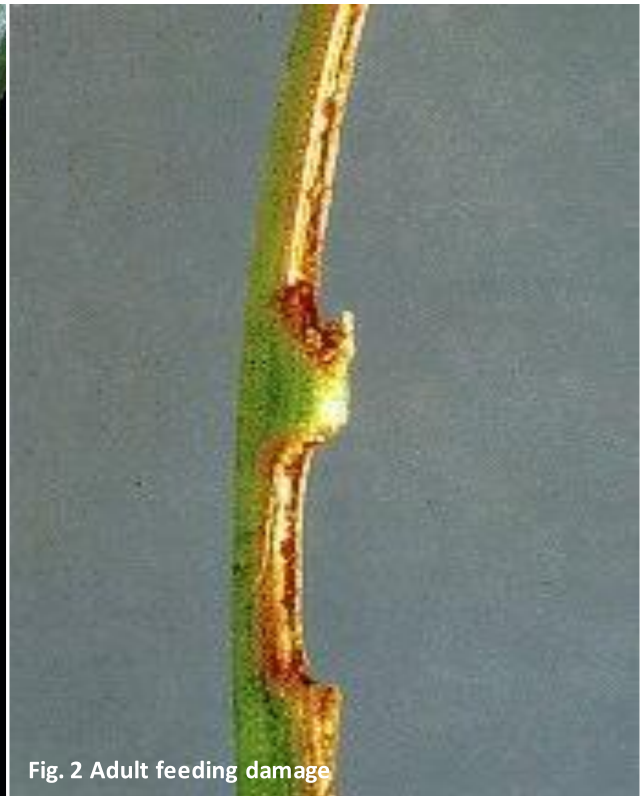


Fig. 2 Adult feeding damage

Fig. 3 Adult feeding damage

Fig. 4 Browning of attacked needles

Fig. 5 Needle browning

Bagworm

Overview: Bagworms are a very common and potentially serious pest of evergreen ornamentals in North Carolina. Heavy infestations on preferred hosts such as juniper and arborvitae can result in complete defoliation, branch dieback, or tree mortality. Bagworms, named for the bag-like sac formed around feeding larvae, are actually the larval stage of a small moth. However, female bagworms never become a moth in the typical sense: they are wingless, legless, lack antennae and mouthparts, and spend their entire lives inside of their larval bag.

Causal Agent: Bagworm (*Thyridopteryx ephameraeformis*)

Hosts: Ornamental conifers; especially junipers, arborvitae, and baldcypress. Occasionally minor infestations can be found on southern pines, maple, oak, dogwood, and willow.

Symptoms / Signs: Larvae (Fig. 3) construct an elongated silk bag interwoven with twigs and foliage within which they feed and pupate (Fig. 1). The bag is enlarged as the larvae grows, and may eventually become 2 ½ inches long. Larvae feed only on the epidermal cells of foliage; therefore the foliage remains on the tree, but will turn brown and die. Heavily infested branches or trees may turn completely brown, may have a fire-scorched appearance, and will be covered in hundreds of bags hanging from twigs by mid-summer (Fig. 2). Females never leave their bag; adult males are small black moths with clear wings and a one inch wingspan (Fig. 4).

Life Cycle: There is one generation per year in North Carolina. Bagworms overwinter as eggs inside of the female's bag. Each female produces 500-1000 eggs in a single mass which hatch in mid to late spring. Larvae begin to feed and construct their bag immediately. They may feed for several months before pupating within their bag which is suspended from a twig on their host. In the fall, male moths emerge and fly off in search of females which produce an attractive pheromone. After mating, females lay eggs within their bag and die. Male moths only live for a few days. Spread of this insect can only be accomplished by movement of the larvae, which can crawl short distances in search of suitable hosts when their original host tree is defoliated. Because dispersal is limited to short distances and so many eggs are produced by each female, populations in a single tree may grow rapidly and infestations are often very heavy. Populations are somewhat cyclical and are reduced by cold winter temperatures and large parasite/predator populations.

Importance: Moderate. Infestations are often severe and result in branch dieback or tree mortality. Some tree species can survive occasional defoliation, but tree health is severely impacted. Fortunately, this pest is easy to control if infestations are detected prior to severe defoliation.

Management: Practical control can be achieved on small to medium size trees by picking off the larvae during the growing season, or by removing the bags of females harboring eggs during the winter. Removed bags should be destroyed. Insecticides are available and effective against actively feeding larvae.

Timeline: Damage is most noticeable in early to mid-summer following emergence of larvae.

Range: Statewide.

Fig. 1 Bagworm larva during pupation

Fig. 2 Heavily infested conifer

Fig. 3 Bagworm larva removed from bag

Fig. 4 Adult male bagworm

Cankerworm

Overview: There are two species of cankerworms in North Carolina: the spring cankerworm and the fall cankerworm. Although both species are similar in behavior and appearance, their names indicate the time of year adult moths emerge and when eggs are laid. Cankerworm larvae are important defoliators of many hardwood tree species. Complete defoliation commonly occurs during severe infestations, resulting in growth loss, decline, or even mortality. These insects are also considered to be a serious nuisance because of the impact they have on the appearance of landscape trees, their tendency to drop or dangle from trees on a silken strand, and the accumulation of frass below infested trees. Cankerworms are just a few species of insects commonly referred to as inchworms, loopers, or spanworms whose larvae move by arching their body dramatically to bring their hind legs up to meet their front legs.

Causal Agent: Spring cankerworm (*Paleacrita vernata*) and fall cankerworm (*Alsophila pometaria*)

Hosts: A wide range of hardwoods; primarily ash, maple, oak, elm, hickory, beech, linden, and apple.

Symptoms / Signs: Fully grown larvae can be more than an inch long, vary in color from light green to black, and have narrow white or yellow stripes on their sides. Spring cankerworms have only two pairs of prolegs at the end of their abdomen (Fig. 2) while fall cankerworms have three pairs and a broad dark stripe down their back (Fig. 1 & 3). Color is highly variable. The larvae crawl in the typical style of an inchworm by moving their rear prolegs up to their front legs on the thorax while arching their back. Younger instars create small holes in the foliage during feeding (Fig. 7); later instars consume the entire leaf with the exception of the midrib (Fig. 8). Female adult moths are wingless and drab gray to brown (Fig. 6). Adult males are light gray or tan with a 1½ inch wingspan (Fig. 4). Small oval-shaped eggs are laid in bark crevices (spring cankerworm) or barrel-shaped eggs are laid in flat clusters that may completely surround small branches (fall cankerworms).

Life Cycle: Spring cankerworms emerge in early spring, mate, and lay eggs. Fall cankerworms in contrast, emerge in the late fall to mate and lay eggs. The eggs of both species hatch at the time of budbreak of host species. Larvae feed on new and expanding leaves for 6 to 8 weeks, then drop to the ground and burrow into the soil or leaf litter to pupate. Because the adult females lack wings, spread of this forest pest is limited to dispersal of larvae. Early instars may drop to the ground and travel to neighboring trees, or may be carried on the wind by a single silk strand (ballooning).

Importance: Moderate. Infestations can be severe and result in complete defoliation. Healthy trees can recover from an occasional attack, but several consecutive years of defoliation can lead to growth loss, decline, or mortality. Natural predators and parasites tend to keep populations of cankerworms in check, and effectively reduce large populations.

Management: Control is usually not necessary because natural predators and parasites keep populations below unacceptable or seriously damaging levels. Sticky bands can be applied around the stem of susceptible trees to trap females when they emerge from the soil and climb trees to lay eggs (Fig. 5). Insecticides are commercially available to protect high value landscape trees.

Timeline: Spring cankerworm adults emerge and lay eggs in early spring whereas fall cankerworm adults emerge and lay eggs in late fall. Larvae of both species hatch in the spring at budbreak. Feeding ceases by early summer.

Range: Statewide.

Fig. 1 Fall cankerworm larva

Fig. 2 Spring cankerworm larva

Fig. 3 Fall cankerworm larvae

Fig. 4 Adult male fall cankerworm

Fig. 5 Sticky trap

Fig. 6 Female fall cankerworm laying eggs

Fig. 7 Defoliation by young cankerworms

Fig. 8 Defoliation by older cankerworms

Locust Leafminer

Overview: The locust leafminer is an important native pest of black locust that causes more concern than actual harm to its host. The small adult beetle feeds on and skeletonizes leaves, and the beetle larvae mine leaves from the inside. Both forms of feeding result in leaf mortality and entire hillsides of black locust may turn brown. While the damage is highly noticeable and causes great concern with those unfamiliar with this insect's annual activity, defoliation by the locust leafminer rarely causes serious injury to its host.

Causal Agent: Locust leafminer (*Odontata dorsalis*)

Hosts: Black locust. Also found rarely on apple, beech, birch, cherry, elm, oak, wisteria, and hawthorn.

Symptoms / Signs: Adult beetles are less than ¼ inch long, are flat and elongated, have a black head, orange wing covers, and a black stripe down their back (Fig. 1). Adults feed on the lower side of leaves and create small holes; continued feeding eventually leads to a skeletonized or lace-like leaf surface (Fig. 4). Eggs are laid on the lower leaf surface in shingle-like clusters of three to five individuals. Beetle larvae are pale yellow, flattened, and approximately ¼ inch long (Fig. 2). Larvae feed in the inner leaf tissues creating a mine or tunnel through the leaf (Fig. 6). The terminal portion or edges of the leaf are preferred. When mining starts, a small irregular pale blotch appears on the leaf surface (Fig. 5). As the larvae grow, the mines expand and increase in length. Leaves eventually begin to turn brown and die from mining and skeletonizing. Heavily infested trees turn brown, bronze, or gray (Fig. 3).

Life Cycle: There are two generations per year in North Carolina. Beetles overwinter in the leaf litter or other places where suitable protection can be found. They emerge at budbreak and begin to feed on new and expanding leaves. Shortly after leaf expansion, the adult beetles lay eggs on the underside of leaves. Larvae hatch and mine their way into the inner leaf tissue where they begin to feed. Early instars feed together at first within the same mine; then larvae disperse and mines expand in many directions. Feeding continues through mid-summer at which time the larvae pupate within a blister-like chamber at the end of the mine. Frequently, defoliated trees will produce a second set of leaves during the summer. If a second generation is produced and the population is large, the second set of leaves can be consumed, which severely stresses the tree.

Importance: Low. The appearance of mined and skeletonized leaves can be dramatic and worrisome. While it rarely causes serious injury, if trees produce new leaves during the summer and the second set of leaves is also consumed, trees can become stressed. Several consecutive years of severe defoliation twice a year can lead to tree decline or mortality.

Management: Control is usually not necessary; damage is usually only cosmetic. Outbreaks tend to be cyclical and natural predators and parasites tend to reduce large populations before serious damage occurs. For landscape trees, chemical controls are available.

Timeline: Adults feed in early spring while larvae feed during the summer. A second generation begins in July. By August, locust trees may appear brown or gray; symptoms may resemble early fall coloration or drought.

Range: Western North Carolina within the native range of black locust. Landscape plantings in other parts of the state may also be infested.

Fig. 1 Adult locust leafminer

Fig. 2 Locust leafminer larvae

Fig. 3 Heavily infested tree

Fig. 4 Feeding damage

Fig. 5 Mining by early instars

Fig. 6 Mining larva

European Gypsy Moth

Overview: The gypsy moth is a non-native insect introduced to Massachusetts from Europe in the 1860's by a scientist interested in breeding superior caterpillars for silkworm production. Since their escape from captivity, the gypsy moth has spread west and south, and is considered to be the most important defoliator of hardwoods in the eastern U.S. On average, over one million acres of hardwoods are defoliated each year by the gypsy moth; as many as 13 million acres have been defoliated during severe outbreak years. Millions of dollars are spent each year to slow the spread of this pest. The gypsy moth is not yet considered established in North Carolina, but the population front continues to move south out of Virginia, especially in the northeastern part of the state where a quarantine is in effect for Currituck and a portion of Dare county.. Isolated populations of the gypsy moth have been located and successfully eradicated or managed in North Carolina since the 1990's.

Causal Agent: European gypsy moth (*Lymantria dispar*)

Hosts: Hardwoods; especially oak, aspen, apple, sweetgum, basswood, birch, poplar, and willow. Species usually avoided include ash, yellow poplar, sycamore, butternut, black walnut, catalpa, dogwood, holly, and shrubs such as mountain laurel and rhododendron. Conifers may be attacked by later instars during severe outbreaks.

Symptoms / Signs: Newly hatched larvae are less than ¼ inch long, black, and hairy. When fully grown, larvae can be up to three inches long and hairy with five pairs of blue spots followed by six pairs of red spots running down their back (Fig. 1). Adults are 1 – 1½ inches long. Females are white and flightless; males are slightly smaller, drab brown, and fly in a zig-zag pattern (Fig. 4). Eggs are laid in tan colored masses of several hundred individuals (Fig. 2). Egg masses are usually laid on the undersides of branches, within bark crevices, or in other concealed locations. During outbreaks, large amounts of frass may accumulate below infested trees (Fig. 9).

Life Cycle: There is only one generation per year. Egg hatch in early spring coincides with budbreak of host species (Fig. 3). Larvae may begin to feed immediately, or alternatively, larvae may spin a long silken thread that can carry them on the wind to neighboring trees (ballooning). Young instars create small holes in the soft tissue between leaf veins; older larvae consume the entire leaf, feeding from the outer edge inward. Normally, larvae feed at night and descend from the canopy during the day to hide under flaps of bark or branches. During heavy infestations, larvae will feed throughout the day until the entire tree is defoliated, then they descend in search of a new host. Pupation occurs in early summer. When females emerge, they are flightless, are heavily laden with unfertilized eggs, and they release a pheromone which attracts the male moths. Hundreds of eggs are laid in masses shortly after mating. During outbreaks, females may crawl off host trees in search of a suitable hiding place to lay egg masses. Frequently, eggs are laid on objects transported by humans (e.g. vehicles, firewood, or lawn furniture) (Fig. 5), assisting in the long-distance spread of this pest. Outbreaks are common, but populations tend to be regulated by weather, predators, and disease.

Importance: High. During outbreak years, defoliation by this pest can be severe (Fig. 8). Healthy trees can survive occasional defoliation, but repeated attacks may lead to tree death or decline, especially in stressed trees.

Management: North Carolina participates in the national Slow the Spread program, which is designed to slow the south and westward spreading gypsy moth population front. Pheromone-baited traps (attractive only to male moths) are deployed state-wide to detect isolated populations of the gypsy moth that may have entered the state (Fig. 7). High numbers of moth catches in a trap may reveal the location of a new infestation. Aerial treatments with insecticides or biological controls, such as bacteria and viruses, are used to eradicate these populations (Fig. 11). Eventually however, it is expected that the gypsy moth will become established in the state. Insecticides are available to treat individual infestations (Fig. 10). Egg masses can be scraped off trees during the winter, caterpillars can be picked from trees by hand when they descend during the day (larvae will gather under a strip of burlap wrapped around the trunk) (Fig. 6), and biological controls are commercially available.

Timeline: Emergence occurs in early spring; feeding occurs through late spring or early summer. Adults are active for several weeks during the summer; eggs are laid by the end of July or early August.

Range: Not yet permanently established in North Carolina; isolated populations continue to pop up throughout the state, but are usually treated and eradicated within one year.

Fig. 1 Gypsy moth larva

Fig. 2 Egg masses

Fig. 3 Newly hatched larvae

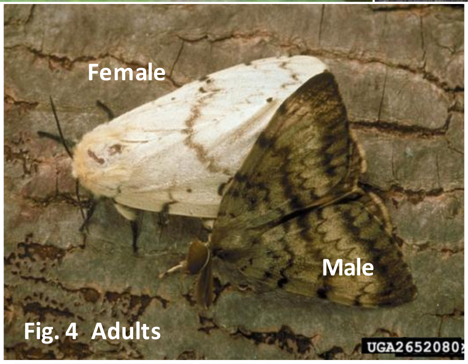


Fig. 4 Adults

Fig. 5 Females laying eggs

Fig. 6 Trapping larvae

Fig. 7 Detection trapping

Fig. 8 Defoliated hardwood stand

Fig. 9 Frass accumulation

Fig. 10 Insecticide application

Fig. 11 Aerial spraying

Japanese Beetle

Overview: The Japanese beetle is a non-native insect introduced in the northeastern U.S. in 1916. Since that time, it has continued to spread south and west and now infests most of the eastern U.S. The adult beetles feed on the foliage of dozens of tree and shrub species, especially ornamentals and landscape plantings. Defoliation can be severe and a tree's appearance can be seriously impacted. Larvae feed primarily on the roots of grasses, and can become a serious pest of turfgrass during heavy infestations.

Causal Agent: Japanese beetle (*Popillia japonica*)

Hosts: Several hundred species of hardwood trees and shrubs are hosts of adult beetles; preferred hosts include rose, crape myrtle, apple, cherry, Japanese maple, sassafras, sycamore, elm, azalea, plum, peach, pin oak, birch, beech, willow, black walnut, and viburnum. Dogwood, ash, magnolia, sweetgum, holly, yellow poplar, redbud, lilac, and conifers are avoided. Beetle larvae feed on the roots of herbaceous plants, particularly turfgrass.

Symptoms / Signs: Adult beetles skeletonize leaves giving them a lace-like appearance (Fig. 2). Heavily infested trees may appear scorched. Heavy infestations of grubs may result in circular, expanding patches of dead and dying turfgrass. Adult beetles are approximately ½ inch long, broadly oval in shape, metallic green, and have bronze wing covers (Fig. 1). Small white tufts of hair that look like white dots can be found along the edges of the beetle's body along the wing covers. When an infested branch is shaken, the beetles will play dead and drop to the ground. Beetle larvae (grubs) are white and thick bodied with six small legs emerging from just behind the head (Fig. 3). Grubs are up to one inch long and can be found within a few inches of the soil surface during the growing season or 4-8 inches below the soil line during the winter. Japanese beetle grubs are easily confused with grubs of native beetle species, not all of which are plant pests.

Life Cycle: There is one generation per year in North Carolina (Fig. 5). Adult beetles emerge from the ground in late May and early June. They immediately begin to feed on nearby plants. Males fly short distances in search of females, which produce attractive pheromones. Females occasionally stop feeding and burrow into nearby turf to lay up to a dozen eggs approximately 3 inches below the soil line. Each female will continue to feed and lay eggs throughout the summer until 40-60 eggs have been laid. By mid-summer, eggs hatch and grubs begin to feed on the roots of grass and other herbaceous plants. Grubs will feed until late fall, then they will descend deeper into the soil and lie dormant for the winter. When temperatures warm again in early spring, feeding resumes until late spring. Pupation lasts for about 2 weeks, after which adult beetles emerge from the ground.

Importance: Moderate. Japanese beetles are a serious nuisance on ornamentals and landscape plantings, and they are considered to be one of the most important pests of turfgrass. The appearance of trees and shrubs can be negatively impacted during heavy infestations, and nearby turfgrass can be killed in large patches. Because defoliation is usually minor and occurs later in the growing season, tree health is usually not seriously impacted.

Management: The Japanese beetle is notoriously difficult to control. An integrated pest management program that is based on biological, cultural, and chemical controls is the only effective option to reduce beetle numbers below an acceptable threshold; complete eradication is impossible. Surveying and population monitoring are the first step. Commercially available traps baited with pheromones can give you an idea of the adult beetle population during the growing season (Fig. 4). Pheromone baited traps catch many adult beetles, but may also lure many more beetles into the area that do not get caught. Traps should be placed away from susceptible plants. During a heavy infestation a trap can fill completely in 1-3 days. Grub populations can be assessed in late spring and late summer by removing and examining a section of sod near the edge of symptomatic turf. A heavy infestation is indicated by more than 10 grubs per square foot. Chemical controls are available and somewhat effective at protecting small to medium size plants. Biological controls such as Bt, parasitic nematodes, and milky spore disease are commercially available, but their effectiveness can vary considerably. Use resistant plants and increase the distance between turf and susceptible plants.

Timeline: Emergence of adults occurs in late spring and early summer; adults feed throughout the summer. Grubs feed throughout the summer and fall, lie dormant in the soil during the winter, and resume feeding in spring.

Range: Statewide.

Fig. 1 Japanese beetle adult

Fig. 2 Skeletonizing

Fig. 3 Japanese beetle grub

Fig. 4 Japanese beetle trap

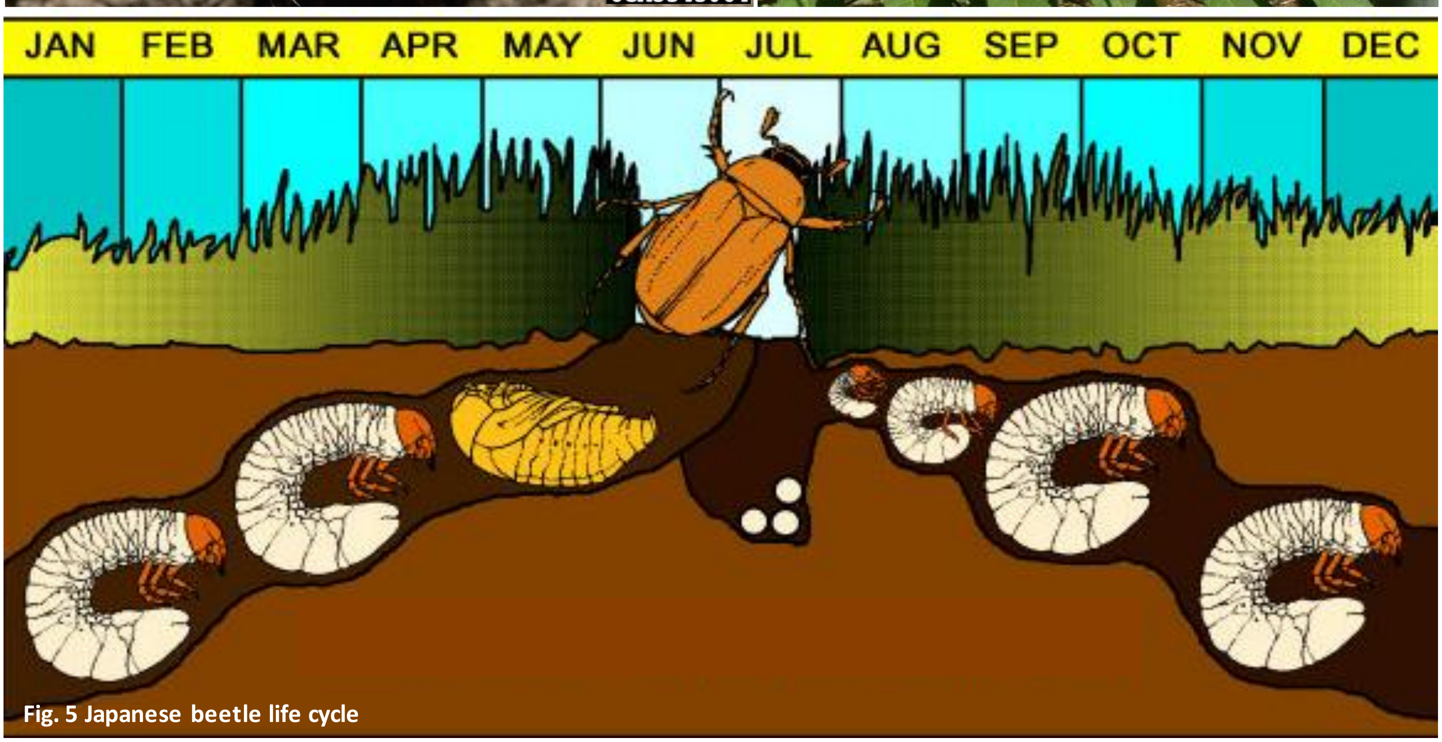


Fig. 5 Japanese beetle life cycle

Southern Pine Beetle

Overview: The southern pine beetle is the most destructive forest insect in North Carolina. Populations are cyclical; during outbreak years, southern pine beetles can attack healthy trees of all age classes and tens of thousands of acres of pine can be killed (Fig. 3). When beetle populations are low, the southern pine beetle is almost strictly a secondary pest. Because of its destructive potential, beetle activity is closely monitored by the North Carolina Forest Service. Proper forest management and control measures are necessary to prevent large outbreaks.

Causal Agent: Southern pine beetle (*Dendroctonus frontalis*)

Hosts: All southern pines are susceptible; preferred hosts include loblolly, shortleaf, Virginia, pond, and pitch pine. Eastern white pine and longleaf pine are considered to be less susceptible.

Symptoms / Signs: The first indication of an infested tree is discolored foliage. Needles will turn yellow, red, and finally brown. If trees are attacked late in the growing season, symptoms may not appear until the following spring. Resin flow out of beetle entrance holes dries on the stem forming whitish-yellow “pitch tubes” that resemble popcorn (Fig. 5). Pitch tubes may not form during drought. Beetles spread from a tree that has been successfully attacked and killed to surrounding trees forming a “beetle spot.” Spots tend to spread downwind and can range from a few trees to hundreds of acres in size. Trees of all sizes can be attacked. Blue-stain fungi introduced by the beetles may give the outer sapwood a blue, purple, or blackish discoloration (Fig. 4).

Southern pine beetles are approximately 1/8 inch long, dark reddish-brown or black in color, and have a rounded or broadly pointed hind end (Fig. 1 & 2). They bore into a tree leaving a small (1/16 inch) entrance hole and form an S-shaped winding gallery in the inner bark (Fig. 7). Larval galleries branch off the adult galleries at approximately ½ inch intervals and may extend for several inches through the inner bark (Fig. 7). Larvae are 1/8 inch long, have a reddish-orange head, and a white crescent-shaped body.

Life Cycle: There are three to five overlapping generations per year in North Carolina; all life stages may overwinter. Females emerge in early spring and bore holes into the bark of a suitable host, then create S-shaped egg galleries in the inner bark and release pheromones to attract males. Healthy trees produce pitch that can expel invading beetles. However, aggregation pheromones released by adults attract large numbers of additional beetles to the tree, overcoming the tree’s defenses. Eggs are laid in niches along the winding gallery and hatch within a few days. Each female can lay more than 150 eggs in her lifetime. Larvae feed on the inner bark for several weeks before pupating in the outer bark and emerging. An entire life cycle is completed in 30-40 days. Beetles tend to disperse in the fall to initiate new spots that will first appear the following spring. Dispersing beetles may fly more than 1½ miles in search of a suitable host. Trees are killed by the girdling of nutrient conducting tissues in the inner bark. Blue-stain fungi, which invade the sapwood and hasten tree death by disrupting water transport, are vectored into the tree by southern pine beetles as they create their galleries. Populations are cyclical and outbreaks occur at 10 year intervals on average. Southern pine beetles, *Ips* engraver beetles, and black turpentine beetles are frequently found attacking the same tree.

Importance: High. During outbreaks, healthy trees of all age classes can be killed. Thousands of acres and millions of board feet of timber can be lost in a single outbreak year.

Management: Prevention of outbreaks is critical and starts with proper forest management (e.g. maintaining proper stocking levels, removal of diseased trees, and planting more resistant species such as longleaf pine) and early detection and control of newly established beetle spots. Surveys are conducted bi-annually across the state to detect new beetle spots. Pheromone-baited traps are used to monitor the populations of both southern pine beetles and the predatory checkered clerid beetles (Fig. 6). Increasing ratios of southern pine beetle to clerids may indicate increased risk of an outbreak. Infested trees and a 75-100 foot buffer of green trees should be cut and removed from the stand or felled into the center of the spot to eradicate beetles and suppress outbreaks (Fig. 8 & 9). Insecticides applied to the main stem and branches are available to protect high-value landscape trees.

Timeline: Beetles are active throughout the growing season. Symptoms begin to appear in late spring.

Range: Statewide.

Fig. 1 Southern pine beetle

Fig. 2 Southern pine beetle

Fig. 3 Beetle outbreak

Fig. 4 Blue-stain

Fig. 7 SPB galleries

Fig. 5 Pitch tubes

Fig. 6 Checkered clerid

Fig. 8 Beetle spot before control

Fig. 9 Beetle spot after “cut and leave”

***Ips* Engraver Beetles**

Overview: *Ips* engraver beetles are secondary forest insects that attack trees that have been stressed by predisposing factors such as fire, drought, storm damage, lightning strikes, or poor stand conditions. Occasionally, they can attack and kill small groups of healthy trees when the conditions are suitable. However, outbreaks of these beetles tend to dissipate when environmental stresses are relieved. Beetle larvae feed on the inner bark and girdle the tree's nutrient conducting tissue. There are three species of *Ips* engraver beetles in North Carolina; a single species may attack alone or along with other *Ips* species, southern pine beetles, and/or black turpentine beetles.

Causal Agent: *Ips* engraver beetles: small southern pine engraver beetle (*Ips avulsus*), five-spined engraver beetle (*Ips grandicollis*), and six-spined engraver beetle (*Ips calligraphus*).

Hosts: All southern pine species are susceptible.

Symptoms / Signs: The first indication of an infested tree is discolored foliage. Needles will turn yellow, red, and finally brown (Fig. 6). If trees are attacked late in the growing season, symptoms may not appear until the following spring. Resin flow out of beetle entrance holes dries on the stem forming whitish-yellow or amber "pitch tubes" that resemble popcorn (Fig. 5). Pitch tubes may not form during drought. Beetles spread from a tree that has been successfully attacked and killed to surrounding trees forming a "beetle spot." Mortality in *Ips* beetle spots tends to be more scattered than in a southern pine beetle spot and is usually limited to only a few trees. Blue-stain fungi introduced by the beetles may give the outer sapwood a blue, purple, or blackish discoloration (Fig. 4).

Ips engraver beetles are reddish-brown to black in color and between 1/10 to 1/4 inch long with *I. calligraphus* being the largest and *I. avulsus* being the smallest (Fig. 1). Their hind end is not rounded like the southern pine beetle. Instead, their wing covers are notched at their ends to form a scoop (used to clear frass and sawdust from galleries), giving the beetles the appearance that their posterior has been chopped off. The scoops are also lined by small spines, the number of which gives the beetles their common names (Fig. 3). They bore into a tree leaving small entrance holes, and form vertically oriented galleries in the inner bark that branch occasionally giving them an I, Y, X, or H shaped appearance (Fig. 2). Dozens of larval galleries branch off the adult gallery and fan out for several inches through the inner bark. Larvae are the same size as adults when full grown, have a reddish-orange head, and a white body.

Life Cycle: There are four to five overlapping generations per year in North Carolina; all life stages may overwinter. Females emerge in early spring and bore holes into the bark of a suitable stressed host, construct egg galleries in the inner bark, and lay eggs which hatch within a few days. Larvae feed on the inner bark for several weeks before pupating in the outer bark and emerging. An entire life cycle is completed in 20-40 days. Trees are killed by the girdling of nutrient conducting tissues in the inner bark, but the beetles also carry blue-stain fungi which invade the sapwood and disrupt water transport, further weakening the tree and accelerating its death. The three species of *Ips* engraver beetles tend to target specific regions of the tree. The small southern pine engraver usually attacks small branches and terminals in the upper crown, the five-spined engraver attacks in the mid-crown, and the six-spined engraver usually attacks the largest branches and main stem in the lower 1/3 of the tree. All age classes are susceptible to attack. One or more species of *Ips* engraver beetles, southern pine beetles, and black turpentine beetles are frequently found attacking the same tree.

Importance: Moderate. Significant mortality can occur when conditions are suitable. *Ips*-related stress or mortality can also enable the build-up of other bark beetle populations such as the southern pine beetle.

Management: Prevention of outbreaks starts with proper forest management. Scattered mortality usually does not warrant control measures. Infestations usually subside after drought when normal rainfall returns. During larger infestations, infested trees should be cut and removed from the stand to eradicate beetles and prevent additional spread; *Ips* populations can build up in logging debris or felled trees. Insecticides applied to the main stem and branches are available to protect high-value landscape trees.

Timeline: Beetles are active throughout the growing season. Symptoms begin to appear in late spring.

Range: Statewide.

Fig. 1 *Ips* engraver beetles

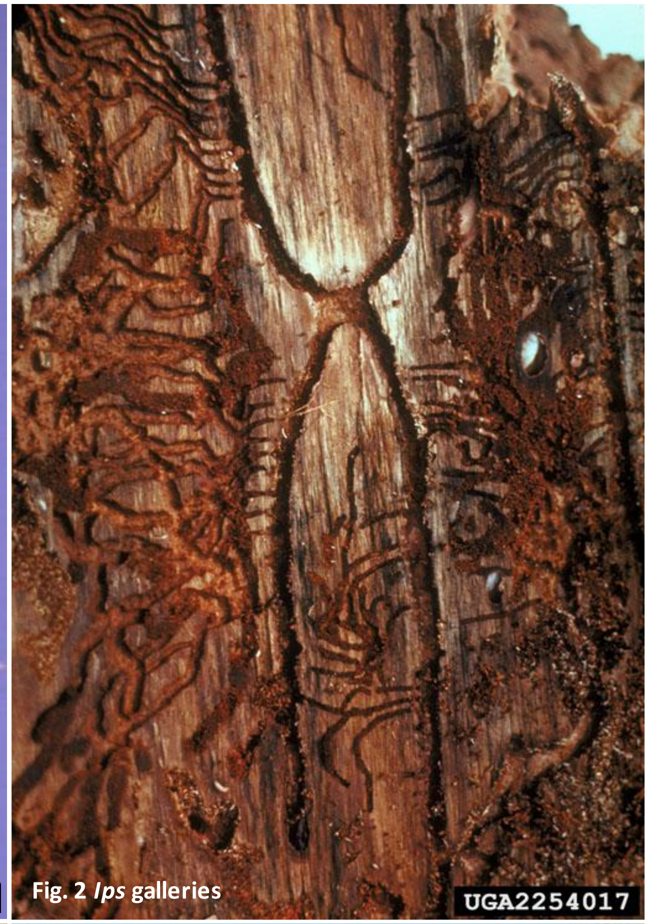


Fig. 2 *Ips* galleries

Fig. 3 Posterior of *Ips* beetle

Fig. 4 Blue-stain

Fig. 5 Pitch tube

Fig. 6 *Ips* mortality

Black Turpentine Beetle

Overview: The black turpentine beetle is primarily a secondary forest pest that usually only attacks trees stressed by predisposing factors. Beetle activity tends to be highest in overstocked stands, or in trees recently wounded by logging activity, fire, or storm damage. Attacks generally occur in the lower 15 feet of the main stem; when infestations are light only localized patches of inner bark are killed and the tree will survive. Mortality can occur when galleries completely girdle the stem. Occasionally populations can reach high enough levels to kill trees that appear to be healthy, but rapidly expanding and destructive outbreaks similar to the southern pine beetle or even *Ips* engraver beetles do not occur. Infested trees are commonly attacked by other bark beetles.

Causal Agent: Black turpentine beetle (*Dendroctonus terebrans*)

Hosts: All southern pine species are susceptible.

Symptoms / Signs: The first indication of an infested tree is discolored foliage. Needles will turn yellow, red, and finally brown. If trees are attacked late in the growing season, symptoms may not appear until the following spring. Resin flow out of beetle entrance holes dries on the stem forming whitish-yellow or amber “pitch tubes” that resemble popcorn (Fig. 5 & 6). Pitch tubes may not form during drought. Attacks usually occur in the lower 15 ft of the main stem. Black turpentine beetles usually do not carry blue-stain fungi like the other pine bark beetles.

Black turpentine beetles are brown to black in color, 3/8 inch long (over twice the length of southern pine beetles which are similar in appearance) (Fig. 1 & 2), and have a rounded posterior (as opposed to the “chopped off” rear end of the *Ips* engraver beetles) (Fig. 3). Adult beetles create winding galleries that are more than 1/8 inch wide and often filled with sticky reddish-brown sawdust (Fig. 7). Larvae are nearly as long as adults when fully grown, have a reddish-brown head, and a white crescent-shaped body (Fig. 4). Because eggs are laid in clusters within the adult gallery, larval galleries tend to originate close together and fan out over time.

Life Cycle: There are two to three overlapping generations per year in North Carolina; all life stages may overwinter. Females emerge in early spring and bore holes into the bark of a suitable stressed host, construct egg galleries in the inner bark, and lay eggs which hatch within two weeks. Males and other females are attracted to the trees by pheromones and volatile compounds released from wounds. Larvae feed on the inner bark for several months before pupating in the outer bark and emerging. An entire life cycle is completed in 2½ to 4 months. Trees are killed by the girdling of nutrient conducting tissues in the inner bark. Younger trees are generally not attacked. One or more species of *Ips* engraver beetles, southern pine beetles, and black turpentine beetles are frequently found attacking the same tree. Black turpentine beetles are not common vectors of blue-stain fungi.

Importance: Low. Mortality can occur when conditions are suitable. Black turpentine-related stress or mortality can also enable the build-up of other bark beetle populations such as the southern pine beetle.

Management: Prevention of outbreaks starts with proper forest management. Avoid injuring trees during logging operations and drought (Fig. 8). Check residual trees frequently after logging operations for beetle activity. Remove wounded trees with significant black turpentine beetle activity to prevent population build-up. Scattered mortality usually does not warrant control measures, but because populations build slowly, infestations should be monitored for several years to ensure problematic levels of this pest do not develop. Insecticides applied to the main stem are available to protect trees that have minor wounds, in stands with significant mortality, evidence of growing beetle populations, or in high-value landscape situations. Chemical applications may be successful in saving trees if infestations are detected and treated early.

Timeline: Beetles are active throughout the growing season. Symptoms begin to appear in late spring.

Range: Statewide.

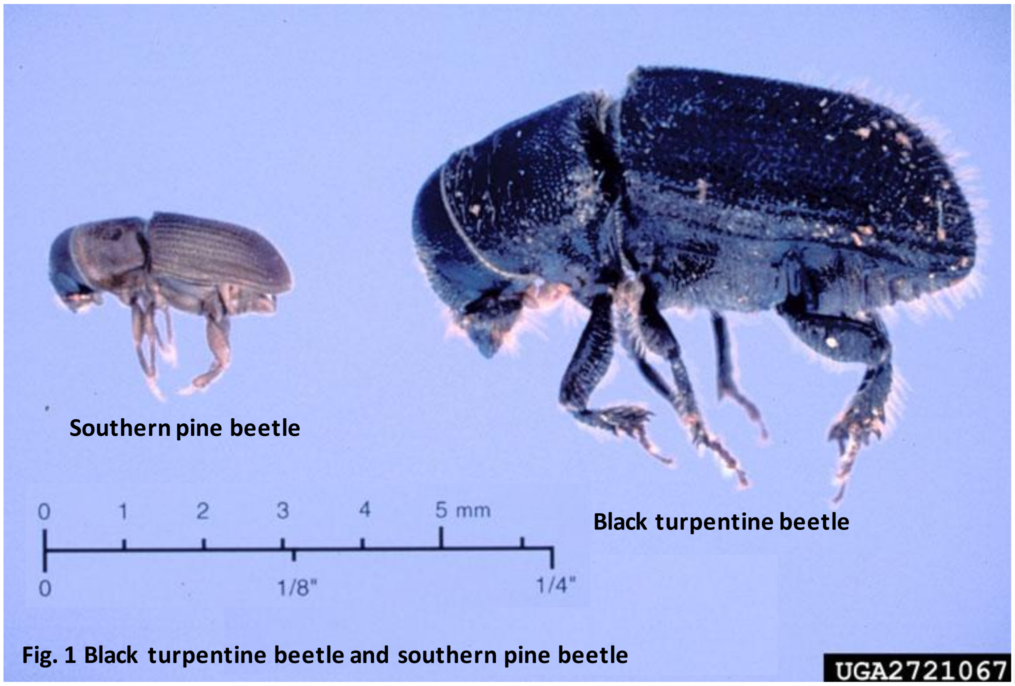


Fig. 1 Black turpentine beetle and southern pine beetle

Fig. 2 BTB

Fig. 3 Black turpentine beetle posterior

Fig. 4 Larvae

Fig. 5 Pitch tubes

Fig. 6 Pitch tubes

Fig. 7 Adult gallery

Fig. 8 Logging injury

Elm Bark Beetles

Overview: Before the 1930's, elm bark beetles were considered to be of little importance. But when the Dutch elm disease fungus was introduced into the U.S., these beetles quickly formed a symbiotic relationship with the deadly pathogen. There are two species of elm bark beetles: the native elm bark beetle and the now more common and dominant European elm bark beetle, which was first discovered in Boston in the early 1900's. The beetles are efficient vectors of the Dutch elm disease pathogen, carrying it up to several miles from tree to tree. In turn, the fungus creates dead and dying elms in which the beetles can breed and reproduce. The two beetle species are easily differentiated by the shape of their brood galleries. Timely removal of infested trees can limit the impact of Dutch elm disease.

Causal Agent: The native elm bark beetle (*Hylurgopinus rufipes*) and the European elm bark beetle (*Scolytus multistriatus*)

Hosts: Elm species.

Symptoms / Signs: *See Dutch elm disease* for more information.

The adult European elm bark beetle is reddish-brown and slightly glossy, approximately 1/4 inch long, with a concave posterior and a small spine projecting from the underside of the abdomen (Fig. 1). The native elm bark beetle is slightly smaller, dull brown, with a rounded rear end (Fig. 4). Larvae of the two species are nearly impossible to distinguish, but the brood galleries on the undersides of the bark are easy to differentiate. European elm bark beetles excavate a main gallery that is approximately 2 inches long and parallel with the wood grain (vertically oriented), with larval galleries extending perpendicular to the wood grain (Fig. 2). The main galleries of native elm bark beetles in contrast, are horizontally oriented and the larval galleries run with the wood grain (Fig. 3). Galleries resemble a centipede in outline.

Life Cycle: Native elm bark beetles overwinter as fully grown larvae in dead or dying trees, or as adults in the bark of large limbs or the main stem of living elms. Adults emerge in spring and tunnel into the bark of freshly dead or dying elms to lay their eggs. European elm bark beetles in contrast, overwinter as immature larvae and pupate in the spring before emerging. Adults fly around for several weeks and feed on the tender bark in branch crotches (Fig. 5 & 6) before laying eggs in an unhealthy elm. Feeding activity of both beetle species is primarily responsible for transmitting Dutch elm disease. Larvae feed for several weeks before pupating at the end of their gallery and emerging. Emergence of adult beetles may leave thousands of tiny "shot holes" in the stem and branches of dead or dying elms. In North Carolina, 2-3 generations may occur annually.

Importance: High. Although the vast majority of American elms have already been eliminated by Dutch elm disease, many beautiful trees have survived and remain susceptible to attack. New cultivars of American elms resistant to Dutch elm disease may still harbor these beetles, posing a threat to non-resistant individuals.

Management: Removal of diseased, dead, dying, and/or beetle-infested trees is critical to protect other trees in the surrounding area (Fig. 7). If caught early, individual diseased or beetle-infested branches can be removed and destroyed. Wood from removed trees should be destroyed, or securely sealed in plastic for a minimum of one year to ensure all disease transmitting beetles are trapped and killed. The bark should be removed from elm firewood to eliminate breeding habitat and should not be transported to other areas. Insecticides to prevent infestation or kill beetles before they can emerge are commercially available for high-value trees, but their effectiveness is questionable.

Timeline: Beetles emerge in spring, feeding occurs throughout the growing season with several overlapping generations.

Range: Statewide.

Fig. 1 European elm bark beetle

Fig. 2 European elm bark beetle gallery


Fig. 3 Native elm bark beetle gallery

Fig. 4 Native elm bark beetle


Fig. 5 Feeding beetle

Fig. 6 Feeding damage

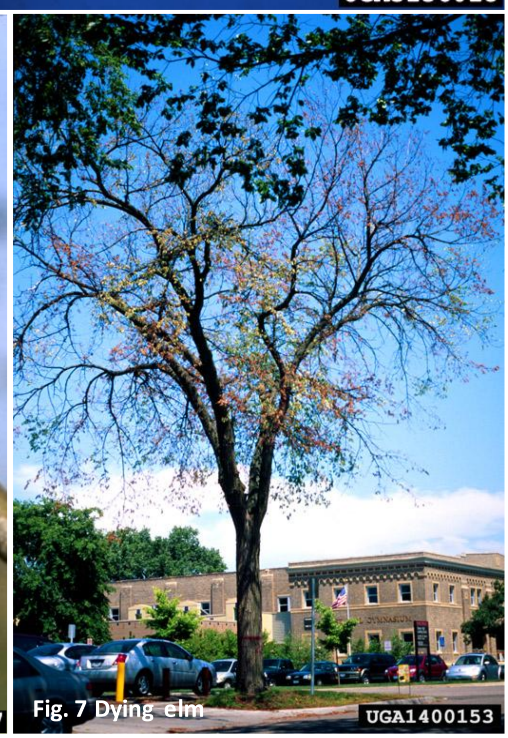


Fig. 7 Dying elm

Hickory Bark Beetle

Overview:	The hickory bark beetle is considered to be the most important pest of hickory in the U.S. Adult beetles feed on small twigs and the bases of leaf petioles; larvae feed on the inner bark of the main stem. Defoliation by adults is usually noticed first, but the most serious damage is caused by the galleries formed in the inner bark which girdles the tree's nutrient conducting tissue. Hickory bark beetles usually only attack stressed or unhealthy trees. Vigorous trees are seldom attacked except when large beetle populations are produced from nearby brood material. Heavy infestations usually kill a tree; light infestations may only girdle branches or a portion of the trunk causing dieback. Girdling of the inner bark is often rapid and severe, resulting in serious injury or death before symptoms are noticed. These beetles are thought to be contributors to a hickory decline disease complex.
Causal Agent:	Hickory bark beetle (*Scolytus quadrispinosus*)
Hosts:	Hickory species. Butternut and pecan are also susceptible; black walnut is attacked rarely.
Symptoms / Signs:	The earliest symptoms of attack are usually red discoloration and/or wilting of leaves, premature leaf drop, crown thinning, and broken twigs that are not completely severed but rather hang from the tree. As symptoms progress, larger twigs and limbs begin to die, and terminal growth may appear stunted and/or tufted. Trees may be killed; dieback usually starts in the top of the tree and spreads downward (Fig. 5). Adults are less than ¼ inch long, short, stout, and dark brown or black (Fig. 1). The underside of the posterior is concave with small spines (Fig. 4). Larvae are slightly longer when fully grown, with a reddish-orange head and white crescent-shaped body. Short egg galleries formed by the adult usually run parallel to the wood grain (vertically oriented) with dozens of larval galleries fanning out giving the appearance of a centipede etched in the outer sapwood and inner bark (Fig. 2). Fine boring dust may accumulate on bark flaps and at the base of heavily infested trees, and many 1/8 inch round exit holes may be visible on the bark (Fig. 4).
Life Cycle:	Nearly-mature larvae overwinter and resume feeding for a short time before pupating in the spring. Adults emerge in late spring or early summer and fly into the upper crown to feed on the soft bark in the crotches of small twigs and at the base of leaf petioles. Adults may also tunnel into and feed on the soft tissues of young shoots. After feeding for 1-2 weeks, the adults seek out weakened host trees and bore into the main stem to create a short egg gallery in which 20-60 eggs are laid. Eggs hatch in 10-12 days and larvae feed on the inner bark for several weeks before pupating in the outer bark. There are two generations of the hickory bark beetle annually in North Carolina.
Importance:	Moderate. Individual trees that become infested may be killed. Outbreaks are rare, but occasionally outbreaks have occurred during which thousands of trees have been killed.
Management:	Good cultural practices such as thinning, pruning, fertilization, and irrigation are important for promoting and maintaining good tree vigor. Removal of diseased, dead, dying, and/or beetle infested trees is critical to protect other trees in the surrounding area. Bark should be removed from felled trees to eliminate breeding habitat. Bark should also be removed from firewood to eliminate breeding habitat and infested firewood should not be transported to other areas. Insecticides to prevent infestations are effective if an attack is suspected and caught early.
Timeline:	Beetles emerge in late spring or early summer. Adults feed throughout the summer, while larvae feed in the summer and into the fall. Symptoms usually become evident in late summer or early fall.
Range:	Statewide.

Fig. 1 Hickory bark beetle

Fig. 2 Hickory bark beetle galleries

Fig. 3 Hickory bark beetle posterior

Fig. 4 Exit holes

Fig. 5 Declining hickory

Pine Sawyer Beetles

Overview: Pine sawyers are destructive wood boring beetles whose larvae feed on green or freshly cut pine logs, dead trees, or occasionally dying trees. In addition to wood rotting and wood staining fungi introduced by the beetles, galleries degrade the value of lumber considerably; if the larvae penetrate deep into the sapwood, the value of lumber may be reduced by up to 35 percent. Adult beetles feed on the needles and soft bark of young twigs. These insects make the salvage of dead or dying pines and the storage of cut logs problematic.

Causal Agent: Southern pine sawyer (*Monochamus titillator*) and whitespotted pine sawyer (*Monochamus scutellatus*)

Hosts: The southern pine sawyer can attack all southern pine species. The whitespotted pine sawyer prefers eastern white pine, but will also feed on fir and spruce.

Symptoms / Signs: Removal of bark from infested trees may reveal the winding feeding galleries of larvae in the inner bark; as the larvae mature, the galleries become wider and deeper and will score both the bark and sapwood (Fig. 3). Galleries may be packed with wood shavings; wood shavings and frass may also be expelled through holes in the bark (Fig. 7). Sawdust and frass may accumulate on the ground beneath infested trees and logs. Galleries in the inner bark will end at a wide elliptical chamber where larvae tunnel into the sapwood. Exit holes are round and may exceed 1/4 inch in diameter (Fig. 4).

Adult southern pine sawyers are 1 to 1¼ inches long, mottled gray-brown-green, and have very long antennae that may be over 3 inches in length (Fig. 1). Larvae are white and legless, may be up to 3 inches long when fully grown, have large black mandibles, and pronounced segmentation/ribbing along the length of their bodies (Fig. 2).

Whitespotted pine sawyers are shiny black, slightly smaller (3/4-1 inches long), and have a distinct white spot at the junction of the wing covers (Fig. 6). Males have very long antennae (approximately 2 inches long), while females have antennae about as long as their bodies. Females may also be mottled with faint irregular white blotches on their bodies and faint white banding on their antennae (Fig. 5). Larvae are up to 2 inches long, whitish in color with an amber-brown head, distinctly segmented, and have a pair of dark mandibles.

Life Cycle: Adult beetles lay their eggs in etched out egg niches in the inner bark from June through September. Adults will not lay their eggs on trees lacking bark. Eggs hatch in about 2 weeks, and larvae begin to tunnel through and feed in the inner bark. Larvae overwinter in a dormant state in galleries formed deeper in the wood. Feeding resumes with warmer temperatures in the spring. When larvae reach a sufficient size, they bore into and feed deeper in the sapwood. Beetle larvae may penetrate six or more inches beneath the bark before excavating towards the surface again to pupate. After pupation, adult beetles chew through the wood to reach the surface, leaving a round exit hole in the bark. Adults feed on needles and tender bark on the underside of small twigs. In North Carolina, there are up to three generations of the southern pine sawyer, but only one generation of the whitespotted pine sawyer.

Importance: Moderate. Although not a serious threat to forest health, sawyer beetles can degrade the value of logs and lumber. Boring by larvae may introduce decay fungi and wood stain fungi into the wood causing further degradation.

Management: Rapid harvesting and utilization of dead trees, dying trees, or fresh cut logs will reduce infestations and the severity of wood degradation. If immediate utilization is not possible, logs can be debarked, immersed in water, or sprayed with an appropriate insecticide. Stacking logs in large piles in shady areas can greatly reduce the number of attacks because the beetles are sun loving. Logs can be stacked on site between September and June with little risk of attack.

Timeline: Adults emerge in late spring or early summer and egg-laying occurs throughout the summer. Larvae feed throughout the growing season, but lie dormant in the sapwood during the winter months.

Range: Statewide.

Fig. 1 Southern pine sawyer

Fig. 2 Southern pine sawyer larva

Fig. 3 Pine sawyer galleries

Fig. 4 Emerging adult

Fig. 5 Whitespotted pine sawyer

Fig. 6 Whitespotted pine sawyers

Fig. 7 Sawdust accumulation

Ambrosia Beetles

Overview:	Ambrosia beetles are very small insects that do not feed on trees; rather they create vast networks of tunnels or galleries in wood to "farm" ambrosia fungi upon which both adults and larvae feed. Ambrosia beetles typically attack recently dead, dying, or severely stressed trees. They also attack green logs and unseasoned lumber. The activity of ambrosia beetles can result in considerable degradation of lumber. There are thousands of species of ambrosia beetles worldwide, but with few exceptions, they are an indicator of dead or dying trees rather than a serious threat to tree health.
Causal Agent:	Ambrosia beetles: Order Coleoptera, Family Curculionidae, Subfamilies Scolytinae and Platypodinae.
Hosts:	Most conifer and hardwood species can be attacked by ambrosia beetles; most ambrosia beetles are host species specific.
Symptoms / Signs:	Accumulation of very fine sawdust around the base of a tree and in bark crevices will be the first and most obvious indicator of the presence of ambrosia beetles (Fig. 3). In older infestations, piles of sawdust can become quite large. Because sawdust expelled by ambrosia beetles is often mixed with excrement, toothpick-like strands of sawdust may stick several inches out of entrance holes to galleries (if it has not rained or been windy in recent days) (Fig. 4). Small pin-hole sized round entrance and exit holes will riddle the bark of a heavily infested tree. Removal of bark and examination of sapwood will reveal the galleries formed by larvae and adults; tunnels will be darkly stained with ambrosia fungi (Fig. 6). There are thousands of species of ambrosia beetles worldwide. Most are less than 1/4 inch long, light brown, reddish brown, dark brown, or black. Some are slightly hairy while others are hairless and shiny. Most ambrosia beetles are elongated, and some have small spines that protrude from their posterior end (Fig. 1).
Life Cycle:	Adult ambrosia beetles carry spores of their symbiotic ambrosia fungi in special pouches within their mouth to start new fungi "gardens." Adults are attracted to stressed, dying, or recently killed trees. When a suitable host is located, adults bore into the sapwood and begin to lay eggs (Fig. 5). When eggs hatch, larvae begin to tunnel parallel to the wood grain (Fig. 8). The wood is not consumed by the adults or larvae; rather the excavated sawdust is pushed out of the tree to keep tunnels clear. Fungal spores are released from the mouth of adults; fungi quickly geminate and begin to invade and feed on the surrounding sapwood. Nutrients gathered and spores produced by the fungi are concentrated on the surface of gallery walls. Larvae and adult beetles feed on the nutrient-rich spores and fungal mycelia. Because the fungi require adequate moisture in the wood to grow, beetles do not attack trees that have dried much beyond 40 percent wood moisture content. There may be three or more overlapping generations of ambrosia beetles per year.
Importance:	Low. Although not a serious threat to forest health, ambrosia beetles can degrade the value and strength of logs and lumber (Fig. 7). Interestingly, the darkly stained galleries and networks of fine tunnels formed by ambrosia beetles are prized by many woodworkers for their uniqueness (Fig. 2).
Management:	Rapid harvesting and utilization of dead and dying trees, fresh cut logs, and lumber will reduce infestations and the severity of wood degradation. Living trees infested by ambrosia beetles will likely not survive, and should be removed if they present a hazard. Be aware that ambrosia beetles can attack isolated branches and wounds; these infestations are not a threat to tree health. Control is not recommended in forest or landscape situations because the beetles will not attack even moderately healthy trees.
Timeline:	Beetles will be active throughout the growing season.
Range:	Statewide.

Fig. 1 Examples of ambrosia beetles

Fig. 2 Infested wood

Fig. 3 Sawdust accumulation

Fig. 4 Frass toothpicks

Fig. 5 Eggs and larvae in gallery

Fig. 6. Stained gallery entrances

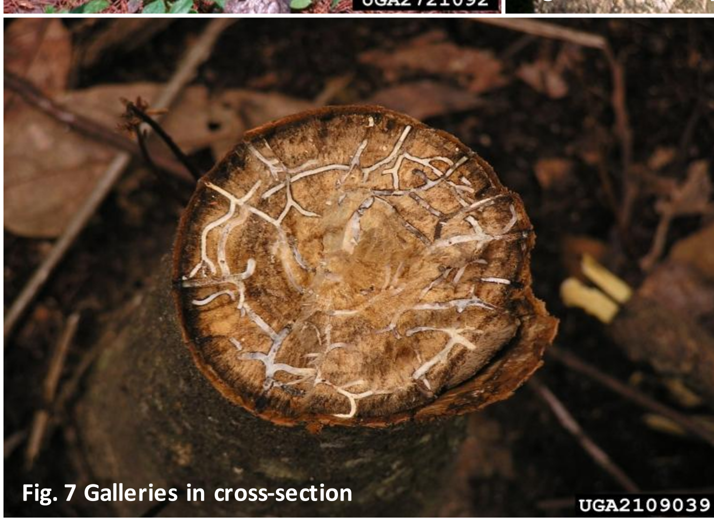


Fig. 7 Galleries in cross-section

Fig. 8 Adult and larval galleries

Asian Longhorned Beetle

Overview: The Asian longhorned beetle is a serious threat to many hardwood species. First introduced in solid wood packing material from Asia in the mid-1990's, this non-native invasive insect has since been discovered in Illinois, New York, New Jersey, Massachusetts, and Ohio. Populations have been relatively contained and eradication efforts have been moderately successful in limiting its spread, but the Asian longhorned beetle has yet to be completely eradicated from the U.S. This insect has the potential to cause more damage than Dutch elm disease, chestnut blight, and the gypsy moth combined. Suspected infestations of the Asian long-horned beetle should be reported immediately to NCFS Forest Health staff.

Causal Agent: Asian longhorned beetle (*Anoplophora glabripennis*)

Hosts: Complete host range unknown, but dozens of hardwood species are known to be susceptible. Preferred hosts include maple, willow, horsechestnut, buckeye, elm, birch, sycamore, hackberry, ash, and aspen. Also known to be susceptible are apple, mulberry, cherry, plum, pear, oak, and black locust.

Symptoms / Signs: Detection of new infestations is difficult because newly infested trees exhibit few, if any, external symptoms. Egg laying sites are round, dime-sized depressions that may be visible on bark (Fig. 6). Round, pencil-sized exit holes left by emerging adult beetles may be seen on the branches or trunk (Fig. 4). Oozing frothy or foamy sap may be seen exuding from exit holes; frass and coarse sawdust accumulate at the base of heavily infested trees and in bark crevices (Fig. 5). External bark cracking may be observed surrounding galleries in the inner bark. Removal of bark from infested trees may reveal the winding, coarse frass-filled larval galleries that etch the outer sapwood and inner bark. Galleries penetrate into the sapwood and heartwood as larvae mature. As larvae continue to feed and populations increase, wilting foliage, premature leaf drop, crown thinning, and branch dieback will occur (Fig. 7). When infestations are severe, bark will become separated from the sapwood (Fig. 8). Trees can be killed several years after the initial infestation.

The Asian longhorned beetle is about 1 to 1½ inches long, jet black (with possible bluish tinge), shiny, and has up to 20 distinct white spots. Antennae are very long with black and white bands. Males are slightly smaller than females; female antennae are only about as long as their body (Fig. 1). Larvae may exceed 2 inches in length when fully grown, are white to cream colored, are distinctly segmented, and have a dark set of large distinct mandibles (Fig. 2). The thorax of larvae has a brown shield on the back.

Life Cycle: Asian longhorned beetles can fly up to 400 yards in search of a host tree. The females usually lay their eggs in the same tree from which they emerged as adults, migrating only when the population density becomes too high. During the summer months, the adult female chews 35 to 90 individual depressions into the host tree's bark and lays an egg in each. Eggs hatch in 10-15 days and the larvae tunnel into the tree's inner bark to feed for several weeks. The larvae tunnel deeper in the tree's sapwood and heartwood where they mature and pupate (Fig. 3). Pupae become adults inside the tree during the winter months. The full-grown adult beetles bore out of the tree the following spring or summer leaving a 3/8 inch round exit hole; emergence occurs as early as May and as late as October or November. Adults feed on leaves, twigs, and on tender bark in branch crotches for several weeks before mating and laying eggs. There is one generation per year in the northern United States.

Importance: High. Dozens of hardwood species are threatened. The economic and ecological impact of widespread infestations is unknown, but is expected to be catastrophic.

Management: Avoid interstate movement of firewood which can introduce the Asian longhorned beetle to new areas and accelerate its spread. Quarantines are in effect in and around currently infested areas which prevent movement of wood, logs, and living trees out of the area. Dead or dying infested trees should be removed immediately and destroyed. Systemic insecticides can be used to protect trees from attack or eradicate beetles from lightly infested trees.

Timeline: Beetles are active throughout the growing season.

Range: Northeastern United States. Not currently found in North Carolina. Potential impact statewide.

Fig. 1 Asian longhorned beetle

Fig. 2 Larva

Fig. 3 Galleries in cross-section

Fig. 4 Exit holes

Fig. 5 Frass

Fig. 6 Egg site

Fig. 7 Thinning crown

Fig. 8 Girdled tree

Emerald Ash Borer

Overview:	The emerald ash borer is a non-native invasive forest pest that was first discovered in Michigan in 2002; it probably arrived in the U.S. in solid wood packing material from Asia. The larvae feed on the inner bark of ash trees and disrupt their ability to transport water and nutrients. Trees decline and die over a period of several years. Tens of millions of ash trees have been killed since its introduction, and the emerald ash borer threatens billions of others across the U.S. and Canada. The beetle can only spread a few miles per year naturally; however, movement of this pest in firewood has accelerated dispersal across much of the northeastern U.S. If emerald ash borer is suspected, it should be reported to NCFS Forest Health Staff immediately.
Causal Agent:	Emerald ash borer (*Agrilus planipennis*)
Hosts:	All ash species are highly susceptible.
Symptoms / Signs:	Detection of new infestations is difficult because newly infested trees exhibit few, if any, external symptoms. Increased woodpecker activity may be the first sign that a tree is infested. D-shaped exit holes left by emerging adult beetles may be seen on branches or the trunk. Bark may split vertically adjacent to larval feeding galleries (Fig. 10). Epicormic sprouts may form on the trunk or large branches (Fig. 9). Removal of bark from infested trees may reveal the winding, frass-filled larval galleries that etch the outer sapwood and inner bark (Fig. 4&5). Discolored sapwood may result from opportunistic fungi around galleries. As larvae continue to feed and populations increase, wilting foliage, premature leaf drop, crown thinning, and branch dieback will occur (Fig. 8). Many trees will lose between 30 and 50 percent of their canopy within a few years of the initial infestation, and die within 3-4 years. Although stressed trees are initially more attractive than healthy trees, when populations are sufficient, all ash trees greater than 1inch in diameter will be attacked. Adult beetles are slender and 1/4 to 1/2 inch long (Fig. 1&2). Males are generally smaller than females. Adults are usually bronze, golden, or reddish green overall, however, their metallic emerald green wing covers give them an overall green appearance when they are at rest. The top of the abdomen is metallic purple-red and can be seen when the wings are spread (Fig. 3); this characteristic distinguishes the emerald ash borer from all other insects that are otherwise similar in appearance. The prothorax, the segment just behind the head, is slightly wider than the head and the same width as the base of the wing covers. Larvae when fully grown are 1¼ inches long, white to cream-colored, have distinctly bell-shaped body segments, and are flattened in appearance (Fig. 6). They have a brown head that is retracted into the prothorax so that only the mouthparts are visible. The abdomen has 10 segments, and the last segment has a pair of small, brown, pincer-like appendages.
Life Cycle:	Research suggests there would be one generation per year in North Carolina. Adult beetles begin to emerge in spring; activity peaks between mid June and early July, and continues through August. Adult beetles only live for three weeks on average. They are most active during the day, particularly when it is warm and sunny, and feed on ash foliage leaving small, irregularly shaped holes along the leaf margins. Adults feed for several weeks before mating and each female can lay more than 100 eggs during her short lifespan. Eggs are deposited individually in bark crevices or under bark flaps on the trunk or branches. Eggs hatch in 7 to 10 days and the new larvae chew through the bark and into the inner bark where they feed for several weeks. As the larvae grow, their galleries become progressively wider and etch the outer sapwood and xylem. Feeding is completed in autumn, and fully grown larvae overwinter in shallow chambers in the sapwood. Pupation begins in late April or May; adults emerge several weeks later through D-shaped exit holes about 1/8 inch diameter (Fig. 7).
Importance:	High. The survival of all native ash species in North America is threatened by this pest.
Management:	Avoid interstate movement of firewood which can introduce the emerald ash borer to new areas and accelerate its spread. Dead or dying infested trees should be removed immediately and destroyed. Systemic insecticides can be used to protect trees from attack or eradicate beetles from lightly infested trees. Insecticide treatments are costly and require reapplication every 1-2 years.
Timeline:	Beetles are active throughout the growing season.
Range:	Much of the eastern U.S.; found in North Carolina in 2013. Potential statewide impact.

Fig. 1 Emerald ash borer

Fig. 2 Emerald ash borer

Fig. 3 Emerald ash borer

Fig. 4 Galleries

Fig. 5 Galleries

Fig. 6 Larva

Fig. 7 D-shaped exit holes

Fig. 8 Thinning crown

Fig. 9 Epicormic sprouting

Fig. 10 Bark splitting

Sirex Woodwasp

Overview: The Sirex woodwasp is a non-native invasive forest pest introduced from Europe, Asia, and Northern Africa. Although only recently introduced to the northeastern U.S. and not currently causing widespread mortality, there is serious reason for concern. The Sirex woodwasp has spread to South America, South Africa, New Zealand, and Australia where it causes more than 80 percent mortality in stands planted with North American pine species (including several species of southern pine). Spread of this wasp into the southern U.S. could have disastrous consequences. The adult wasp injects a pathogenic fungus and toxic mucus during oviposition that kills the tree. Wasp larvae bore through the wood and feed on the fungus. Because the larvae bore deep into the sapwood, the Sirex woodwasp is often transported in solid wood packing material and it is the most common exotic species of woodwasp found at ports of entry. Suspected infestations of the Sirex woodwasp should be reported immediately to NCFS Forest Health staff.

Causal Agent: Sirex woodwasp, also known as the European woodwasp (*Sirex noctilio*)

Hosts: Complete host range is unknown, but all southern pine species are potentially susceptible. Infestations have been confirmed in loblolly, slash, and shortleaf pines in other countries.

Symptoms / Signs: Trees usually wilt and die within 3-6 months of the initial attack. Foliage of infested trees initially wilts, hangs straight down, and changes color from green to yellow to red and brown (Fig. 3). Resin beads may form at and drip from egg laying sites, which are most common on the mid-stem (Fig. 5). Discolored sapwood that has been killed by a toxic mucus and wood rotting fungus may be visible beneath the bark around oviposition sites.

Adult wasps are approximately 1 to 1½ inches long, have a cylindrical body, and black antennae. Females have a metallic blue or black head and body with orange legs, (Fig. 1) and a long spike-like projection at the end of the abdomen. Males have a metallic blue head and thorax, the abdomen is orange with black at the base and tail end, and the hind legs are black (Fig. 2). Larvae are creamy-white cylindrical grubs over an inch long with a dark spine at the end of the abdomen (Fig. 7). Larval galleries are winding or serpentine, are approximately 3/8 inches wide, and are usually tightly packed with reddish-gold sticky frass (Fig. 6). Round exit holes (1/8 – 3/8 inches wide) may riddle the main stem on heavily infested trees (Fig. 4). Because there are many native species of woodwasps (horntails) that are similar in appearance, suspected Sirex woodwasps should be submitted to Forest Health staff for identification.

Life Cycle: There are dozens of species of horntails in the U.S., but they only attack dead or dying trees. Sirex woodwasps, while they prefer stressed and suppressed trees, are able to overcome the defenses of even healthy pines when populations are high. Adults emerge from July through September with peak emergence in August. Females are attracted to stressed trees. They drill their ovipositors into the outer sapwood and inject a symbiotic fungus (*Amylostereum areolatum*), a toxic mucus, and up to 450 eggs. The fungus and mucus act together to kill the tree and create a suitable environment for larval development. Unfertilized eggs develop into males, while fertilized eggs produce females. The larval stage lasts approximately 10 months, during which they feed on the fungus as they tunnel through the wood. Mature larvae pupate close to the bark surface. Adults emerge about 3 weeks later.

Importance: High. The Sirex woodwasp could have devastating consequences on the pine forests of the South.

Management: There is currently a quarantine against transport of untreated wood (packing material, firewood, untreated lumber, mulch, Christmas trees, etc.) and living pines from states known to have Sirex infestations. Preventing the introduction of this pest into North Carolina is critical because few control options are available. The Sirex woodwasp has been successfully managed using a parasitic nematode that infects sirex woodwasp larvae and ultimately sterilizes the adult females. These infected females emerge and lay infertile eggs that are filled with nematodes, which sustain and spread the nematode population. The nematodes effectively regulate the woodwasp population below damaging levels.

Timeline: Adults emerge in the summer and early fall; feeding by larvae occurs year-round.

Range: Northeastern U.S. (Fig. 8); has not been found in North Carolina. Potential statewide impact.

Fig. 1 Sirex woodwasp female

Fig. 2 Sirex woodwasp male

Fig. 3 Wilting

Fig. 4 Exit holes

Fig. 5 Resin

Fig. 6 Larval galleries

Fig. 7 Larva

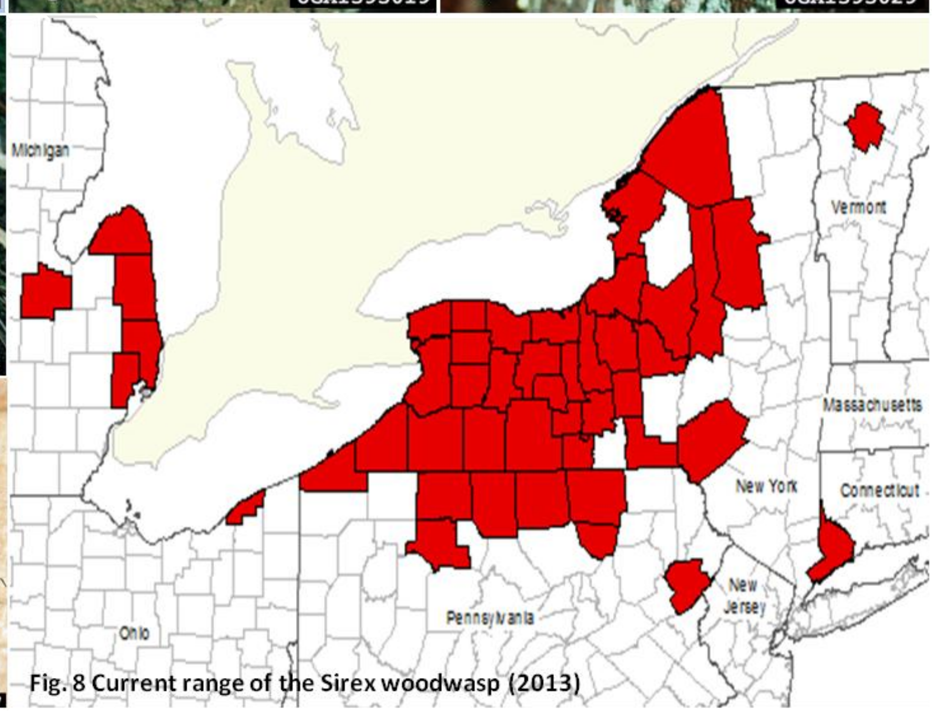


Fig. 8 Current range of the Sirex woodwasp (2013)

Pales Weevil

Overview: The Pales weevil is the most important and destructive forest pest of pine seedlings; during outbreaks, mortality in new plantings often exceeds 50 percent. The weevil has become a serious problem because of the silvicultural methods commonly utilized for pine management: mainly, the practice of planting seedlings in recently cutover stands of pine. Weevil larvae feed in fresh logging slash, dead root systems, and even dead standing trees. Adult weevils feed on the tender bark of young seedlings upon emerging from logging slash. Therefore, new plantings in cutovers are often placed in close proximity to high populations of weevils and severe infestations result. Plantings can be timed to avoid attack, and insecticides are commonly applied in seedling nurseries before shipment of seedlings into the field.

Causal Agent: Pales weevil (*Hylobius pales*)

Hosts: All southern pine species are susceptible.

Symptoms / Signs: Adult weevils prefer to feed on the lower stem of seedlings near the soil line. Feeding sites are small, irregular patches where the bark has been nibbled off and may darken over time. Resin may dry and crystallize on the wound giving the stem a sugar-coated appearance (Fig. 2). If the seedling is girdled, foliage will rapidly turn from green to yellow to red to brown. Needles may be shed as the seedling dries out. During heavy infestations, bark can be stripped from large portions of the stem or even the entire seedling.

The Pales weevil is approximately 1/4 inch long, reddish-brown, and has a long trunk-like snout. Small patches of yellowish-white hairs speckle the wing covers (Fig. 1). The adults feed at night and hide in leaf litter or below the soil line during the day (Fig. 3), so the presence of this pest is usually confirmed by feeding damage rather than direct observation of the weevil itself. Larvae are found in logging slash, root systems of cut trees, and recently killed trees. They are nearly 1/2 inch long when fully grown, creamy-white in color, and have a reddish-orange head. Larval galleries are several inches long and wind through the inner bark (Fig. 4). Pupation chambers and surrounding galleries will be packed with frass and coarse sawdust.

Life Cycle: Adult weevils overwinter in the soil, although they may be active during the winter months when temperatures rise above 50º F. In spring, adults emerge from the soil and are attracted to fresh cut stumps and logging debris, where they mate and lay eggs. Females burrow into the soil and nibble small egg niches in the roots, stumps, and buried logging debris; several eggs are laid in each niche. Larvae hatch in 1-2 weeks and feed on the inner bark for several months. Before pupation, larvae create a pupal chamber stuffed with frass and coarse sawdust. If eggs are laid before July, adults will emerge in late summer or early fall and feed on the tender bark of seedlings or twigs on larger trees. If eggs are laid after July, larvae will overwinter in their galleries and emerge as adults the following spring. There is only one generation per year.

Importance: Moderate. Large infestations can be destructive to new plantings, but insecticide-treated seedlings and proper forest management can effectively reduce the risk.

Management: Seedlings treated with an insecticide before planting are protected from heavy attacks, although minor feeding damage can be expected because the weevils must ingest the insecticide to be killed. If stands are harvested after the end of June, planting should be delayed for one entire growing season; adult weevils will emerge the spring after harvesting, and if seedlings have been planted, they may be attacked. In stands harvested before July, adult weevils will emerge from logging debris in the fall and disperse in search of seedlings.

Timeline: Weevils are active throughout the growing season and even during winter months when temperatures occasionally warm. Adult weevils generally prefer to lay eggs in logging debris that is less than one year old. Adults will emerge in the same growing season if eggs are laid prior to July. Adults will emerge the following spring if eggs are laid after June.

Range: Statewide.

Fig. 1 Pales weevil

Fig. 2 Girdled seedling

Fig. 3 Feeding adults

Fig. 4 Larval alleries in cut stump

Nantucket Pine Tip Moth

Overview: Nantucket pine tip moth larvae bore into and kill the growing shoots of southern pines. While trees are rarely killed even by heavy infestations, economic losses can result from growth loss and deformed main stems. Tip moth outbreaks are most common and severe in pine plantations less than five years old. Wide spaced plantings are preferred, but as crowns close and trees increase in height, attacks become rare. This insect also attacks female flowers and developing cones, so it can be a serious concern in seed orchards.

Causal Agent: Nantucket pine tip moth (*Rhyacionia frustrana*)

Hosts: Southern pines; longleaf, slash, and eastern white pine are considered to be resistant but may be attacked when populations are high.

Symptoms / Signs: Attacks are generally limited to trees less than 5 years old; trees taller than 12 feet are rarely attacked. Needles on infested shoots will yellow and turn brown (Fig. 4); shoots will die and curl over (Fig. 2). Severity of symptoms is dependent on the progress of larvae through the shoot. Symptoms may be limited to only a few inches at the end of shoots, or may extend for a foot or more. Terminal shoots and rapidly growing main laterals are preferred. When terminal shoots are killed, adjacent laterals will compete for dominance giving rise to deformed trees with multiple stems or leaders (Fig. 6).

Breaking open killed shoots will reveal a hollow feeding gallery running down the center of the shoot. When fully grown, larvae are almost 1/2 inch long, light brown to orange-red, and worm-like (Fig. 3). Younger larvae are paler in color and have black heads. Moths have a 1 inch wing span, a gray head and body, and wings that are reddish-orange or copper in color (Fig. 1).

Life Cycle: The moth overwinters as a pupa within the killed shoot. Emergence occurs in late winter or early spring; moths mate and lay flattened eggs at the base of needles or in bud scales. Young larvae may feed on needles and the surface of young succulent shoot growth, but then proceed to the shoot tip and begin to mine through buds or stem tissue. Pupation occurs at the bottom of the mined shoot (Fig. 5). There are 3-5 generations per year in North Carolina.

Importance: Moderate. Serious injury to trees is rare, even during heavy infestations. Trees can experience growth reduction and may be deformed by loss of terminal shoots.

Management: Insecticides are available but usually unnecessary unless infestations are unusually severe. Young trees will fully recover; growth loss and deformity is usually minimal. Chemical applications may be necessary to protect high value seed trees, landscape trees, and ornamentals. Chemical applications must be timed properly to target each generation of moths.

Timeline: Adults emerge in late winter or early spring. Larvae feed throughout the growing season.

Range: Statewide.

Fig. 1 Nantucket pine tip moth adult

Fig. 2 Damaged shoot

Fig. 3 Larva

Fig. 4 Attacked sapling

Fig. 5 Pupa

Fig. 6 Deformed growth

Twig Pruners and Girdlers

Overview: Twig girdlers and twig pruners are a general term for wood boring beetles whose larvae tunnel through twigs of many hardwood species. As a result, twigs become almost completely severed and may eventually break and fall off. Although this activity rarely kills trees, it can significantly slow growth and alter tree form. Loss of terminal shoots can lead to sprouting and competition for dominance by lateral shoots leading to multi-stemmed trees lacking a main leader. Twig pruner larvae sever the twig from the inside, whereas twig girdler adults sever the twig from the outside at the time of egg laying.

Causal Agent: Several beetle species including the twig pruner (*Anelaphus villosus*) and the twig girdler (*Oncideres cingulata*)

Hosts: Hardwoods. The twig pruner prefers oak, chestnut, hickory, pecan, maple, flowering fruit trees, redbud, sweetgum, sassafras, persimmon, and elm. The twig girdler attacks elm, oak, redbud, apple, hickory, pecan, persimmon, aspen, locust, and dogwood.

Symptoms / Signs: Abundant small branches and twigs laying on the ground below susceptible host trees late in the growing season are an indicator of twig pruner or girdler activity. If the twigs are more or less clean cut, it is most likely the twig pruner; if the twigs have a broken central core then twig girdlers may be responsible. Twigs 1/4 to 2 inches in diameter are normally attacked. Heavily infested trees may have many attached branches with wilting/browning foliage giving the tree a drought-stricken appearance.

Twig pruner larvae may be found within broken or fallen twigs; they are a creamy-white colored round-headed borer with long yellow hairs primarily on the thorax. Adults are 1 to 1½ inches long, elongated, with brown bodies, gray speckles, and long antennae (Fig. 6). Larvae leave distinct concentric circular cuts from the inside of the twig, leaving only bark to hold the branch in place; eventually the bark gives way and the twig falls to the ground. Fully grown twig girdler larvae are creamy white, are less than an inch long, and are found in fallen twigs throughout the winter, spring, and summer. Adults emerge in the fall and are drab gray longhorned beetles less than 1 inch in length (Fig. 2).

Life Cycle: Adult twig pruners emerge in spring and lay eggs in small bark niches at the base of leaf petioles. Larvae hatch and immediately bore into the center of the twig; then they tunnel down the twig towards the base. The twig will remain alive and often asymptomatic until the fall when larvae begins to move into the sapwood by making expanding circular cuts towards the bark. Only the bark holds the twig together (Fig. 5). Before the twig breaks off, the larvae backs up into the end of the twig and plugs the hole with frass and sawdust. The larvae feed in fallen twigs throughout the fall and overwinter as pupae. The adult emerges from the hollowed out branch in the spring. There is one generation per year.

Twig girdler adults are active in late summer and early fall. Females lay eggs in small slits in the bark of terminal twigs or lateral twigs; up to a dozen eggs may be laid in each twig. Females then chew a thin continuous notch around the twig below the eggs to girdle it (Fig. 2). The twigs die shortly thereafter and fall to the ground (Fig 4). Eggs hatch before the onset of winter, but larvae do not begin to feed until spring when they tunnel into the cut end of the twig and feed on the sapwood throughout the summer. They create small holes in the bark to expel frass (Fig. 3). Larvae pupate and emerge as adults in September. There is one generation per year.

Importance: Low. However twig girdler/pruner activity can slow growth, and more importantly, disfigure young trees considerably. In forested situations, activity can be expected but will usually be below acceptable thresholds. Damage can be severe to landscape trees and ornamentals.

Management: Broken twigs can be gathered and destroyed in the fall to prevent girdler/pruner activity the following year.

Timeline: Adult girdlers emerge in the fall; young larvae are dormant during the winter and feed throughout the following growing season. Adult pruners emerge in the spring; larvae feed through the growing season and overwinter as pupae. Twigs will begin to die and fall off in the fall.

Range: Statewide.

Fig. 1 Twig girdler

Fig. 2 Girdler

Fig. 3 Twig girdler larva

Fig. 4 Girdled twigs

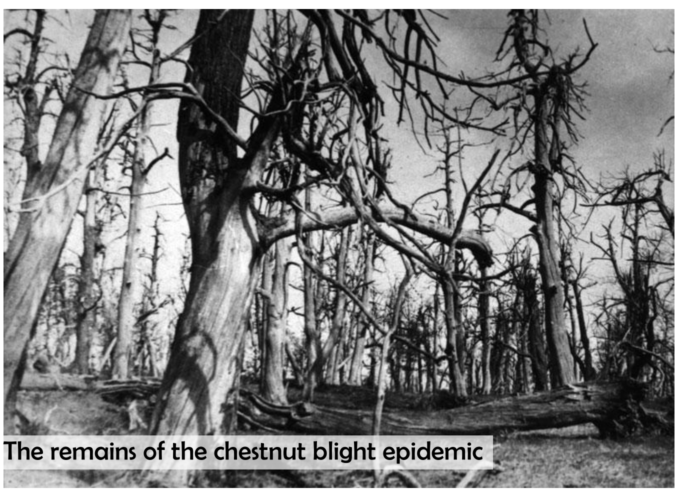

Fig. 5 Twig pruner larva in pruned twig


Fig. 6 Twig pruner

Forest Diseases

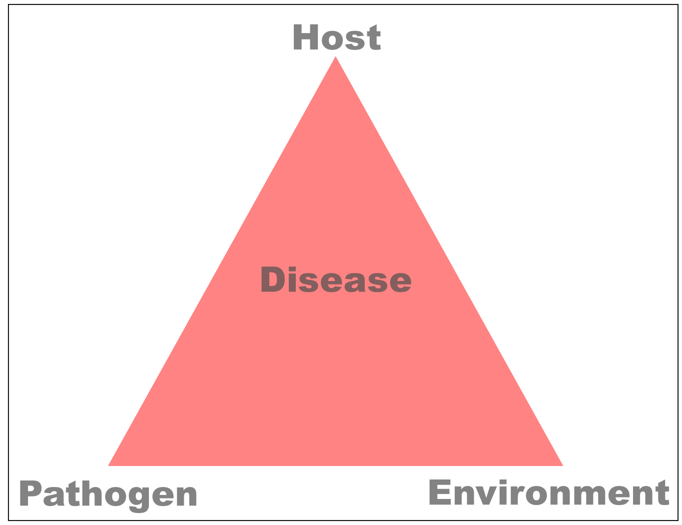
Forest Pathology

Tree diseases are the leading cause of timber losses each year in the U.S. In fact, the average total loss of timber due to disease-caused mortality and growth loss nearly equals the losses caused by all other stress agents combined. Diseases have and will continue to result in catastrophic epidemics that can wipe-out entire tree species and destroy native forest ecosystems. Chestnut blight was the first of many such epidemics, which virtually eliminated the most common tree species in the eastern U.S., the American chestnut, from its natural range in less than 40 years. Dutch elm disease, dogwood anthracnose, beech bark disease, sudden oak death, and laurel wilt have since followed. Other diseases pose little or no threat to tree survival, but are no less problematic because they reduce growth significantly, degrade wood, destroy fruit and seed crops, or make landscape trees and ornamentals unsightly or hazardous.



The remains of the chestnut blight epidemic

Forest pathology is the study of tree diseases including diseases of trees in forests, plantations, nurseries, urban areas, and landscape settings. In addition, forest pathology also encompasses the science of wood degradation and decay. In fact, the field of forest pathology is considered to have begun with Robert Hartig's investigations of wood decay by fungi in the 1850's. Forest pathology is a sub-discipline of ***plant pathology*** which is the study of plant diseases. A ***plant disease*** is defined as a sustained disruption in physiological or structural functions of a plant due to an attack by a pathogen that results in death, damage to cells or tissues, reduced growth or vitality, or economic losses. A disease is an interaction between a pathogen and its host that can only occur under certain environmental conditions. This can be demonstrated by the ***disease triangle***, which visualizes disease as an interaction between three components: host, pathogen, and environment. If one of the three components is lacking, disease cannot occur.



Pathogens are parasitic microorganisms that cause disease, meaning they attack plants to obtain the energy and nutrients necessary to complete their life cycle resulting in harm to their host plant. Pathogenic (disease-causing) microorganisms include bacteria, viruses, nematodes, and most commonly, fungi. Not all microorganisms are ***pathogenic***; in fact, most microorganisms are ***obligate saprophytes*** meaning they can only feed on dead organic material. These microorganisms play an important role in decomposing dead plant material and recycling nutrients. Most plant pathogens are ***facultative pathogens***, meaning that they can live on dead plant material, but can also attack living plants and cause disease. Other pathogens are ***obligate pathogens*** that can only survive on a living host plant.

Oyster mushrooms (*Pleurotus ostreatus*) are obligate saprophytes

Fusiform rust is caused by *Cronartium quercum f. sp. fusiforme*; an obligate pathogen

All plant pathogens are infectious and transmissible, meaning they can spread from one host plant to infect another. Plant pathogens cause disease, they are not diseases themselves. For instance, the fungus *Cryphonectria parasitica* is the name of the pathogen that causes chestnut blight in American chestnuts. Remember: a disease is the resulting interaction between a host, pathogen, and environment.

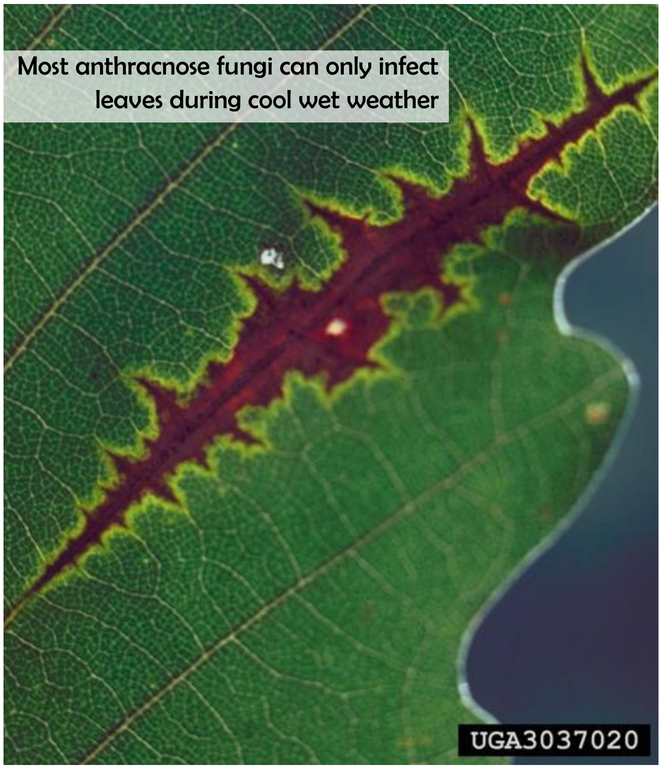
Plant pathogens cannot attack and parasitize any plant species; instead, plant pathogens are host-specific. A ***host*** is a plant that can be infected and parasitized by a specific plant pathogen. Most plant pathogens have only one or a few suitable host species; however, some pathogens can attack hundreds of plant species. The mechanisms that determine which pathogens can attack which plants are very complicated and result from complex interactions and signals between the two organisms.

Trees have evolved structural and chemical defenses such as thick bark, waxy leaf coatings, root secretions, and anti-microbial toxins that prevent infections. These "pre-formed" defenses are always in place and provide general protection from all microorganisms. But certain plant pathogens have developed ***virulence factors*** that enable them to overcome general plant defenses. Virulence factors such as enzymes that degrade plant tissues, special structures that can pierce plant cells, or specialized metabolic pathways that can neutralize host toxins, may allow a microorganism to become pathogenic. In response, plants have developed methods to detect pathogens that can overcome pre-formed defenses, and in response, they initiate powerful "induced" defenses. When one of these pathogens is detected during the infection process, induced defenses such as increased production of anti-microbial compounds or instantaneous death of infected cells can prevent the pathogen from parasitizing the plant and causing disease. Of course, pathogens continue to adapt induced plant defenses by hiding the chemical signals that alert plants to an attack or adding developing additional virulence factors.

Ophiostoma ulmi, the causal agent of Dutch elm disease, can only infect elm species

A plant that possesses the ability to prevent infection is completely ***resistant*** to that specific pathogen. Some resistant plants can become infected, but are able to minimize disease development and are therefore considered to be partially resistant. ***Susceptible*** plants are vulnerable to pathogen attacks that result in severe and damaging disease. Resistance and susceptibility form a continuum that ranges from completely resistant to highly susceptible. A plant can be resistant to one pathogen but susceptible to another. Each host-pathogen interaction is unique.

Regardless of how susceptible a plant may be to a given pathogen, disease cannot occur unless the environmental conditions are just right. Pathogens have very specific environmental requirements to complete their life cycle. Many fungi only produce spores within a very narrow temperature range. Some spores can only spread in splashing rain, high winds, or with a specific insect vector. Certain fungal spores can only germinate if the leaf surface is wet, and can only infect through a natural plant opening or wound. Even if all these conditions are met, some fungi can only infect a host that has been sufficiently weakened by predisposing factors. The environmental conditions for each host-pathogen interaction are unique. If conditions are not correct, disease will not result.

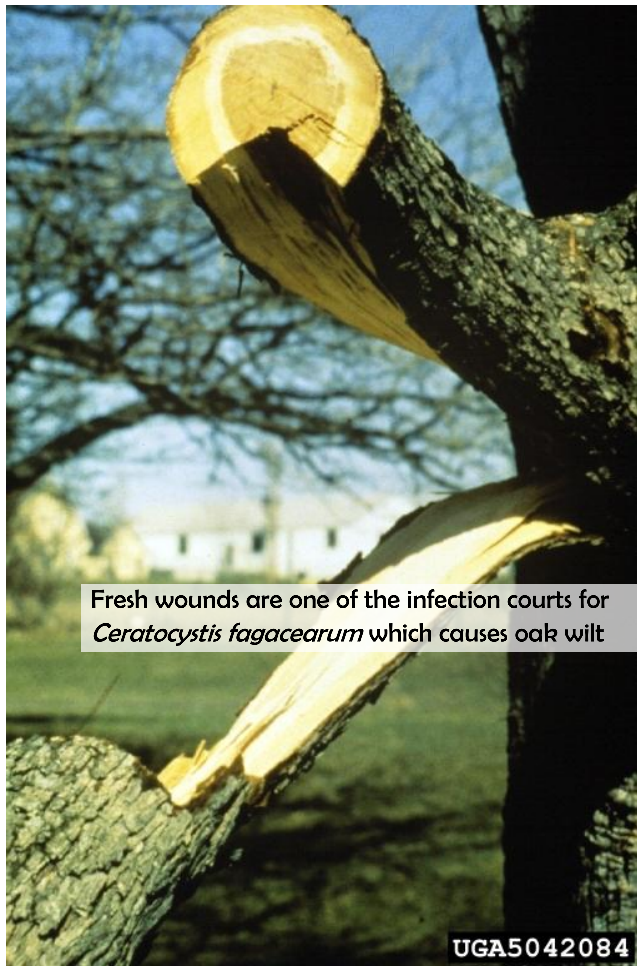


The interactions between a host, pathogen, and environment that result in disease occur in several distinct stages that together make up the ***disease cycle***.

The Disease Cycle

1) ***Transmission*** is the movement of the pathogen from one host plant to another. While some pathogens can simply grow through the soil from one plant to another, most pathogens cannot survive for very long outside their host, so transmission usually involves special mechanisms. Many pathogens require an insect vector to carry them from one plant to another; the insects unknowingly carry the pathogen in their mouths or on their bodies and transmit them to new hosts while feeding. Some fungi produce special spores that can be carried by the wind or splashed around by rain drops. Phytophthora species (fungus-like organisms) and nematodes can swim through moist soil in search of new hosts. Some pathogens are transmitted in plant seeds or can grow from one tree to another through interconnected root systems.

2) ***Infection*** is the act of the pathogen entering the host. Some pathogens can directly penetrate plant cells or tissues by physical force; others must enter through natural plant openings such as stomata. Some pathogens can only infect through open wounds in the plant, and insect vectored pathogens may only enter the plant during the insect's feeding process. The actual location of the infection is known as the ***infection court***. Many infection courts are only vulnerable to infection under certain environmental conditions, for example when leaves are wet, when wounds are fresh, or when young seedlings first emerge from the soil.



3) ***Colonization*** is the invasion of plant tissues by the pathogen. The pathogen must spread through the plant by growing through or between cells, or by spreading through the plant's vascular system. Most fungi for instance grow through the plant using long, filamentous structures called mycelia. Bacteria on the other hand, must swim or be carried in the

plant's vascular system. The extent of colonization by some pathogens is very limited (e.g. leaf spot diseases) while other pathogens colonize the entire plant (e.g. vascular wilt diseases).

4) ***Parasitism*** occurs when the spreading pathogen begins to feed on plant tissues. In most cases, plant cells are penetrated and killed by the pathogen, and the nutrients are absorbed. It is the act of parasitism that causes most damage to plants by killing plant cells and tissues, interfering with physiological processes or structural functions, and draining a plant of its energy reserves.

5) ***Symptom development*** occurs in response to the damage caused by the pathogen. Symptoms are a plant's reaction to colonization and parasitism by the pathogen. Some symptoms are a direct result of pathogen activity (leaf lesions caused by a fungus killing leaf cells), while others may be caused indirectly (wilting of a tree due to a pathogen attacking the root system). In most cases, symptoms are the only visible evidence that a plant is diseased.

6) ***Reproduction*** of the pathogen is necessary to complete its life cycle. Different pathogens reproduce in different ways. Viruses are replicated by the plant cell's own genetic machinery. Bacteria and some yeast-like fungi simply divide to create new individuals. Nematodes are animals that lay eggs or may even give birth to live offspring. Most fungi produce special fruiting bodies that are capable of producing hundreds of billions of spores. Most plant pathogenic fungi produce microscopic fruiting bodies, but some produce larger fruiting bodies that we know as mushrooms. All plant pathogens are capable of reproducing asexually (without mating), and most are capable of sexual reproduction in some form.

7) ***Transmission*** is most often accomplished by reproductive structures such as spores, so therefore successful transmission follows reproduction and is necessary for the pathogen to complete its life cycle. Diseases caused by pathogens that complete their life cycle only once per year are known as ***monocyclic diseases***; diseases caused by pathogens with the ability to complete their life cycle more than once in a growing season are ***polycyclic diseases***. Pathogens that are not transmitted before the end of the growing season must reside within the host plant or form survival structures to overwinter.

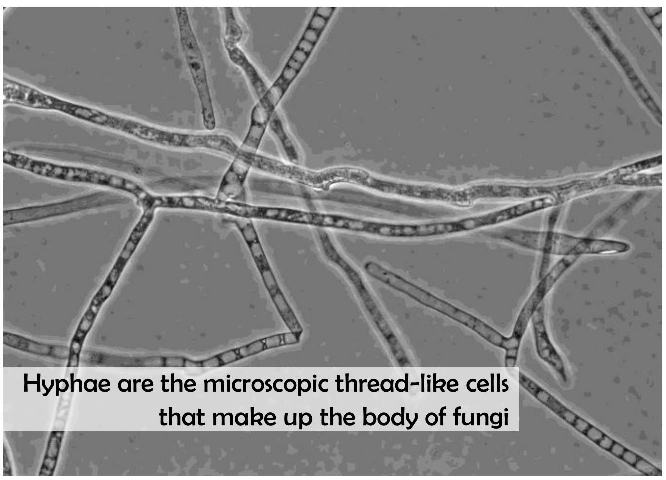
The disease cycle for each host-pathogen-environment interaction is unique. Therefore most forest pathology references provide detailed information on the disease cycle for each specific disease. Identifying "weak points" or vulnerabilities in the disease cycle is the first step in designing control or management strategies. Familiarity with the disease cycle of common or potentially damaging diseases is important for proper forest management.

Fungi

Fungi are filamentous microorganisms that lack chlorophyll and must therefore obtain nutrients from living hosts or organic matter. At one time, fungi were considered to be plants. However, they differ from plants in so many ways that they are now classified in their own kingdom separate from both plants and animals. Over 75,000 species of fungi have been named and described, but it is thought that over one million species of fungi may exist world-wide. Mycology is the study of fungi and closely related organisms such as slime molds and water molds (e.g. *Phytophthora* species) which are not true fungi.

The diversity of fungi, their biology, roles, and uses are so vast and varied they cannot be described in detail here. Most fungi can only feed on dead organic material. These fungi play crucial roles in decomposition and nutrient recycling. Some fungi produce chemicals or have special metabolisms that are utilized by humans to produce antibiotics, beer, wine, bread, soy sauce, industrial enzymes, and detergents. Some fungi are edible, and the mushrooms of many fungi are prized by mushroom hunters and chefs alike. Others are highly toxic or even psychotropic to humans and/or other animals. Some fungi cause disease in humans; others parasitize insects and nematodes and can be used as biological controls. Fungi are also the most common and important plant pathogens. The vast majority of plant diseases are caused by fungi, even though only a relatively small percentage of fungi are pathogenic.

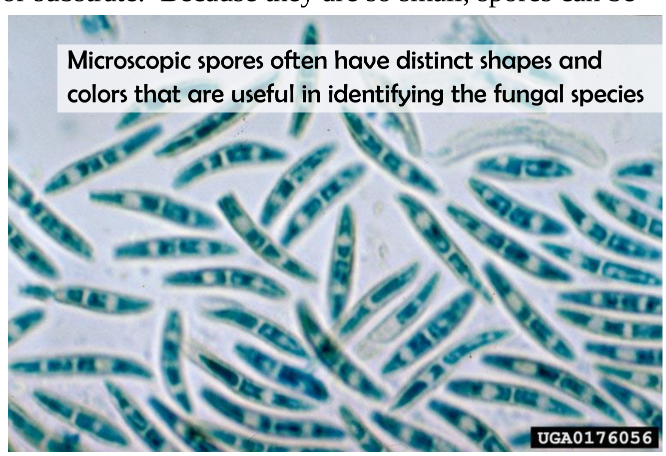
In their most basic form, fungi are networks of filamentous or thread-like strands known as ***mycelium***. A single thread of mycelium is called a ***hypha***. Hyphae are microscopic tube-like cells that can branch, grow very quickly at their tips, and are generally considered to be the main body of the organism. The cell walls of fungi are composed of chitin (as opposed to cellulose in plants), and each hyphae is filled with protoplasm that flows throughout the mycelium network. Some species form dense clusters of mycelium that can be visible to the naked eye. For instance, some *Armillaria* species (common wood and root rotters) form dense mycelial strings called ***rhizomorphs*** beneath the bark of their host that resemble black shoestrings. Others may form thin fan-like mats, or even thick clumps that can rupture the surface of tree bark. However, the most commonly visible sign of fungi are mushrooms, which are the large spore-producing fruiting structure of the fungus. Compared to the network of mycelia, mushrooms are a relatively small structure produced on the surface of the ***substrate*** the fungus is growing in. Mushrooms are only formed by a relatively small percentage of fungi however; most mushroom-forming species are saprophytes as opposed to plant pathogens.


Hyphae are the microscopic thread-like cells that make up the body of fungi

Most plant pathogenic fungi do not form mushrooms. Instead, they produce microscopic spore-producing ***fruiting bodies*** that are seldom visible to the naked eye. Some fruiting bodies, and the spores they produce, are very colorful and become so numerous that they may occasionally become visible on the surface of an infected plant. Spore shapes, colors, and sizes vary widely, and can be used to identify fungi when examined under a microscope. The number of spores produced by a fungus is nearly incomprehensible. For instance, a single "artist's conk" from the common wood rotter *Ganoderma applanatus* can produce 30 billion spores each day (the equivalent of 350,000 spores per second). Because of their small size and tremendous numbers, the air we breathe is literally filled with fungal spores. This is necessary for the fungi to ensure that at least some of their spores will land on a suitable host plant or substrate.

Orange tendrils of thousands of sticky spores emerging from small fruiting bodies called pycnidia

Spores are specialized fungal structures that serve many purposes. First and foremost, spores are like fungal seeds that germinate under the right conditions, forming new hyphae that grow down into their host plant or substrate. Because they are so small, spores can be carried for hundreds or thousands of miles, allowing transmission of fungi over long distances. Some fungal spores are specially adapted to survive in water or in the mouths of insects. Some may be excreted in sticky secretions that allow them to adhere to insects or the legs of birds and small mammals. Others may be so small they can be translocated in a plant's vascular system. Many spores serve as a fungus's overwintering structure.



Microscopic spores often have distinct shapes and colors that are useful in identifying the fungal species

Some fungal spores can survive for years without germinating and still remain viable. Fungicides used to kill plant pathogens may be ineffective against spores because they are generally physiologically inactive or dormant. Only after they germinate will those compounds be effective.

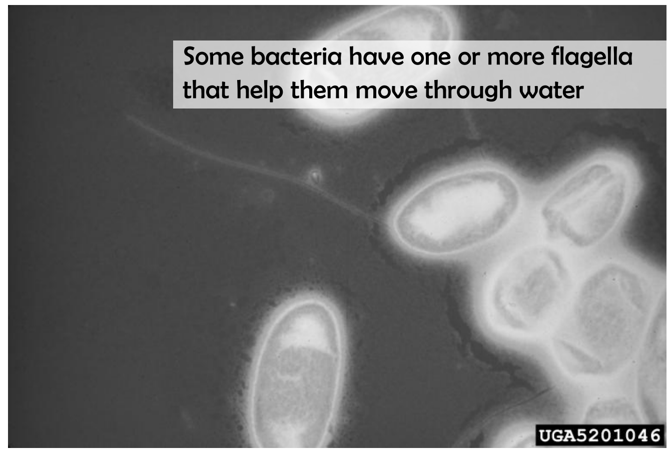
Bacteria

Bacteria are single celled organisms that lack a nucleus or organelles. They are much smaller than fungi, and are only visible under very powerful microscopes. There are several important tree diseases caused by bacteria but none are responsible for major losses of forest trees. However, bacterial diseases such as fire blight can have a significant impact in fruit orchards for example, and many such as wetwood and crown gall commonly affect landscape trees and ornamentals.

Bacterial leaf scorch can be a serious problem on landscape trees and ornamentals

Plant pathogenic bacteria are either spherical or rod-shaped, and some have one or more flagella that enable them to move through water. Bacteria multiply by division (or fission), which can occur in as little as 20 to 30 minutes. Therefore, bacterial populations can grow exponentially, meaning they have remarkable potential for rapid population growth. For example, single bacteria can give rise to a population of 2 sextillion bacteria in a single day!

Bacteria do not form spores, and therefore cannot be disseminated on the wind. Instead, most bacteria are spread in water droplets (e.g. in rain splash or wind-driven rain) or by insect vectors. Bacteria can also be spread from plant to plant on contaminated equipment used for pruning or cultivation. Unlike fungi, bacteria lack the ability to directly penetrate their host. Instead, they must enter through natural plant openings or wounds. As they spread through an infected plant, they release extracellular enzymes that degrade and digest plant cells, providing the nutrients necessary for growth and multiplication. Bacteria invade and colonize the spaces in between plant cells, and as populations grow rapidly, plant cells can be crushed by the vast number of bacteria and overwhelmed by high concentrations of bacterial enzymes. In addition, bacteria produce large amounts of gummy polysaccharides that clog the plant's vascular system and reduce water movement in the xylem. Toxins that prevent photosynthesis or other essential physiological processes may also be produced.

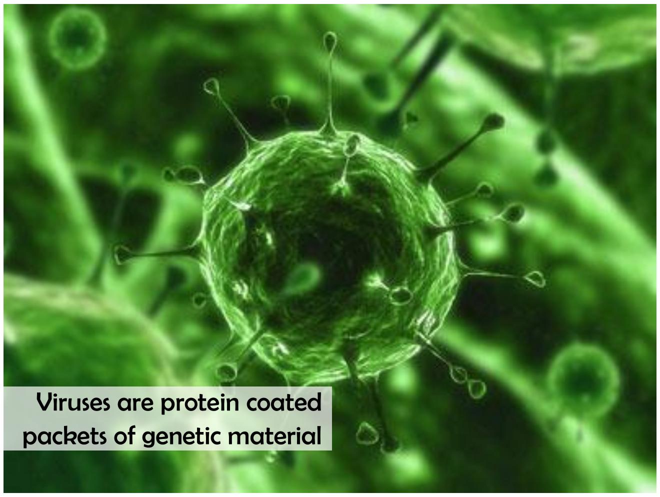


Some bacteria have one or more flagella that help them move through water

Bacteria cannot survive complete desiccation, and therefore, their survival is dependent upon a constant association with water. During the winter months, bacteria survive either within their host, in the soil, in seeds, or in their insect vectors. In the case of trees, many bacteria will survive at the edges of perennial cankers, within the vascular system, or in association with the roots. Some bacterial colonies will produce a gummy substance that prevents desiccation. Bacteria that cause foliage diseases usually perish after leaf fall because they cannot compete with other saprophytic bacteria and fungi that feed on the dead plant material. Instead, these bacteria overwinter in and are transmitted to new hosts in the spring by insect vectors.

Viruses

Viruses are extremely small pathogens that cannot be seen using normal light microscopes. Instead, they can only be seen using very powerful electron microscopes. Unlike other pathogens, viruses are not cellular organisms (in fact, most scientists do not classify them as living organisms), but are instead composed of a nucleic acids (DNA or RNA) protected by a protein coat. They come in a variety of shapes including rod-shaped, spherical, or crystalline. Because they are not classified as living organisms, they are simply named for the host they infect and symptoms they cause (e.g. tobacco mosaic virus). While most viruses are species specific, a few can cause disease in a wide range of hosts. This occasionally leads to some confusion in the naming of viruses because two distinct diseases in two different hosts may actually be caused by the same virus.

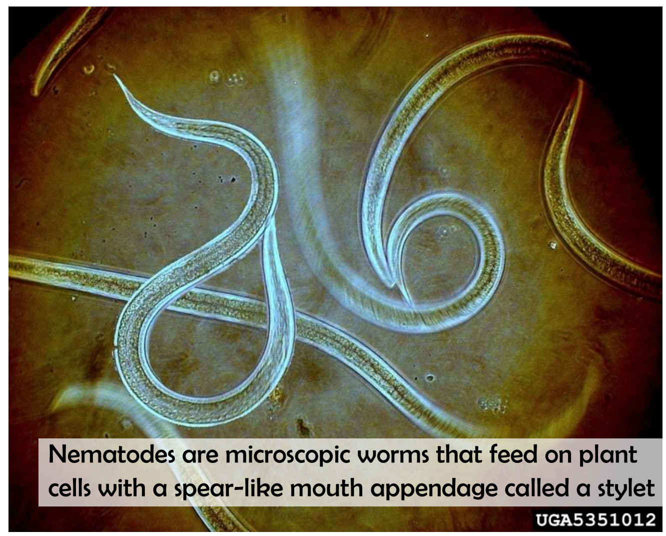

Viruses are protein coated packets of genetic material

Viruses are not true parasites because they do not feed on the cells of their host, and they lack an ability to replicate themselves. Instead, viruses are able to replicate and cause disease because of their ability to "reprogram" infected host cells to produce more viruses, and in the process, the host cell is damaged or killed. After entering a host, the virus injects its nucleic acids (usually RNA for plant viruses) into a host cell. The nucleic acids contain all of the genetic information necessary to replicate the virus in its entirety. The host cell does not distinguish the virus' genetic material from its own DNA, and as a result, it is essentially tricked into producing thousands of copies of new viruses. Eventually, the cell is overrun with the virus and is destroyed. The viruses are then released from the cell to attack surrounding cells.

Because viruses cannot survive for long outside of their host, their transmission is limited to insect vectors, seeds, and vegetative propagation of plant material. Insects feeding on an infected plant may harbor the virus in their digestive system for weeks or months, and can transmit the virus to every plant it feeds on during that time. Fortunately there are few serious tree diseases caused by viruses. Most tree viruses, such as elm mosaic virus, maple mosaic virus, ash ring-spot virus, and birch line pattern virus are minor nuisances. Others, like blackline disease of walnut caused by the cherry leafroll virus, can cause death.

Nematodes

Nematodes are the only animals that are considered to be plant pathogens. Nematodes are microscopic roundworms that posses a stylet (spear-like mouth appendage) that is capable of piercing the plant cell wall, injecting digestive enzymes, and sucking out nutrients. While nematodes lack the ability to multiply as rapidly as fungi, bacteria, and viruses, the damage they cause when piercing cell walls and injecting toxins can be devastating. A single nematode can destroy hundreds or thousands of plant cells during its lifetime, and each plant can be attacked by millions of nematodes at once. Parasitized plants are seldom killed, but may be stunted and weakened making them more susceptible to nutrient deficiencies, cold damage, drought, and other pathogens and insects.



Nematodes are microscopic worms that feed on plant cells with a spear-like mouth appendage called a stylet

Each generation of nematodes takes approximately 30 days to develop, and each female can lay 200 - 500 eggs. Nematode larvae resemble small adults and seek out feeding sites. During feeding, the nematodes mature into adults. Some plant parasitic nematodes become sedentary when mature, while others remain mobile and may continue to move from cell to cell to feed. Some species of nematodes have separate male and female individuals and are capable of sexual reproduction. If males do not exist or are rare in a species, the females are capable of **parthenogenesis**. Nematodes prefer warm soil temperatures and the length of the life cycle may be shortened considerably in warmer climates resulting in larger populations. Nematodes overwinter in all life stages, but populations may dramatically decline if the winter is particularly cold.

Nematodes are capable of moving for short distances through the soil, but movement is generally limited to a few feet annually. These organisms are not very strong and can only travel through porous soils or existing passageways formed by other soil-inhabiting organisms. Nematodes are also able to spread more rapidly through well cultivated and aerated soils because of the decreased soil density in these situations. Nematodes are easily transported in soil or on contaminated equipment, and can be spread rapidly in irrigation water and runoff. A few plant parasitic nematodes can be transmitted by insect vectors.

There are few serious tree diseases caused by nematodes; most nematode infections go undetected and only become problematic because they weaken the tree and make the host more susceptible to other stress agents. However, some nematodes such as the pine wilt nematode of Japanese black pine have drawn serious attention because of their ability to spread and cause disease in both introduced and native southern pine species.

Anthracnose

Overview: Anthracnose is a general term for a group of diseases on hardwoods that cause lesions on leaves, twigs, and fruits. Generally, these diseases are cosmetic and cause no serious damage to the tree (but there are some exceptions). There are many species of fungi known to cause anthracnose, but most only infect one or a few specific host species. Therefore, these diseases are named for the tree species on which they may be found (Fig. 1-6). For example, the most common anthracnose diseases in North Carolina include sycamore anthracnose, oak anthracnose, maple anthracnose, and dogwood spot anthracnose. Disease cycles and control strategies are similar regardless of the causal organism; therefore specific identification of the fungal species is not usually necessary. Dogwood anthracnose (not to be confused with dogwood spot anthracnose) is a serious disease of dogwood, and most often results in the death of the host; the following information does not apply to dogwood anthracnose (*see Dogwood Anthracnose*).

Causal Agent: Fungus (*Gloeosporium* spp., *Gnomonia* spp., and *Apiognomonia* spp.)

Hosts: A wide variety of hardwoods. Common hosts include oak, maple, sycamore, ash, walnut, and dogwood.

Symptoms / Signs: Symptoms vary with species, but in general the most obvious symptoms are the leaf lesions produced in the spring and expand throughout the summer. Lesions often begin as pale green or greenish-grey blotches, but then turn yellow, tan, reddish-brown, or brown. Often lesions have a distinct, colorful margin.

Lesions tend to begin along leaf veins (because the depressions along veins hold water for a longer period of time and spores tend to collect there), but often rapidly expand. Expansion often follows the soft tissues adjacent to veins, and may result in the coalescing of many lesions. Severely infected leaves may have a scorched appearance, becoming almost completely brown, wilted, or cupped. (*Note: drought symptoms and/or leaf scorch differ because the browning and wilting of leaf tissue begins at the leaf tips and leaf margins and progresses inward*).

Some trees respond to infection by prematurely shedding leaves (e.g. sycamore and ash), but others retain their leaves until normal leaf drop in the fall (e.g. oak). In sycamore, the fungus is able to grow out of leaves into adjacent twigs where it causes small cankers, shoot dieback, witches brooms, and/or deformed twigs.

Disease Cycle: Most anthracnose fungi infect their hosts during the spring, just as the first new leaves begin to expand; infections continue through the summer while environmental conditions are suitable. Spores are released from last year's diseased tissue (most commonly from fallen leaves). Spores can be spread by wind or rain-splash, and can only infect soft, succulent tissues such as new shoots, flowers, and fruits, but leaves are the most severely infected. The fungus obtains nutrients from plant cells, and in turn the cells are killed creating the leaf lesion. The lesion expands as the fungus spreads. During periods of sustained leaf wetness and cool temperatures, spores are produced from leaf lesions which can re-infect the same leaf or neighboring leaves. New infections usually do not occur after mid-summer. Most anthracnose fungi over-winter on the ground in fallen leaves, but some (e.g. sycamore anthracnose) can also spread from the leaves into adjacent shoots and over-winter in the twigs where they directly infect new leaves in the spring. Anthracnose fungi that spread from leaves into twigs may cause small cankers on woody tissues adjacent to the infected foliage.

Importance: Low. Anthracnose diseases are generally cosmetic and cause no serious damage to the tree. In years of severe disease, trees can become unsightly or even appear to be dying, causing great concern to homeowners.

Management: Management for anthracnose is usually not necessary as it causes no serious harm to the tree; however, aesthetic concerns may warrant an attempt to reduce disease severity. Plant trees on a wide spacing, keep the surrounding area clear of vegetation, and prune properly to improve air circulation within the crown. Raking and destruction of leaves in the fall is often very effective in reducing disease incidence the following spring. Fungicides are available for small ornamentals and shade trees.

Timeline: Infection occurs in early spring and may continue through early summer. Symptoms begin to develop shortly thereafter; some tree species may begin to lose infected leaves during the summer months.

Range: Statewide.

Fig. 1 Sycamore anthracnose

Fig. 2 Sycamore anthracnose

Fig. 3 Maple anthracnose

Fig. 4 Dogwood spot anthracnose

Fig. 5 Ash anthracnose

Fig. 6 Oak anthracnose

Brown Spot Needle Blight

Overview:	Brown spot needle blight is the most important disease of longleaf pine in the southeastern United States. The blight kills needles and slows growth, and is particularly important because it reduces seedling survival after planting and prolongs the period of time seedlings spend in the grass stage. Brown spot has little or no impact on trees more than 10 feet tall. Warm and wet weather favors this disease.
Causal Agent:	Fungus (*Mycosphaerella dearnessii*; syn. *Scirrhia acicola)*
Hosts:	Longleaf pine. Other southern pine species may become infected, but disease symptoms are usually not severe (*see Needle Cast*). Brown spot can cause significant damage to Scots and Ponderosa pines grown for Christmas trees, and on many ornamental and exotic pine species.
Symptoms / Signs:	Usually only seedlings (Fig. 1), small saplings, and the lower branches of larger trees are affected by brown spot (Fig. 3). Lesions on needles can appear at almost any time of year, but most commonly between May and October. Lesions start out as a small grayish-green spot; then turn yellow. As the lesion expands, the inside of the spot will turn brown and have a yellow or chestnut brown margin (Fig. 2). Lesions may expand all the way around the needle, or coalesce with other spots. Girdled needles will then turn brown and die from the tip of the needle down to the lesion, but the base of the needles will stay green. Needles with many spots will have a banded or mottled appearance. Eventually infected needles will be killed. Dead needles turn reddish-brown and then fall off. If infections are severe and happen for many consecutive years, seedlings may develop a needle-free stem with only the terminal bud surrounded by a tuft of green needles. Fruiting bodies that release spores are produced throughout the year and will appear as small black dots within lesions (Fig. 4).
Disease Cycle:	The brown spot fungus overwinters in the lesions of both living and dead needles, and produces both sexual and asexual spores in the South. Sexual spore production begins in early spring, peaks in late summer, and is halted during the winter months. Infections resulting from sexual spores are usually very mild. Asexual spores can be produced on both living and dead needles, and may be produced throughout the entire year. Many generations of asexual spores are produced annually, resulting in rapid disease buildup. Fruiting bodies produce and expel spores in warm wet weather, and infection can only occur when needles are wet. Asexual spores are spread by rain-splash, wind-driven rain, and contaminated equipment; only sexual spores are airborne. It generally takes 2-3 consecutive years of warm wet weather for severe disease epidemics to develop.
Importance:	Moderate. Brown spot needle blight kills needles, slows growth, weakens seedlings, reduces seedling survival after planting, and prolongs the period of time seedlings spend in the grass stage. Brown spot is a disease of importance and concern in seedling nurseries (Fig. 5).
Management:	Seedlings with resistance are available and should be planted when possible. Remove and destroy infected seedlings to reduce inoculum levels. Plant seedlings on a wide spacing and keep the surrounding area clear of vegetation to improve air circulation. Fungicide treatments (root-dip) for seedlings are available and can reduce brown spot incidence in new plantings. Avoid activities in the stand that may spread spores, especially during warm wet periods. Regular, low intensity, prescribed burns during the winter are the most effective way to control brown spot. Seedlings can survive the low intensity fires that destroy dead or infected needles harboring spores (Fig. 6 & 7). Fungicides are available for Christmas tree plantations.
Timeline:	Infection occurs mainly during warm wet periods throughout spring, summer, and fall. Symptoms develop within a few weeks of infection.
Range:	Longleaf pine in central and eastern North Carolina; a possible concern for Christmas tree growers in the western part of the state.

Fig. 1 Blighted needles

Fig. 2 Needle lesions

Fig. 3 Needle blight

Fig. 4 Fruiting bodies on needle


Fig. 5 Infected seedlings

Fig. 6 Pre-burn

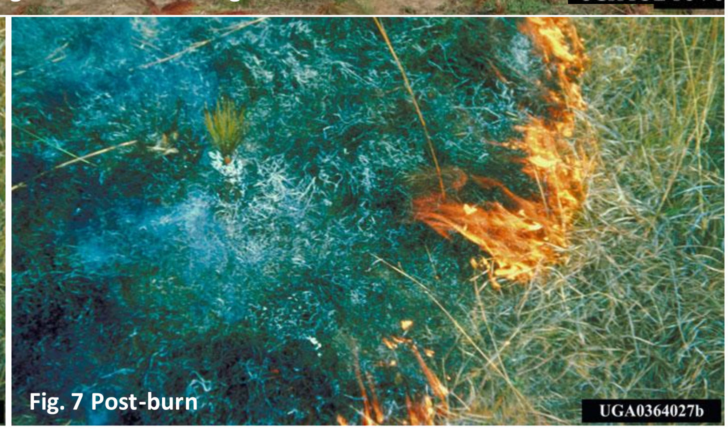


Fig. 7 Post-burn

Pine Needle Cast

Overview:	Needle cast is a general term for a group of foliar diseases on pine which cause small spots or lesions on needles, needle browning, needle death, and premature needle drop. For the most part, these diseases are cosmetic and cause no serious damage to the tree. There are more than 30 species of fungi known to cause needle casts, but only a few affect southern pines. Disease cycles and control strategies are similar regardless of the causal organism; therefore specific identification of the fungal species is not usually necessary.
Causal Agent:	Fungus (*Lophodermium* spp., *Ploioderma* spp., and others; the most common is *Ploioderma lethale* and *Lophodermium pinastra*).
Hosts:	All southern pines are susceptible with the exception of longleaf pine (*see Brown Spot Needle Blight*). Needle cast fungi are often very host-specific.
Symptoms / Signs:	Most needle cast fungi infect young, newly formed needles in the late spring or early summer; however, symptoms do not begin to develop until the following winter or early spring. The first symptoms of infection are small yellow spots on needles less than one year old. Yellow spots begin to turn brown and expand to form bands that surround the entire circumference of the needle (Fig. 3). In spring, the bands may turn pale yellow or grayish-brown. Tips of the needles and tissue between multiple bands will then turn brown and die; the base of the needle will often stay green. Infected needles (especially needles with completely dead tips) will begin to prematurely drop in the late spring and throughout the summer the year after infection occurs. On severely diseased trees, all needles from the previous growing season may be lost, leaving only new growth (Fig. 1 & 2). Heavily defoliated branches and shoots may not grow very much, therefore new needles produced will be very close together around the shoot tip, giving it a tufted appearance. Damage is most severe in dense plantings, on small trees, and on the lower branches of larger trees. Trees of all sizes can become heavily infected when weather conditions are suitable. Severe infections are often confused with bark beetle infestations. Needle cast is most commonly confused with the normal loss of old needles which typically occurs during the fall.
Disease Cycle:	In the late spring (April – May) sticky spores are produced on lesions from the previous year's infections. The spores are spread by splashing rain or may be carried by strong winds for short distances. Infection can only occur during wet and cool weather. The fungus grows slowly, and the first symptoms of infection will not be visible until the following spring. The fungus eventually expands to surround the entire needle, at which time small black fruiting bodies form within the lesion and produce spores (Fig. 4). There is only one disease cycle per year.
Importance:	Low. Needle cast diseases are generally cosmetic and cause no serious damage to the tree. In years of severe disease, trees can become unsightly or even appear to be dying, causing great concern to homeowners.
Management:	Management for needle cast is usually not necessary as it causes no serious harm to the tree; however aesthetic concerns may warrant an attempt to reduce disease severity. Plant pines on a wide spacing and keep the area clear of vegetation to improve air circulation. Destruction of diseased needles that have fallen is ineffective because these needles have already released their spores before falling to the ground.
Timeline:	Infection occurs in late spring or early summer. Symptoms begin to show the following year in late winter or early spring and through the summer. Normal shedding of older, non-diseased needles usually occurs in the fall.
Range:	Statewide.

Fig. 1 Needle cast

Fig. 2 Needle cast

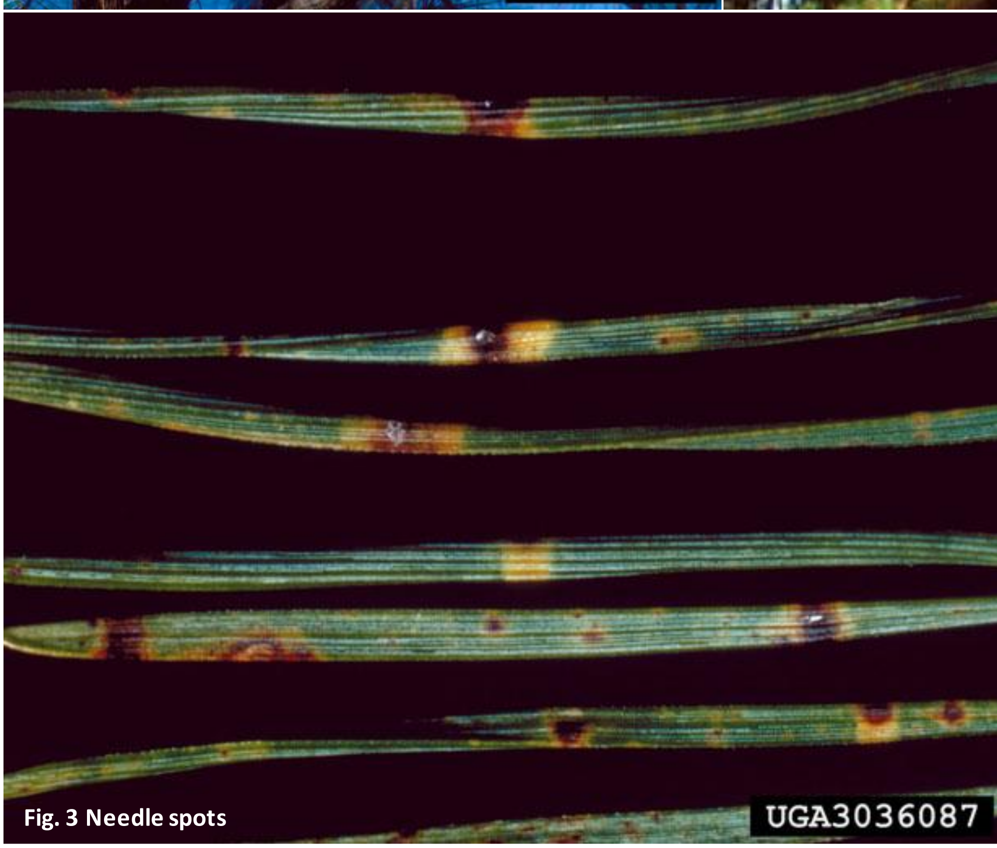


Fig. 3 Needle spots

Fig. 4 Fruiting bodies

Dogwood Anthracnose

Overview: Dogwood anthracnose is caused by a fungus that was introduced from Asia to the eastern United States in the late 1970's. Since its arrival in North Carolina, the disease has spread across much of the western part of the state and threatens to wipe out dogwoods at higher elevations. The disease is similar to many other anthracnose diseases because its airborne spores infect soft succulent tissue (especially leaves), but the dogwood anthracnose fungus can grow out of the leaves and cause girdling cankers (bark lesions) on branches and stems that eventually kill the tree.

Causal Agent: Fungus (*Discula destructiva*)

Hosts: Flowering dogwood and Pacific flowering dogwood. Several exotic dogwood species and cultivars (e.g. hybrids of Kousa x flowering dogwood) are now available that are resistant.

Symptoms / Signs: Shortly after infection in early spring, leaf lesions will appear on the upper leaf surface (Fig. 1). Spots will have a tan center with a purple or reddish margin; black spots (fruiting bodies) often appear on the underside of the leaf directly below leaf lesions. Lesions expand, often killing a large portion of the leaf (Fig. 2). Lesions that occur on leaf margins may expand and give the leaf a scorched appearance (Fig. 3). Leaves often droop and die, and can be retained on the tree through the winter months. Flower bracts can also become infected and may have lesions similar to those found on leaves (Fig. 4).

The fungus spreads out of the leaf causing cankers on stems and branches. Cankers are often centered on a small dead shoot or twig. Split bark and swelling may indicate the location of cankers (Fig. 5); removal of bark around these areas will reveal a tan to dark brown, often elliptical canker (Fig. 6).

Diseased trees will decline over several years; often lower branches will die first. Dogwoods will compensate for the loss of branches by producing lots of epicormic sprouts (suckers) on the stem or large branches, but these shoots are easily infected and are often the pathway for the fungus to enter and kill the main stem.

Dogwood anthracnose is often confused with dogwood spot anthracnose and drought; however, dogwood spot anthracnose does not cause cankers. Dogwood anthracnose is currently not known to be present in central and eastern North Carolina; in these regions dogwoods frequently suffer from drought-related decline or mortality and other common pests such as dogwood spot anthracnose and dogwood borer.

Disease Cycle: Asexual spores are produced from fallen leaves (infected the previous year) and stem cankers in early spring just as new leaves are beginning to expand. The spores are sticky and are easily spread by rain-splash, birds, and insects; spores are not easily spread by the wind. Infection occurs on soft succulent tissue such as leaves, flower bracts, and young shoots, but even thin bark can be directly penetrated under good conditions. Infection can only occur when leaves are wet for prolonged periods of time during cool weather. Additional spores are produced throughout the spring and summer when conditions are suitable. The fungus spreads from leaf tissue into adjacent twigs and branches where it parasitizes the inner bark and causes cankers. Cankers may eventually expand to girdle branches and stems. The pathogen overwinters in fallen leaves and cankers.

Importance: High. Dogwood anthracnose may potentially eliminate native dogwoods from the mountains of North Carolina.

Management: Plant trees on a wide spacing, keep area clear of competing vegetation, and prune trees regularly to improve air circulation. Dogwoods are an understory species, but planting them in partial sunlight will help keep leaves dry. Rake and destroy fallen or diseased leaves in the fall or winter, prune off branches with cankers, and remove epicormic sprouts to reduce disease incidence the following year. Remove severely diseased trees. Proper tree care is critical to keep trees healthy; water during dry periods (apply water to soil only), fertilize (avoid high nitrogen fertilizers), mulch around trees. Prune during hot and dry weather to avoid infection of wounds. Fungicides are available, but must be applied every 7 – 10 days during the spring and summer.

Timeline: Infection occurs in early spring and may continue through the summer during cool wet weather. Leaf symptoms begin to develop within a few weeks of infection; cankers can be seen year-round.

Range: Western North Carolina.

Fig. 1 Early leaf lesions

Fig. 2 Leaf lesions

Fig. 3 Leaf lesions

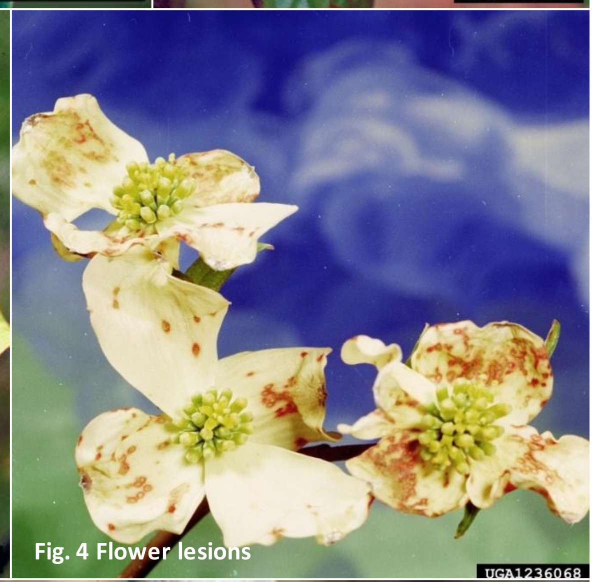


Fig. 4 Flower lesions

Fig. 5 Canker

Fig. 6 Canker with bark removed

Fusiform Rust

Overview:	Fusiform rust is a very common and potentially serious disease, especially of slash and loblolly pines. The disease causes swellings (galls) on stems and/or branches which deform trees, reduce growth, and weaken wood making the trees more susceptible to breakage in high winds or bark beetle attack. Fusiform rust is also a problem in seedling nurseries; seedlings can be killed by the disease or the disease can be transported from the nursery to new plantings. The fusiform rust fungus requires an alternate host (oak) to complete its life cycle.
Causal Agent:	Rust fungus (*Cronartium quercum* F. sp. *fusiforme*)
Hosts:	Slash and loblolly pines are highly susceptible. Pitch and pond pine are also common hosts. Longleaf pine is moderately resistant and shortleaf pine is highly resistant. The alternate host of *C. quercum* include many species of oaks; most commonly water, willow, laurel, blackjack, southern red, and turkey oaks. The disease only causes small leaf spots (lesions) on oak foliage.
Symptoms / Signs:	On pine, the most obvious symptom of infection is the formation of a spherical or spindle-shaped gall on a branch or main stem (Fig. 1). Galls are caused by chemicals released by the fungus that trigger abnormal and excessive wood growth. Pitch canker is commonly found in association with fusiform rust galls, so the gall may be pitch-soaked and/or exude sap (Fig. 6). Galls are often produced at the base of infected seedlings, though the swelling may be minor and often occurs at or below the soil line; these infections are frequently overlooked (Fig. 3). Fusiform rust will frequently kill the lower needles of seedlings in nursery beds. During cool spring months, bright orange spores are often produced on the gall surface (Fig. 1 & 7). These aeciospores are blown off by the wind and serve to infect oak leaves. On oak, symptoms are limited to small leaf spots that may be chlorotic or necrotic. Often leaf spots are not noticed. Easier to observe are bright orange spores (urediospores) produced on the underside of the leaf (Fig. 2).
Disease Cycle:	*C. quercum* has five different types of spores, and requires two or more years to fully complete its life cycle (Fig. 5). Bright orange aeciospores are produced on the surface of galls during the cool spring months (February-April). Aeciospores are blown on the wind and infect the leaves of susceptible oaks, where they cause a small leaf spot. After one week, bright orange urediospores are produced on the underside of the leaf, which serve to re-infect the same leaf or nearby leaves to build up inoculum levels. A week later, small brown teliospores are also produced on the underside of the leaf. Teliospores do not directly infect any plants, rather they remain attached to the leaf surface or may be blown off into leaf litter. These spores can survive for several months, until conditions are just right (60-80ºF, 95-100% RH), at which time they germinate and produce basidiospores. The basidiospores are also blown by the wind, back to nearby pines where they can infect needles, young shoots, and thin bark. The fungus grows a short distance into the branch or stem, where it produces plant growth-regulating compounds that cause the surrounding plant cells to rapidly divide and enlarge, forming a gall. If conditions are right during the first year of infection, pycniospores in orange droplets are produced on the gall surface (September - February) and allow sexual reproduction of the fungus.
Importance:	High. Fusiform rust can be devastating in plantation and seedling nursery settings.
Management:	Avoid planting susceptible species in areas with a historically high incidence of fusiform rust. Relatively resistant loblolly pine seedlings are available, but disease may still occur and/or be less severe. Close spacing in pine plantations will allow for some mortality while maintaining adequate stocking levels, and encourage infected branches to break off before the fungus reaches the main stem. Branches with galls within 8 inches of the main stem should be pruned off (Fig. 4). Avoid practices that over-stimulate growth such as fertilization, as this has been shown to increase the incidence of rust.
Timeline:	Orange aeciospores are produced on the gall surface in early spring; followed by orange urediospores on oak leaves. Infection of pines by basidiospores occurs during the late spring / early summer months.
Range:	Statewide, particularly central and eastern North Carolina.

Fig. 1 Gall with aeciospores

Fig. 2 Urediospores on oak

Fig. 3 Infected seedlings

Fig. 4 Branch gall

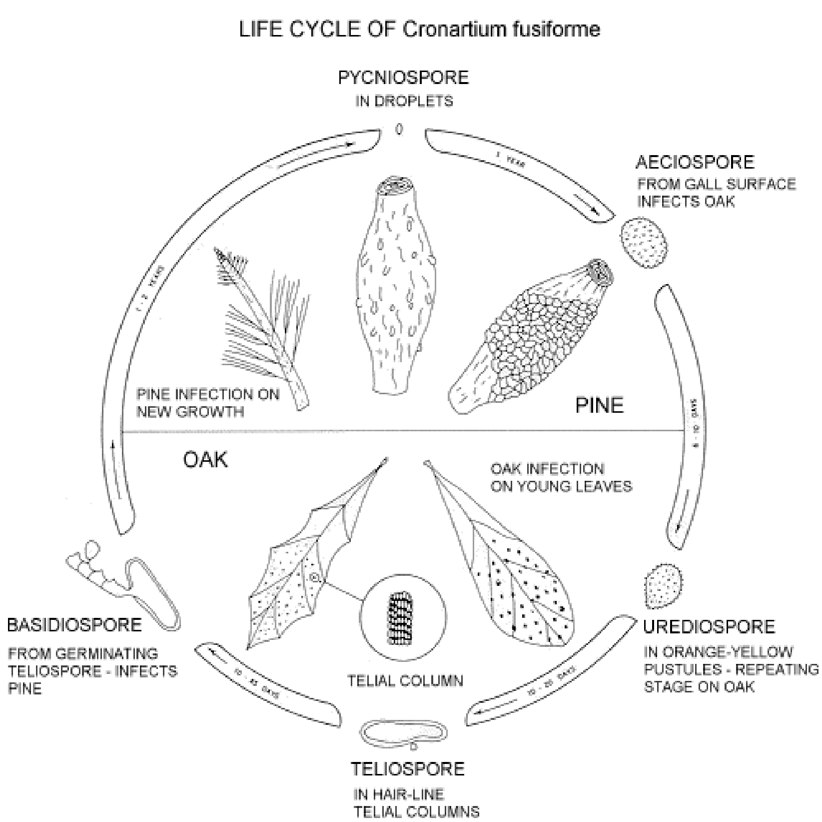


Fig. 5 Fusiform rust disease cycle

Fig. 6 Stem Gall

Fig. 7 Stem Gall

Hypoxylon Canker

Overview: Hypoxylon canker is a secondary disease of many hardwood species that affects trees that are already severely stressed by some other cause. There are many *Hypoxylon* fungi, most of which are strictly wood-rotters, but some species can become pathogenic and kill stressed trees. The disease is most common in large mature trees, especially after prolonged periods of severe drought. Hypoxylon canker is a common contributor to the oak decline disease complex. (*Note: there is a separate, unrelated disease of aspen also called Hypoxylon Canker*).

Causal Agent: Fungus (*Hypoxylon* spp.; most commonly *H. atropunctatum* and *H. mediterranea*)

Hosts: Most common in oaks (especially red oaks, but white oaks are also susceptible). Also found in hickory, maple, beech, sycamore, birch, elm, walnut, and many others.

Symptoms / Signs: Symptoms may initially resemble those of oak decline: delayed bud break; undersized leaves; chlorotic, scorched, or wilted foliage; and branch dieback progressing from the top of the tree downward.

The easiest way to identify Hypoxylon canker is by the large spore-bearing mats (stromata) produced beneath the bark of diseased trees. These stromata usually appear the year following drought (or other severe stress), but may appear within a few months. Stromata will grow in size and eventually rupture the bark; patches of sloughed-off bark range from a few inches to several feet in long. In severe cases, almost the entire tree will lose its bark and be covered in the fungal mats. Stromata are initially tan, brown, or black (Fig. 1 & 2); after all of the spores are released the mats turn grey (Fig. 3 & 4). Trees die quickly, if not already dead, shortly after stromata production.

Disease Cycle: Spores of *Hypoxylon* fungi are airborne and are very common. Even when little or no disease is present in the forest, the fungus is present as a wood-rotter and feeds on dead wood. Trees are most often infected at a very early age through small wounds and natural openings. It is believed that most oaks and other susceptible species have *Hypoxylon* infections, but disease does not develop until trees become severely stressed. In healthy trees, the fungus forms small colonies beneath the bark and cause very little (if any) observable damage. The natural defenses of healthy trees easily keep the infection contained. However, when trees become water stressed, the *Hypoxylon* colonies begin to grow rapidly in the water-depleted sapwood and inner bark. The fungus attacks these tissues, forms stromata, and the bark is sloughed off. With little or no remaining functional vascular system, trees die quickly once the invasion begins. The fungus then invades the remaining wood; initially turning sapwood brown, it causes a yellowish-white decay with black lines.

Importance: Moderate. Following drought, Hypoxylon canker may be responsible for the death of many large mature trees. Valuable shade trees, if not properly cared for, are commonly lost due to Hypoxylon canker.

Management: Few management options are available. Proper tree care is critical. Provide trees with adequate water (at least 1-2 inches per week below the entire drip line), fertilizer if necessary (avoid nitrogen-rich fertilizers), and room to grow with little competition from neighboring trees or understory. Provide a thin layer of mulch (1-3 inches) below as much of the drip line as possible. Avoid planting susceptible species on dry sites.

Timeline: Symptoms usually develop in the year after a drought, but may develop within a few months if conditions are severe. Symptoms most often first appear during late spring and throughout the summer.

Range: Statewide.

Fig. 1 Stromata with spores

Fig. 2 Stromata with spores

Fig. 3 Stromata after spore release

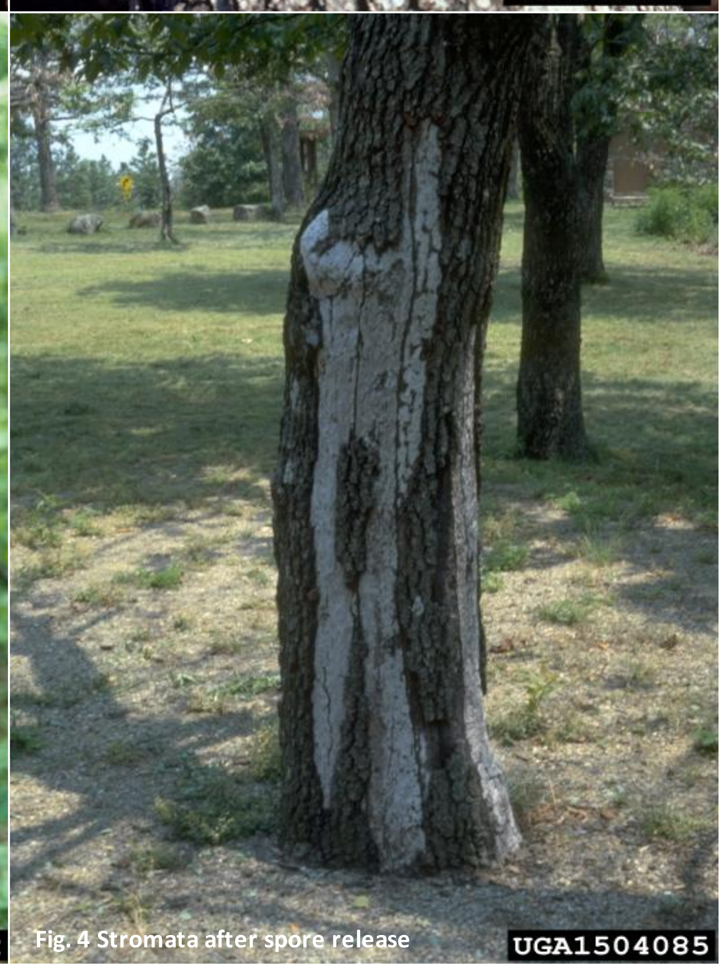


Fig. 4 Stromata after spore release

Pitch Canker

Overview:	Pitch canker is caused by a fungus that creates a resin-soaked lesion in the inner bark and outer sapwood of southern pine species. Most often a nuisance, the disease can deform trees, suppress growth, and kill branches or occasionally entire trees. Contrary to popular belief, the pitch canker fungus is not carried or transmitted by insects; rather the fungus infects trees through wounds including but not limited to insect feeding sites.
Causal Agent:	Fungus (*Fusarium circinatum*)
Hosts:	All southern pine species are susceptible. It is most common in loblolly, slash, and shortleaf pines.
Symptoms / Signs:	The primary symptom of pitch canker is a resin-soaked canker (lesion) (Fig. 2). Small branches or twigs that are infected are often completely girdled and killed (Fig. 3); killing of the terminal or uppermost branches is also very common (Fig. 1 & 6). The fungus can also infect and cause perennial cankers on large branches, main stems (Fig. 4), and even exposed roots. Flowers, cones, and seeds can also be killed. Diseased bark will turn tan to chocolate-brown, and the underlying sapwood becomes yellowish in color and heavily pitch-soaked. Resin-soaking may extend all of the way to the pith in severe cases. Bark remains on the canker and sap will frequently flow out of the lesion and dry on the branch surface or on other understory plants. Pitch canker commonly occurs in close-association with fusiform rust galls. Needles around cankers usually turn yellow, then brown and are killed; they are retained on the tree by dried sap. Green shoots may wilt and die, giving the appearance of a shepherd's crook (Fig. 5).
Disease Cycle:	Asexual spores are usually produced from an individual plant only once a year, but the timing varies widely based on climate, host species, and host age. Therefore spores are usually present year-round (particularly during cool and wet weather). The spores are produced on small pink fruiting bodies on and adjacent to cankers. The spores are easily carried by the wind and may travel for many miles, but must land on a fresh wound (less than a few days old) for infection to occur. Wounds are most often produced by hail, wind, falling cones, equipment, and insects such as twig and cone feeders. The fungus feeds on the inner bark and the tree responds by flooding the tissue with sap to prevent the fungus from spreading further.
Importance:	Moderate. Usually pitch canker is of little concern. Trees are easily able to overcome minor infections of small branches and twigs. Occasionally large epidemics of pitch canker occur, resulting in deformed, stunted, highly stressed, or even dead pines. It can be a serious disease in seedling nurseries. There are quarantines and regulations in effect to prevent movement of this disease to other countries.
Management:	Little can be done to prevent or treat pitch canker. Avoid wounding trees, especially during cool wet weather. Proper tree care is important to help trees overcome infection. Use of fertilizers rich in nitrogen is often accompanied by a large increase in pitch canker incidence. Excessive nitrogen is responsible for the high incidence of pitch canker near exhaust fans of chicken and hog houses.
Timeline:	Symptoms most often appear between fall and spring. Infections occur year-round during cool wet weather.
Range:	Statewide.

Fig. 1 Killed terminal shoots

Fig. 3 Severe infection

Fig. 2 Resin-soaked canker

Fig. 6 Top kill

Fig. 4 Stem canker

Fig. 5 Killed shoot

Wetwood / Slime Flux

Overview: Wetwood is not a serious disease of trees, but is very common and often of great concern to homeowners. Wetwood is a general term for a water-soaked condition of the wood caused by bacteria that occurs naturally in many tree species. Occasionally when pressure builds up in wetwood, wetwood fluids and gases may be released onto the surface of affected stems and limbs. This is known as slime flux. A separate condition known as alcoholic slime flux is also common in many trees, but is unrelated to wetwood. Alcoholic slime flux occurs when fermentation (due to a variety of microorganisms) occurs in sealed cracks and wounds; occasionally gas and ethanol can be released from these as well.

Causal Agent: Bacteria (mostly anaerobic)

Hosts: Found very commonly in elm. Also found in maple, oak, sweetgum, sycamore, willow, hemlock, and fir.

Symptoms / Signs: Wetwood is mostly an internal condition that cannot be detected from the surface. Wood is heavily water-soaked and usually discolored (color varies from pink, yellow, green, brown, red, and black). Pockets of wetwood are usually irregular in shape; the wood often has a sour smell. The condition usually starts in the main stem, but may spread to larger limbs. It is often associated with old wounds, but this is not always the case, and can be found in both heartwood and sapwood. Occasionally wetwood can cause leaf chlorosis, wilting, minor defoliation, and even dieback.

Wetwood is usually noticed when fluid pressure builds up and breaks through the outer sapwood and bark (wetwood slime flux). The fluid will have a sour smell, and leave grey, brown, or black streaks down the bark (Fig. 1 & 4). Alcoholic slime flux will always be associated with an old crack, wound, or cavity (Fig. 3). The flux is colorless (though may be frothy white under pressure) and has a fermented odor. It will also discolor bark. Both wetwood slime flux and alcoholic slime flux are highly attractive to insects such as bees, wasps, ants, butterflies, and moths (Fig. 2). Fluid darkens when exposed to air and may be produced so excessively as to flow or pool on the ground below. Various fungi and bacteria colonize the fluids once exposed to oxygen, and therefore the ooze may become slimy and foul smelling.

Disease Cycle: Wetwood develops due to a bacterial infection and is promoted by a tree's natural physiology. Bacteria enter trees (often when young) through wounds and natural openings and spread through the sapwood. It is unknown what causes the formation of wetwood; initially the accumulation of organic acids, ions, and alcohol draw large amounts of water into the wood, but whether these products are produced by the bacteria, the tree, or a combination of the two is not known. Wood becomes heavily water-soaked (the surrounding wood will be unusually dry) and anaerobic bacteria frequently colonize the area and feed on the cells of the sapwood. The by-products of bacterial activity cause the wood to discolor, have an elevated pH, and smell; pressure of these by-products may cause fluid and gas to escape through the surface.

Alcoholic slime flux occurs when microorganisms (fungi and bacteria) invade cracks, wounds, or cavities and begin to ferment sap and dead wood. Ethanol and gases are produced during the fermentation process, which causes pressure to build. Excess pressure is relieved when liquid and gas is expelled through the surface.

Importance: Low. Wetwood and slime flux do little if any harm to affected trees. Minimal living tissue is destroyed in wetwood; none in alcoholic slime flux. Wood is not rotted or structurally weakened in any way; in fact, wetwood has antibiotic properties and is highly resistant to rot/decay. The disease is mainly a nuisance to homeowners, but does reduce lumber value because it requires more time and energy to dry adequately.

Management: There are no preventative measures for wetwood / slime flux. Fluids can be washed from the bark surface with a mild soap solution. Do not attempt to cut into or drain pockets of wetwood or alcoholic slime flux; introduction of oxygen into these cavities will allow wood-rotting fungi to invade and severe decay can occur.

Timeline: Symptoms usually appear during the spring or summer, but can occur in the fall.

Range: Statewide.

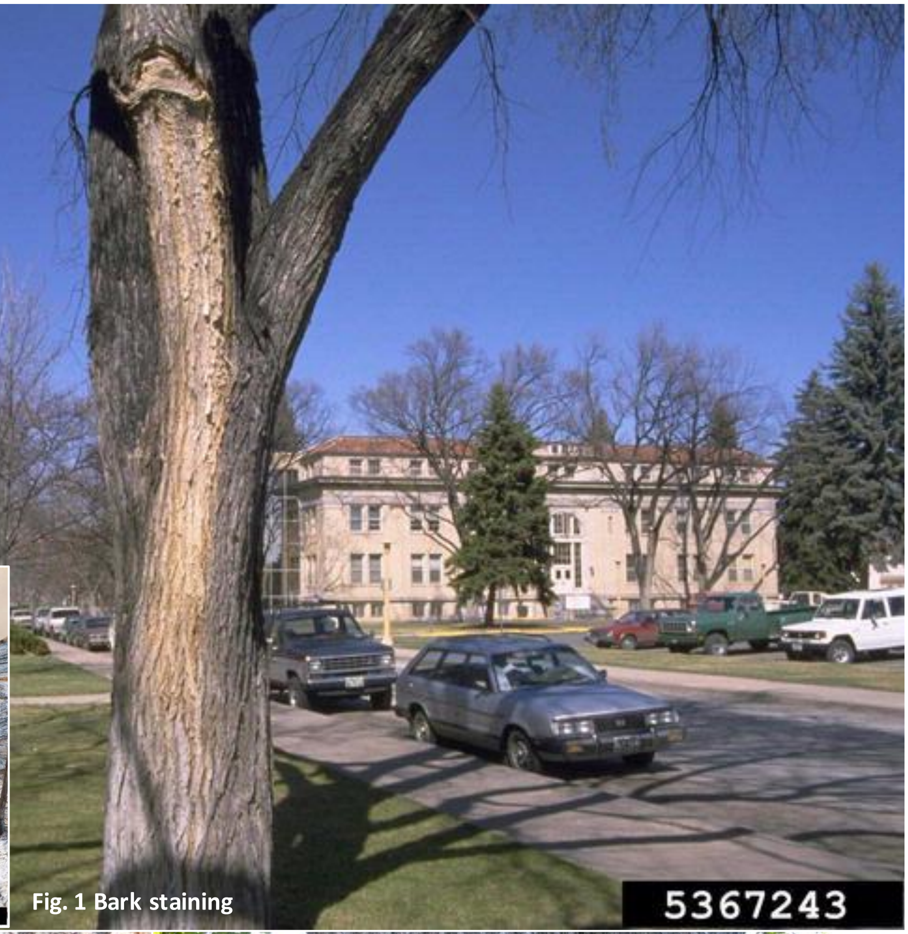


Fig. 1 Bark staining

Fig. 2 Attracted insects

Fig. 3 Bark crack

Fig. 4 Slime flux

White Pine Blister Rust

Overview: White pine blister rust is the most important disease of eastern white pine (and other five-needled pines) in the United States. The white pine blister rust fungus was introduced from Asia in the early 1900's, and causes swollen cankers that eventually girdle entire branches or stems resulting in tree death. The disease is most severe in seedlings and saplings, but mature trees are also susceptible. The white pine blister rust fungus requires an alternate host (*Ribes* spp. in including gooseberry and currant) to complete its life cycle.

Causal Agent: Rust fungus (*Cronartium ribicola*)

Hosts: All five-needled pines (five needles per fascicle) are susceptible. In North Carolina, eastern white pine is the only native susceptible pine species. Alternate hosts are in the genus *Ribes* and include gooseberry and currant.

Symptoms / Signs: Small yellow or red needle spots are usually present on needles at the point of infection (Fig. 3) but are difficult to see. Roughly diamond-shaped cankers (bark lesions) develop a few years after infection. Cankers may be found on the branches or main stem, and are often centered on a small dead twig through which the fungus spreads after infection (Fig. 4). The first symptoms observed are usually individual flagging branches killed by cankers. Cankers that do not completely girdle the stem may not be swollen, rather these lesions tend to be elliptical or elongated with rough bark and a resinous center. Bark around lesions may be brownish-red (Fig. 8). Cankers that girdle the stem completely may become slightly swollen and are usually very resinous (Fig 2). Swelling may develop on the apical (branch tip) side of the lesion because the products of photosynthesis are blocked by girdling cankers and cannot be translocated from the branch to the stem or roots. In late spring or early summer, aeciospores may be visible in yellow-orange blisters on the canker surface (Fig. 6).

Girdling cankers will eventually kill the branch, or if on the stem, the entire tree. Infection in seedlings or small trees usually results in death because the fungus can easily travel the distance from needle to main stem. Infections in mature trees may only result in dead or dying tree tops or large branches; the bottom of the tree occasionally survives the infection (Fig. 7).

Disease Cycle: *C. ribicola* has five different types of spores, and requires three to six years to fully complete its life cycle (Fig. 5). Infection of pine by basidiospores occurs in late summer or early fall during extended periods of cool wet weather. Basidiospores can only travel a couple of miles (usually much less) from the alternate host. Within a few weeks of infection, a small yellow or red spot will appear on the needle surface at the point at which the fungus entered the plant. Unless the tree responds to the attack by shedding infected needles, the fungus will grow out of the needle and into the twig or branch within one year of infection. The fungus continues to spread through the inner bark and living cells of the sapwood at a rate of approximately three inches per year. Infected bark begins to swell due to rapid cell division and growth induced by chemicals released by the fungus. Spermagonia (which produce spores called spermatia) allow the fungus to sexually reproduce and are usually formed on the canker surface (late summer or early fall) with one or two years of infection. Yellow-orange aeciospores (Fig. 1) are also produce on the lesion (in spring) and can be blown many miles to infect the alternate host *Ribes*. Yellow-orange urediospores are produced on the underside of *Ribes* leaves within two weeks, and re-infect the same leaf or neighboring leaves to build up inoculum levels. In the late summer or early autumn, teliospores are produced on the underside of *Ribes* adjacent to urediospores infections. During wet weather, teliospores germinate to form basidiospores which re-infect pine.

Importance: High. This disease wiped out most of the mature white pines in the U.S. during the early – mid 20th century.

Management: Resistant white pine seedlings are becoming available. Eradication of *Ribes* is usually not effective and is no longer practiced. Avoid regenerating pines in small openings more prone to dew/condensation on needles. Prune lower branches (more prone to infection) and infected branches to prevent spread to main stem.

Timeline: Infection of pines occurs in late summer / early fall. Cankers can be seen year round, but produce yellow-orange aeciospores in the spring.

Range: Mountains of North Carolina; within the natural range of white pine where cool and wet conditions are prevalent in the fall.

Fig. 1 Urediospores on *Ribes*

Fig. 2 Dried sap

Fig. 3 Needle lesion

Fig. 4 Canker

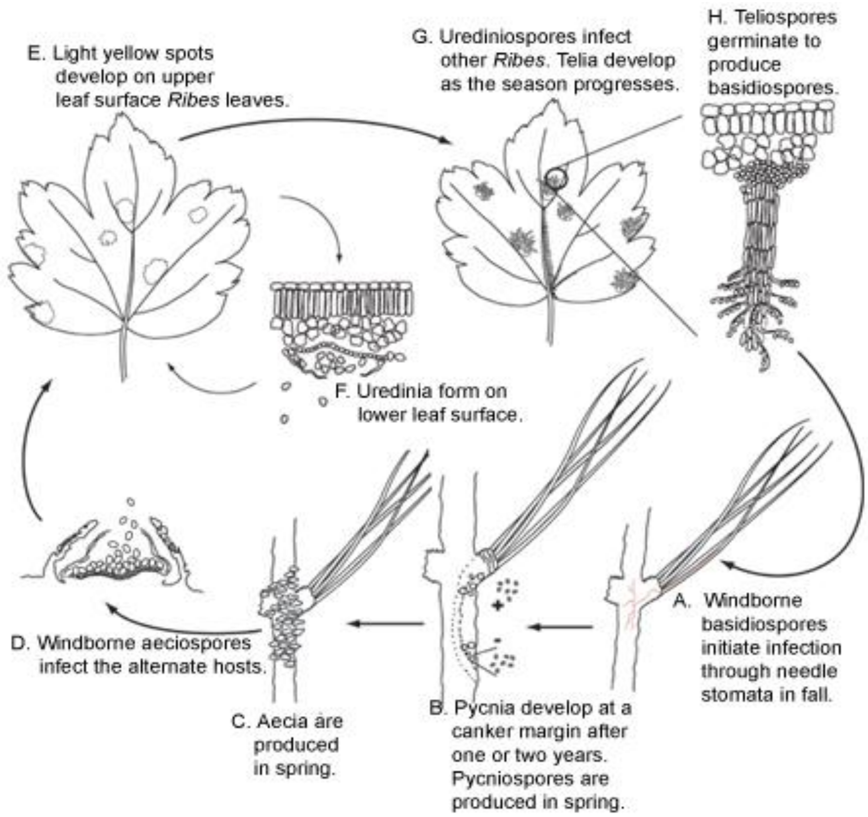


Fig. 5 White pine blister rust disease cycle

Fig. 6 Aeciospores

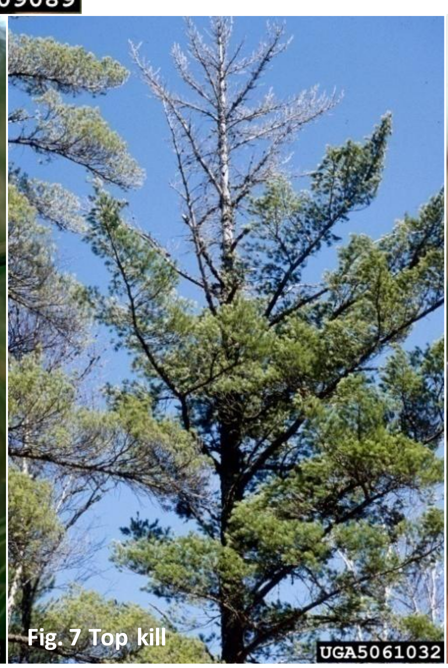


Fig. 7 Top kill

Fig. 8 Resinous canker

Beech Bark Disease

Overview: Beech bark disease was first reported in Canada in the 1920's; since that time it has spread south to some of the western-most counties of North Carolina. It is caused by a fungus and spread by a scale insect; both of which were introduced from Europe. The scale insect itself causes serious damage to the tree, and the fungus causes cankers which eventually coalesce to cause severe decline and death. The disease poses a serious threat to mature beech trees, but young trees and stump sprouts are not affected.

Causal Agent: Fungus (*Neonectria* spp. including the native species *Nectria galligena* and the exotic species *Nectria coccinea var. faginata*) and beech scale (*Cryptococcus fagisuga*)

Hosts: American and European beech.

Symptoms / Signs: Beech scale attacks and forms colonies on large branches and the stem (small braches and twigs are not attacked). The adult is less than 1/16 of an inch long, yellow, round, and slightly elongated, and soft-bodied. Woolly wax filaments are produced by sedentary adults and cover the colonies which begin as scattered white tufts in cracks and crevices. Colonies frequently start on the north side of trees; as the colonies grow they form broad white sheets on the trunk (Fig. 1 & 2). Minor bark necrosis is directly caused by scale infestations, and colonies disappear from killed bark.

After scales become established on the tree, the beech bark fungi begin to attack the tree through the wounds caused by the feeding insects. The fungus kills the inner bark tissue causing an expanding canker with an orange margin (Fig. 5); the edges of the canker will be rough-barked due to the production of callus tissue. Slimy red-brown fluid frequently leaks from cankers (Fig. 4). Dead bark falls off of lesions after a few years. Trees may decline and die over a period of several years; occasionally decay may become so severe in girdled trees that stem breakage occurs before the tree dies completely (Fig. 3). Clusters of small red fruiting bodies are produced on and around cankers in the fall (Fig. 7). Some trees possess various degrees of resistance; cankers on these trees may be limited in size (Fig. 6).

Disease Cycle: Scale insects reproduce once a year; male beech scales are not present in North America, therefore the scales reproduce parthenogenetically. Eggs are laid on the surface of branches and trunks; shortly thereafter the small mobile crawlers emerge. Crawlers may be blown on the wind for several miles; they are mobile for a few days before permanently attaching themselves to the bark and feeding on the nutrient-rich sap of the phloem. As they age, they produce a white waxy protective coating. The scales weaken the tree and kill localized sections of bark allowing infection by *Neonectria* species. Sexual spores of the fungus are produced in the fall through spring on clusters of small red fruiting bodies during wet weather; asexual spores are also produced in late summer and fall. Spores infect the tree through scale feeding sites and cracked dead bark. The pathogen kills the inner bark and outer sapwood; cankers expand most rapidly during cool fall weather. The native *Nectria galligena* usually attacks scaleinfested trees first, but is then displaced by the exotic *Nectria coccinea var. faginata*.

Importance: High. Beech bark disease is a serious threat to mature beeches. After the disease passes through an area, sprouts and seedlings begin to grow again and are not attacked by the scales. Some large trees, which may possess various levels of resistance, may also survive but are usually disfigured. The long term impact of the disease is not known.

Management: Insecticides are available to kill scales and prevent infection by the beech bark pathogens. Promote overall tree health by using proper tree care techniques. Please report suspected cases of beech bark disease to NCFS Forest Health staff.

Timeline: Red fruiting bodies are produced in the fall, and infections occur from fall through spring. Crawlers are active in mid-summer. Cankers expand most rapidly in the fall.

Range: Western North Carolina; potentially statewide.

Fig. 1 Adult scales

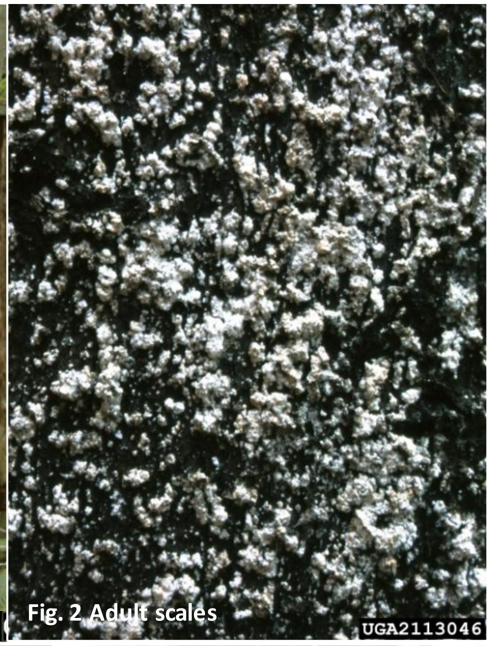


Fig. 2 Adult scales

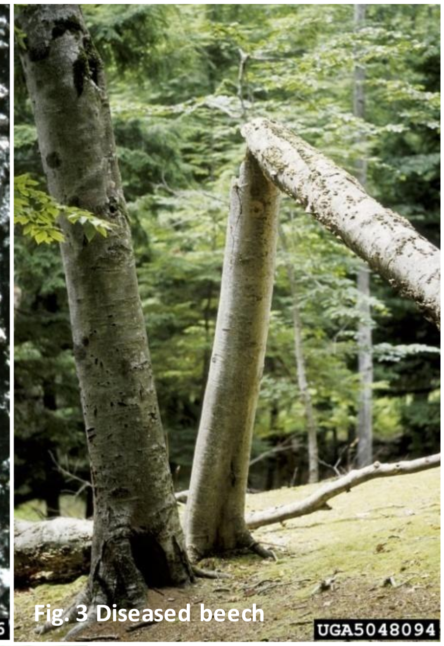


Fig. 3 Diseased beech

Fig. 4 Bleeding canker

Fig. 5 Canker

Fig. 6 Deformed tree

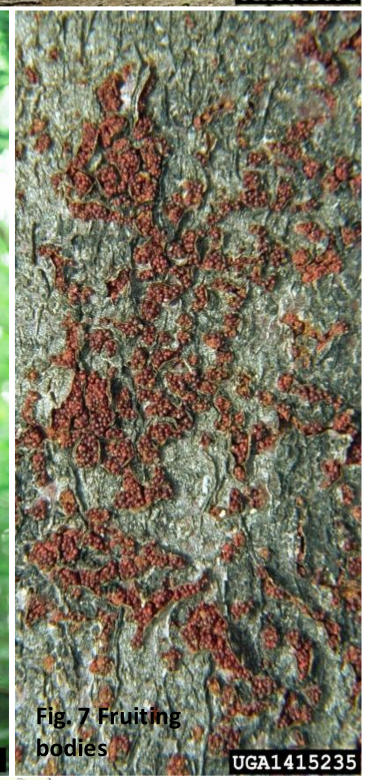


Fig. 7 Fruiting bodies

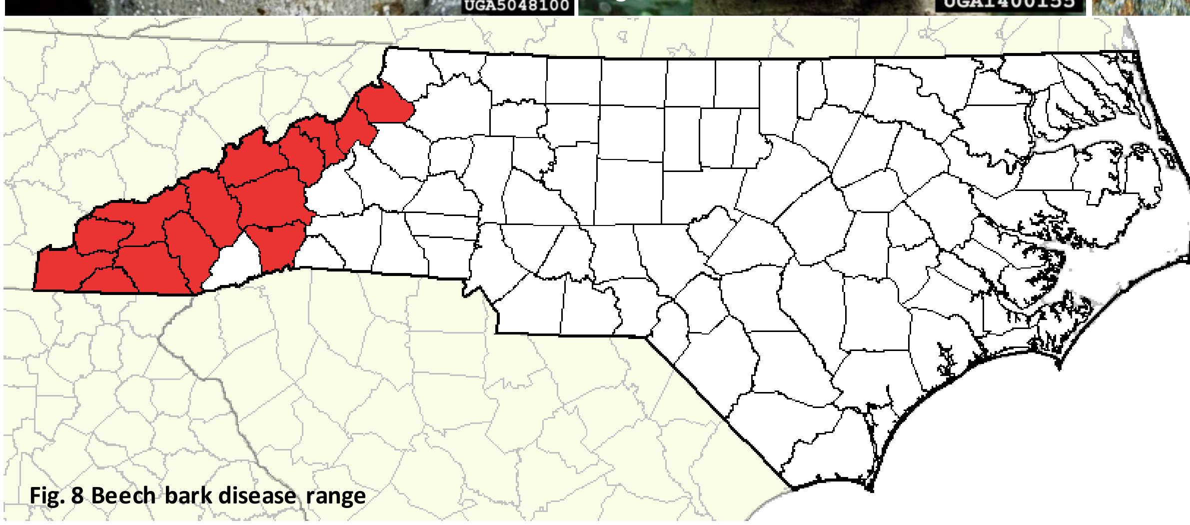


Fig. 8 Beech bark disease range

Sudden Oak Death

Overview:	First discovered in 1995, sudden oak death has become a serious problem in northern California and Oregon. The pathogen is currently killing tanoaks, coast live oaks, and California black oaks in these western states (Fig. 4) and threatens the vast oak forests of the eastern United States. The name "sudden oak death" is somewhat of a misnomer, as trees often die over a period of several years. The disease causes severe girdling cankers on the main stem and large branches. The pathogen is known to infect hundreds of plant species, most of which show no obvious symptoms. Therefore, there is a serious risk that the pathogen will be introduced to new areas on infected landscape plants shipped from nurseries in the Pacific Northwest.
Causal Agent:	Stramenopile; a fungus-like organism also known as a water mold (*Phytophthora ramorum*). Origin is unknown.
Hosts:	Oak species are the most severely affected by the pathogen. In the east, red oaks are the most susceptible. The pathogen can infect and survive in hundreds of other woody and herbaceous plant species, many of which show few symptoms. Rhododendron is an important understory host that is frequently shipped from the west coast for ornamental purposes. The name "sudden oak death" is only used to refer to the disease caused in oaks.
Symptoms / Signs:	On oaks and tanoak, cankers develop in the inner bark and outer sapwood (Fig. 1). Cankers rapidly expand to girdle infected trees, cutting off the tree's supply of water and nutrients. Black or reddish ooze is often observed from stem cankers. Bleeding cankers will stain the surface of the bark (Fig. 2); ooze may be difficult to see if it has dried or has been washed off by rain, but the dark staining will remain (Fig. 3). Black "fungal" lines may be visible in the sapwood beneath cankers, especially in dead trees. Leaves will turn from green to pale yellow to brown within a few weeks of girdling; succulent shoots may also wilt (Fig. 7). Crown dieback begins in the upper branches shortly thereafter (Fig. 6). Infected trees may survive for one to several years. Declining or dead trees may be attacked by secondary insects or pathogens such as ambrosia beetles, bark beetles, twolined chestnut borer, Hypoxylon canker, and Armillaria root rot. Symptoms on other woody and herbaceous plant species vary, but infection occurs mostly on leaves and shoots. Small or large leaf lesions may be present (Fig. 5); premature leaf drop, shoot dieback, wilting, or death may occur.
Disease Cycle:	Spores of *P. ramorum* are rarely produced on trees with cankers. Instead, it appears that most inoculum for the disease is produced from leaf infections on hosts other than oak. Therefore, although infections in foliar hosts do not often result in severe disease, inoculum from these plants is responsible for infecting and killing oak trees. Spores produced on foliar hosts are long-lived, can survive drying and cold temperatures, and are transported in rain splash, in flowing water, on the feet of animals and people, and on contaminated equipment, soil, and nursery plants. Spores that splash onto trees can infect the stem by directly penetrating the bark.
Importance:	High. Sudden oak death is a serious threat to eastern oak forests. The implications of the disease being introduced are unknown. Several nurseries in North Carolina have tested positive for the disease on infected nursery plants shipped from areas where the disease occurs. The pathogen has not been detected on plants outside of these nurseries as of 2011.
Management:	There are no known cures or preventative measures for sudden oak death. Large scale eradication of susceptible hosts in areas where the disease occurs has only been partially successful in slowing the spread. It is critical to prevent the introduction of the disease on infected nursery plants. Purchase plants from local sources when possible; do not purchase or plant diseased or unhealthy plants. Report any suspected cases of sudden oak death to the NCFS Forest Health staff immediately.
Timeline:	Unknown. Foliar symptoms will only be observed during the growing season (with the exception of evergreens such as rhododendron). *P. ramorum* appears to prefer cooler temperatures than other *Phytophthora* species; infections may occur more frequently in spring or fall.
Range:	Statewide risk. The disease of oaks has not been confirmed in North Carolina as of 2010, but the pathogen has been detected in several nurseries within the state on other plant species.

Fig. 1 Canker

Fig. 2 Bleeding canker

Fig. 3 Stained canker

Fig. 4 Sudden oak death epidemic in Oregon

Fig. 5 Leaf lesion

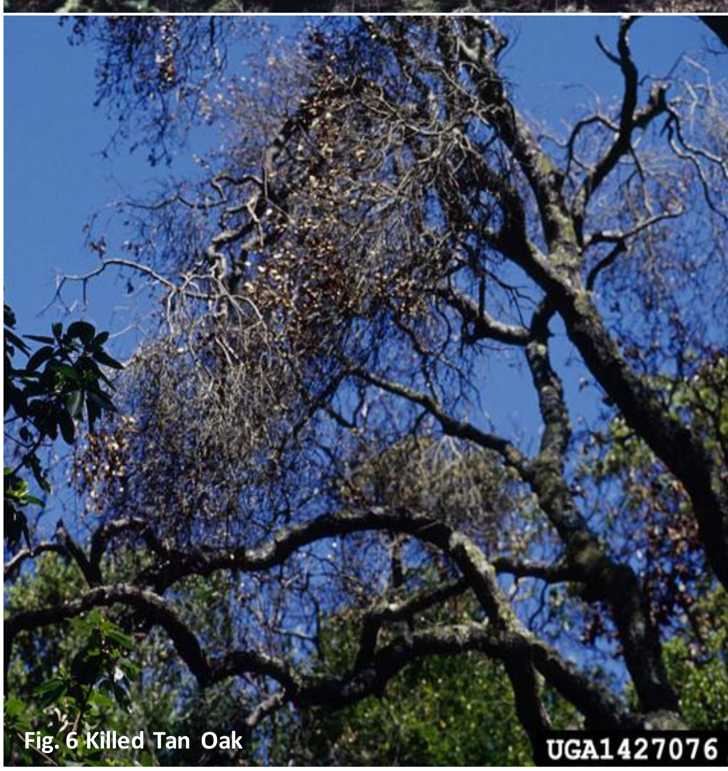


Fig. 6 Killed Tan Oak

Fig. 7 Wilted shoot

Thousand Cankers Disease

Overview: Thousand cankers disease is a newly recognized disease of black walnut caused by the fungus *Geosmithia morbida*. The disease is so named because it is characterized by large numbers of small cankers on the branches and stem that eventually coalesce. This results in widespread necrosis of inner bark tissue, dieback, and eventually death. *G. morbida* is vectored by the walnut twig beetle (*Pityophthorus juglandis*). Both the beetle and fungus are thought to be native to the southwestern U.S. and Mexico. In 2010, the disease was discovered in the eastern U.S.: first in Knoxville, TN and then subsequently in several additional states. The disease could potentially spread through the entire native range of black walnut. Suspected infestations of the thousand cankers disease should be reported immediately to NCFS Forest Health staff.

Causal Agent: Fungus (*Geosmithia morbida*) vectored by the walnut twig beetle (*Pityophthorus juglandis*)

Hosts: Black walnut and butternut; also other *Juglans* spp. native to the western U.S.

Symptoms / Signs: Symptoms usually appear during the summer months (June-August). Early symptoms include thinning crowns, undersized or stunted foliage, branch flagging (Fig. 8), yellowing or wilting leaves (Fig. 7), and brown wilted leaves that remain attached to branches (Fig. 9). Symptoms in individual branches may develop over a period of several weeks; often rapid wilting of leaves soon follows branch flagging. Epicormic sprouting is common. Eventually, individual branches are killed; dieback tends to develop in the upper crown and spreads downward (Fig. 10). Cankers can only be observed if the outer bark is carefully stripped away from infested branches; cankers are not visible on the bark surface. Cankers are diffuse, chocolate brown, usually less than one inch in diameter, and can only be found in the inner bark (periderm), phloem, and cambium tissues adjacent to beetle galleries (Fig 1 & 3). Cankers do not affect the sapwood. Eventually, cankers coalesce and individual cankers can no longer be distinguished (Fig. 2). Trees usually die within 3 years of initial symptom development, but it may take more than 10-15 years after the tree is first attacked for obvious symptoms to develop.

Symptomatic branches will be riddled with many pinhole sized exit holes often spaced closely together (Fig. 6). Walnut twig beetles, which are dark brown and less than 1/16 inch long (Fig. 4&5), initially attack branches greater than 1½ inches in diameter in the upper crown. The stem and larger branches in the lower crown are attacked later as the tree declines. Beetles tend to favor the undersides of branches on the south or west-facing side of the tree. Beetle galleries in the inner bark are winding and usually less than a few inches long (Fig. 3). There may be thousands of beetles in every linear foot of infested branches in the later stages of the disease.

Disease Cycle: The pathogen produces small circular or oblong cankers in the branches and stem. Cankers are often initially restricted to the inner layers of the cork cambium. Over time, the cankers may expand into the phloem and cambium; they become more diffuse and cause affected tissues to soften and turn dark brown or black. Eventually, the cankers coalesce and girdle the branches and stem. The pathogen is thought to require the walnut twig beetle for transmission and infection; it is not known if other methods of spread are possible or if other insects could serve as vectors. Relatively high populations of the walnut twig beetle are required before thousand cankers disease can cause severe decline or mortality. Beetles are likely initially attracted to stressed trees; both males and females emit aggregation pheromones that attract additional beetles when a suitable host is found. Individual beetles can travel up to two miles in search of a host tree. It is not known how many generations of the walnut twig beetle will occur annually in the eastern U.S.

Importance: High. While little is known about how this disease will affect black walnut in the eastern U.S., it has the potential to devastate the host population in its native range. Regulations to limit the spread of this disease are in effect and will significantly limit the sale and transport of walnut material out of quarantined zones.

Management: There are no known cures or preventative measures for this disease. Limit movement of infested wood; without human-assisted movement disease spread will be significantly limited. Report any suspected cases of thousand cankers disease to the NCFS Forest Health staff immediately.

Timeline: Unknown. Symptoms are most visible during the summer months.

Range: Statewide risk, especially western North Carolina. This disease was confirmed in the state in late 2012.

Fig. 1 Cankers around beetle galleries

Fig. 2 Coalescing cankers

Fig. 3 Canker forming around beetle gallery


Fig. 4 Walnut twig beetle


Fig. 5 Walnut twig beetles

Fig. 6 Exit holes and exposed galleries


Fig. 7 Wilting leaves

Fig. 8 Thinning in crown and flagging

Fig. 9 Persistent wilted leaves

Fig. 10 Decline

Fire Blight

Overview: Fire blight is a very important disease of many fruit-bearing trees in the Rose family. It is caused by bacteria that infect leaves, flowers, and fruits; but may also cause cankers, dieback, and even tree death in severe cases. The disease is easily spread by rain-splash, a number of insect vectors, and even on infected pruning tools. Fire blight is usually most severe in years with wet warm springs, especially during the blooming period.

Causal Agent: Bacteria (*Erwinia amylovora*)

Hosts: There are more than 100 species of plants known to be susceptible to fire blight; all are in the Rose family. Trees susceptible include apples, hawthorns, pears, and mountain-ash. The disease can also occur (but is far less common) in the stone fruits: peach, cherry, and plum.

Symptoms / Signs: Blighting of flowers is usually the first symptom to appear in spring. Flowers will darken, droop, shrivel, and turn black. Lesions on fruits, leaves, and green shoots will follow shortly thereafter (Fig. 1 & 2). The tips of infected shoots (and associated leaves) will also droop and turn black (Fig. 5). Wilted shoots will often resemble a shepherd's crook (Fig. 3 & 4). If many shoots are infected, trees will appear to be burned or scorched, hence the name "fire blight" (Fig. 6 & 7).

Cankers may form when branches and stems are infected by the bacteria. Bark on cankers may appear raised and slightly blistered, especially when cankers are actively expanding during the growing season. During the winter months, cankers may appear sunken and bark may be cracked. Cankers can eventually girdle and kill branches or the entire tree. Orange drops of slimy liquid filled with bacteria may be visible oozing on or near infected plant parts during warm and humid weather.

Disease Cycle: Bacteria overwinter in diseased plant parts including twigs and buds with cankers. When warm humid weather returns, small drops of orange fluid ooze from infected plant parts and can be transmitted to new growth via rain-splash, wind-driven rain, irrigation water, insects, birds, and pruning tools. There are many insects known to vector the fire blight bacteria, but the most commonly implicated are cicadas, leaf hoppers, and pollinators such as bees and flies. The bacteria can enter susceptible tissues through small wounds or insect feeding sites, or they may multiply on the plant surface and eventually penetrate through stomata and lenticels. Bacteria populations can double once every hour and spread through plant tissues at rates of up to 10 inches a day. As bacteria spread, they release enzymes that kill and dissolve plant cells; symptoms begin to appear a few weeks after infection.

Importance: Moderate. Fire blight can be of great concern to homeowners and fruit tree orchards. Many fruit trees and ornamentals are highly susceptible and symptoms can be severe in years with warm wet springs. Bradford pears (a popular ornamental) were originally thought to be resistant, but the disease has become prevalent in this pear cultivar.

Management: Prune off infected plant tissues as soon as they are observed; be sure to prune 8 inches or more away from the nearest symptomatic tissue. Prune trees regularly to increase air circulation in the crown. Make sure to sanitize pruning equipment after use to prevent spreading the disease. Most new infections start on flowers; removal of flowers on small trees can prevent infection. Bactericides are available, but proper timing of applications is critical and is difficult to accomplish effectively. Examine trees thoroughly 1-3 weeks after warm wet periods in the spring for any symptomatic tissue and remove.

Timeline: Most infections occur during wet/humid warm weather in the spring. Strong winds and rains during this period dramatically increase disease incidence.

Range: Statewide.

Fig. 1 Leaf lesion

Fig. 2 Fruit lesions

Fig. 3 Blighted shoot

Fig. 4 Blighted shoot

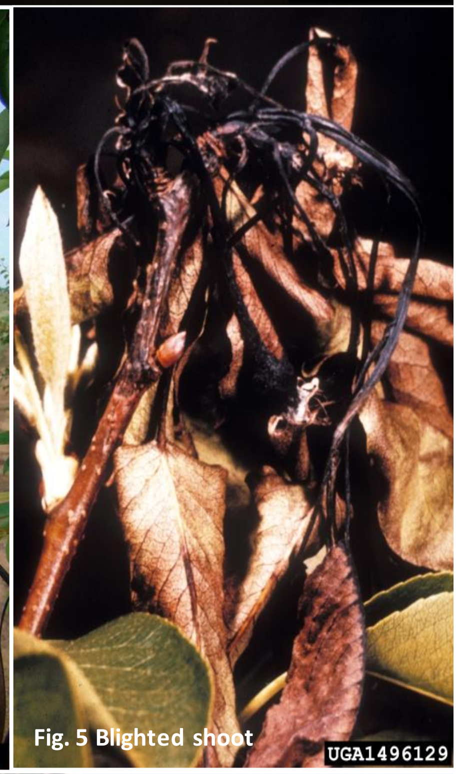


Fig. 5 Blighted shoot

Fig. 6 Severe blight

Fig. 7 Blighted shoots

Bacterial Leaf Scorch

Overview:	Bacterial leaf scorch is caused by a bacterial infection of a tree’s water conducting tissue. The bacteria are vectored by a number of insects. This disease can be very difficult to diagnose; symptoms of bacterial leaf scorch closely resemble those of other vascular diseases, declines, and abiotic stresses such as drought. Symptomatic tissue samples from trees suspected to have bacterial leaf scorch should be submitted to NCFS Forest Health staff or a diagnostic lab for confirmation.
Causal Agent:	Bacteria (*Xylella fastidiosa*)
Hosts:	There are hundreds of known hosts of bacterial leaf scorch. Trees include maple, buckeye, hackberry, dogwood, sweetgum, sycamore, plum, oak, and elm. There are many plants in which the bacteria grow and multiply without symptom development. These plants may serve as inoculum reservoirs.
Symptoms / Signs:	Infection is perennial; bacteria are able to survive from year to year in the vascular system. Bacteria interfere with water transport in the xylem, therefore symptoms closely resemble those of drought and other vascular diseases. Leaf margins turn red or yellow; then leaves will wilt and turn brown especially during the summer months (Fig. 1 & 2). A red or yellow band often separates brown from green tissue. Older leaves are usually scorched first, with symptoms progressing towards shoot tips. Scorched leaves are retained on the tree into the fall. Trees may have decreased fruit production, delayed bud break, reduced growth, stunting, branch dieback, and eventually death. Leaves usually expand normally each year; then symptoms begin to appear in late spring and progress throughout the summer. Hot droughty weather makes symptoms worse. Symptoms may initially appear in isolated branches or sections of the crown, but eventually spread throughout the tree (Fig 3, 4, & 5). Symptoms can fluctuate in severity from year to year.
Disease Cycle:	Bacteria must be introduced into a tree’s vascular system by insects in order for infection to occur. Common insect vectors include spittlebugs, sharpshooters, and leafhoppers; insects pick up the bacteria from infected trees and transmit it during feeding to healthy trees. Bacteria multiply rapidly in the xylem and are carried upward rapidly in the transpiration stream; downward spread occurs more slowly. Symptoms develop within a few weeks to a year depending on tree health and species. The bacteria overwinter in roots and stems and each year they spread to new xylem vessels. The bacteria produce enzymes that dissolve cell wall components and plug the vascular system.
Importance:	Moderate. The disease can be severe, but is not commonly observed in North Carolina. The disease can stress trees and predispose them to attack by other insects and pathogens.
Management:	There are currently no effective treatments for bacterial leaf scorch.
Timeline:	Infections occur during the spring and summer. Symptoms begin to develop within a few weeks of infection. In subsequent years, symptoms begin to develop in late spring and are worst during the summer.
Range:	Statewide.

Fig. 1 Scorched leaf

Fig. 2 Scorched leaves

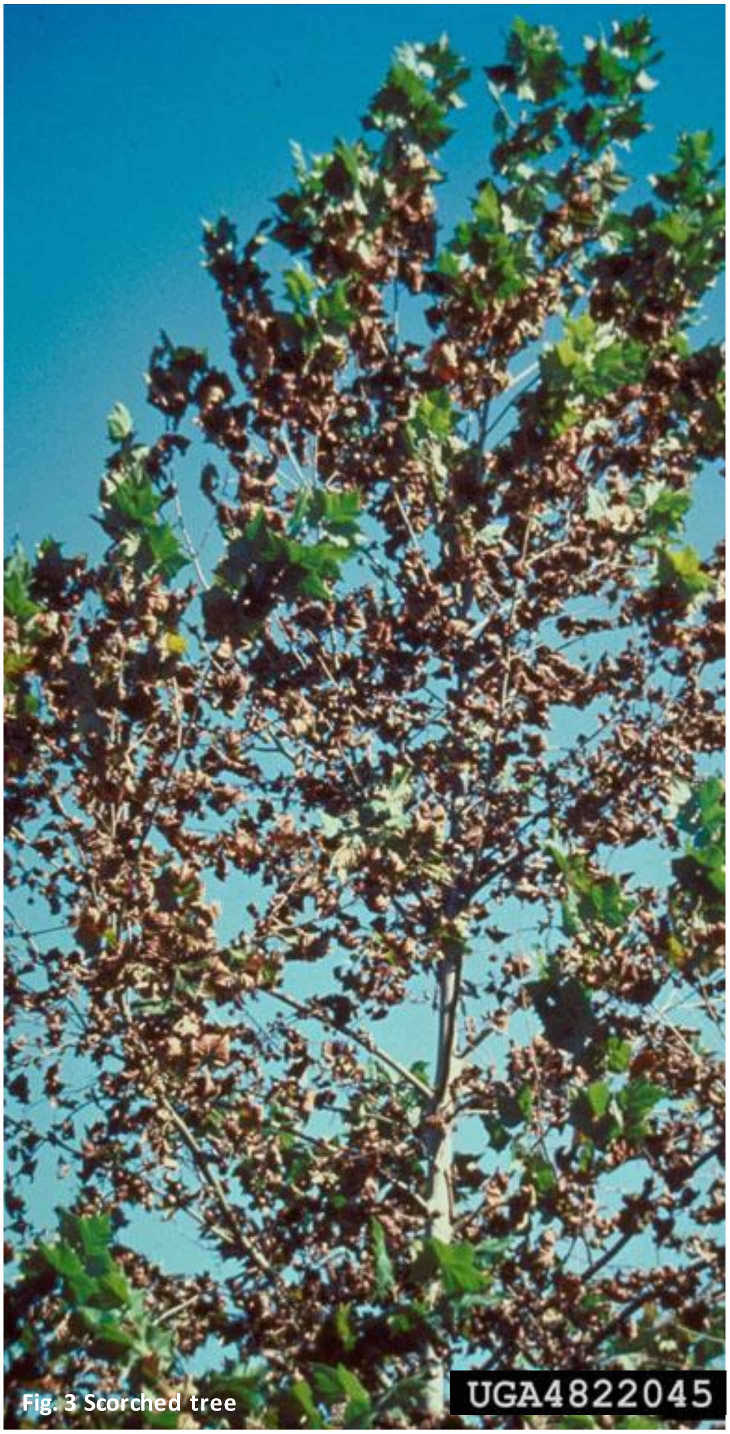


Fig. 3 Scorched tree

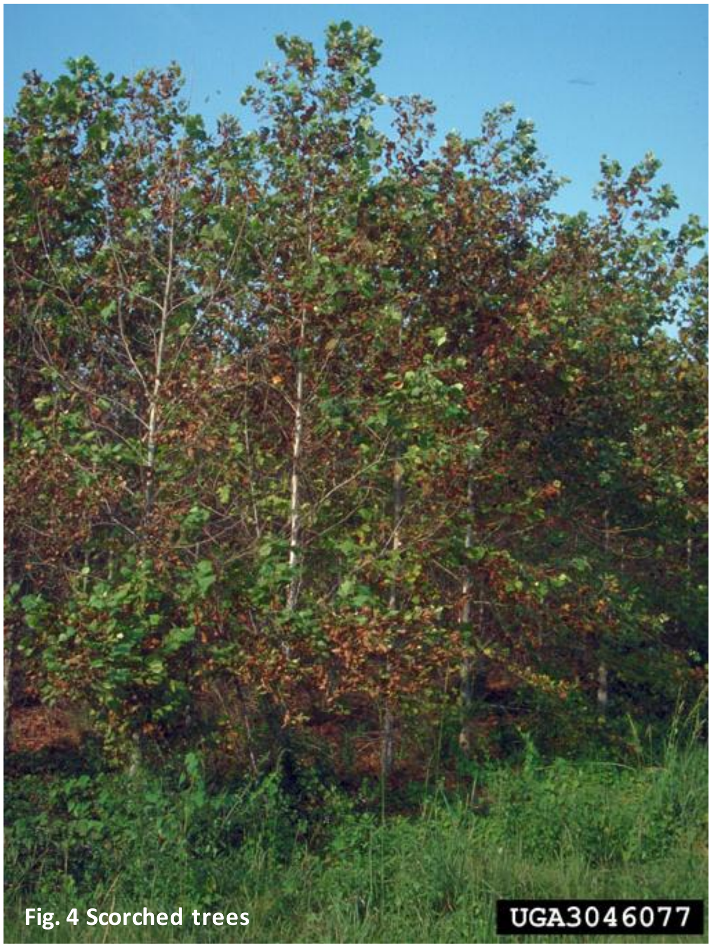


Fig. 4 Scorched trees

Fig. 5 Severely scorched tree

Oak Decline

Overview:	Oak decline is known as a disease complex: a disease that has many contributing stress agents with no single agent playing a dominant role. Oak decline has been a major concern since the 1950's when it was first noticed that mature and otherwise healthy oaks would begin to decline and slowly die over the course of several years. The disease complex affects oaks in both forested and urban settings. Drought, defoliation, and secondary stress agents are common contributors.
Causal Agent:	A combination of biotic and abiotic stress agents; most commonly drought, twolined chestnut borer, Armillaria root rot, late frost, soil compaction, root damage, and mechanical injury.
Hosts:	Oak species. More common in red oaks.
Symptoms / Signs:	Early symptoms include late bud-break, small and/or chlorotic leaves, and scattered dead twigs. Leaf scorch, premature leaf-drop, early fall coloration, epicormic sprouts (suckers), and reduced diameter and shoot growth may also be observed. The most obvious symptoms occur during the later stages of the disease. Large branches or even entire sections of the crown will begin to die. Dieback most often proceeds from the top of the crown downward. This creates a "stag-head" effect: large antler-like branches (with no leaves) sticking up out of the remaining green crown below (Fig. 1 & 5). Oaks affected by decline are often host to a number of secondary insects and diseases, especially *Armillaria* root rot (Fig. 2) and the twolined chestnut borer (Fig. 3 & 4). Signs of many wood borers, secondary fungi, and cankers are often visible.
Disease Cycle:	Decline is usually initiated by a prolonged or reoccurring stress. For instance, while trees can survive the activity of defoliating insects periodically, repeated and severe defoliation by late frost, gypsy moth, or leaf rollers can reduce tree health. Prolonged drought, root compaction, root damage, and mechanical injuries also weaken the tree. These predisposing factors weaken normal defense responses, making trees susceptible to attack by secondary insects and pathogens such as Armillaria root rot, Hypoxylon canker, and the twolined chestnut borer. Attack by these stress agents further decreases the tree's ability to get water and nutrients, and the tree is weakened further. Eventually the oak will succumb to this cycle of accumulating stresses
Importance:	Moderate. Following drought, a significant percentage of mature oaks may begin to decline and die in susceptible forest stands. Trees are particularly vulnerable in urban settings where abiotic stresses are prevalent.
Management:	Proper tree care is critical. Provide trees adequate water (at least 1-2 inches per week below the entire drip line), fertilizer if necessary (avoid nitrogen rich fertilizers), and room to grow with little competition from neighboring trees or understory. Provide a thin layer of mulch (1-3 inches) below as much of the drip line as possible. Avoid planting susceptible species on dry sites. Planting the right species on the right site is the best way to lower the risk of oak decline.
Timeline:	Symptoms are most visible during the summer months when trees are water-stressed. Symptoms commonly appear in the years following a severe drought.
Range:	Statewide.

Fig. 1 Crown dieback

Fig. 2 *Armillaria* fruiting bodies

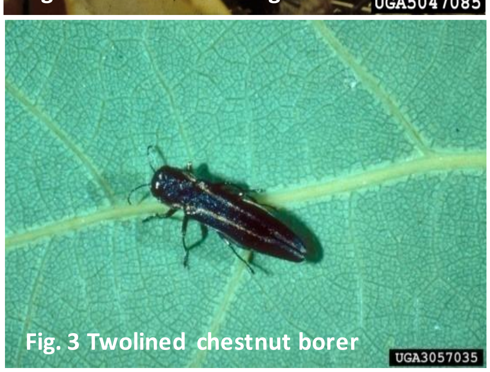


Fig. 3 Twolined chestnut borer

Fig. 4 Twolined chestnut borer larva

Fig. 5 Advanced decline

Oak Wilt

Overview:	Oak wilt is considered to be the most important disease of oaks in the eastern United States. Few other diseases encountered in forestry can kill large mature trees as quickly as oak wilt. The disease is caused by a fungus that spreads through a tree's vascular system. In response, the tree plugs up its vascular system to stop the fungus from spreading, but this also inhibits water movement, so the tree wilts and dies.
Causal Agent:	Fungus (*Ceratocystis fagacearum*)
Hosts:	All species of oak are susceptible to the disease; however, some species are more resistant than others. Oaks in the white oak group can sometimes live for many years with the disease or even recover completely. In contrast, members of the red oak and live oak groups are highly susceptible and usually die within several weeks to several months after infection occurs.
Symptoms / Signs:	Early symptoms are often confused with drought. Leaves in the upper crown usually show symptoms first. Leaves will begin to turn greenish-grey or olive-green, and will have a wilted, limp, or water-soaked appearance (Fig. 1). The leaves will begin to brown at the leaf tips and edges, and then progress inward (Fig. 2). If symptoms begin in a single branch or isolated part of the crown in red oaks, they will rapidly spread through the rest of the tree within a few months (Fig. 3). Symptoms may be halted or only spread slowly in white oaks. Red oaks will often shed their leaves rapidly once infection starts; leaves on the ground may only be partially wilted. In cases where the tree wilts very rapidly, leaves may be retained. White oaks tend to retain wilted leaves for several months. The fungus often spreads through root grafts to neighboring trees, creating a "disease center" with recently infected and wilting trees surrounding dead trees (Fig. 6). The outermost rings of sapwood will almost always be discolored in the wilting branches of white oaks; discoloration may or may not be present in red oaks. Vascular discoloration can be observed by looking at the branch in cross-section, or stripping away the bark to reveal the outer sapwood. Discoloration will look like dark (grayish, purplish, or black) streaking in the outermost ring of sapwood (Fig. 4). Under the right environmental conditions, the oak wilt fungus will produce a black or grayish fungal mat that produces spores (Fig. 7). The mat is produced beneath the bark; enlargement of the mat causes the bark to rupture and allows insects to enter (Fig. 8). Mats are difficult to observe, usually produced in the spring, and have a fruity aroma like bananas or bubble gum. Mats can be just a few inches wide or almost a foot across.
Disease Cycle:	*C. fagacearum* spreads to trees in two different ways: it can be carried by certain oak bark beetles or sap beetles resulting in new disease centers, or it can spread to neighboring trees through root grafts (Fig. 5) resulting in the expansion of disease centers. A beetle carrying the fungus must land on a fresh tree wound in order for infection to occur. Root graft transmission may take one or more years to occur. Oaks respond to infection by plugging up water-conducting vessels of the xylem to prevent further spread of the fungus. However this inhibits water movement in the tree and causes death. Spore mats produced beneath the bark attract sap beetles which can carry spores several miles.
Importance:	High. Quarantines are in effect for counties where oak wilt is present.
Management:	Over-land transmission by insect vectors is managed by removal of diseased trees to eliminate production of spore mats. Firewood from diseased trees should be tightly covered in plastic for at least one year or immediately burned. Avoid pruning oaks during months when spore-vectoring beetles are most active (March-July). Any pruning wounds or injuries during this time should be immediately treated with pruning paint. Root graft transmission is managed by severing root grafts between trees with a vibratory plow or trencher. Systemic fungicides are available for high-value trees and can provide protection for one to two years.
Timeline:	Insect vectors are most active March-July. Spore mats are produced March-May. Most trees begin to wilt between June and September. Trees that are not completely wilted before winter may leaf out in the spring, but quickly wilt thereafter.
Range:	Currently only known to occur in Swain, Jackson, Haywood, Buncombe, and Madison counties.

Fig. 1 Early wilt symptoms

Fig. 2 Wilted leaves

Fig. 3 Wilting oak

Fig. 4 Vascular streaking

Fig. 5 Root grafts

Fig. 6 Disease Center

Fig. 7 Spore mat

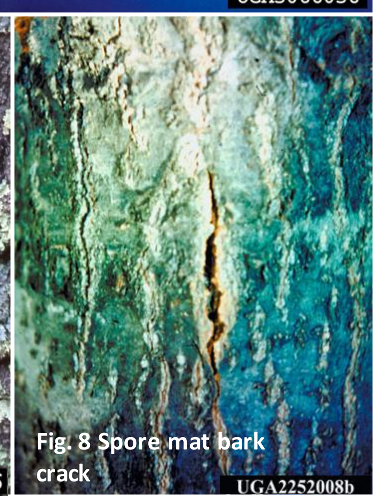


Fig. 8 Spore mat bark crack

Dutch Elm Disease

Overview: Dutch elm disease is a vascular wilt of elms caused by a fungus that is transmitted by bark beetles and root grafts. The fungus originated in Asia; the name "Dutch" refers to the identification of this disease and causal agent in the Netherlands by a Dutch scientist. The story of Dutch elm disease is long and interesting: it spans more than a century and involves complicated international politics, multiple continents, symbiotic relationships between several insects and pathogens, inter-species hybridization of fungi, and in the end, the catastrophic loss of an American icon. The disease has killed millions of elms in both Europe and the U.S. since the early 1900's. Two waves of the disease, first in the 1930's and then again in the 1970's, all but eliminated the American elm from the streets of U.S. cities (Fig. 2). Elms are beginning to make a comeback however, due to integrated management programs, systemic fungicides, and disease resistant cultivars.

Causal Agent: Fungus (*Ophiostoma ulmi* and *Ophiostoma novo-ulmi*)

Hosts: Elms. American and European elm species are highly susceptible; many Asian elm species have partial or complete resistance.

Symptoms / Signs: Early symptoms are often confused with drought. Usually one branch or an isolated area of the crown will "flag": leaves will wilt and turn yellow; then reddish-brown and die (Fig. 3). As the pathogen spreads out of the infected branch, larger areas of the crown begin to rapidly wilt resulting in crown dieback (Fig. 4). Complete wilting can occur within a few months of infection, but it may take a year or more (Fig. 1). Removal of bark on symptomatic branches or the main stem will reveal dark brownish-purple streaking in the outer sapwood (Fig. 5 & 6). Pathogen spread through root grafts may result in wilt development in nearby trees in subsequent years; trees infected through root grafts usually wilt more quickly than bark beetle-related infections.

The fungus produces microscopic fruiting bodies that are not visible in the field. Diagnosis based on vascular streaking/discoloration is usually reliable, but the diagnosis can be confirmed in a laboratory.

Disease Cycle: The fungus spreads to trees in two different ways: it can be carried by elm bark beetles for up to several miles, and it can spread to neighboring trees through root grafts. Adult beetles carry the fungus on their bodies or in their mouthparts, and transmit the pathogen into the tree's vascular system when feeding on tender bark, usually in branch crotches. The fungus kills the branch, then grows downward and spreads through the rest of the crown, and eventually, the root system. Root graft-transmission may take one or more years to occur because the pathogen must grow out of the crown and into the root system. However, when the pathogen spreads to a neighboring tree through roots, it is rapidly carried upward throughout the entire tree. Elms respond to infection by plugging up water-conducting vessels of the xylem to prevent further spread of the fungus, however, this inhibits water movement in the tree and causes death. Beetles use dead elms for breeding habitat.

Importance: High. This disease can be devastating for high-value landscape trees. Large specimens of American and European elms have become increasingly rare.

Management: Transmission by insect vectors is managed by rapid removal of diseased trees to eliminate breeding habitat for elm bark beetles. Firewood from diseased trees should be tightly covered in plastic for at least one year or burned immediately. Do not transport elm firewood. Root graft transmission is managed by severing root grafts between trees with a vibratory plow or trencher. Systemic fungicides are available that can protect high-value trees for one to three years; if the disease is caught early enough and has not spread into the root system, these fungicides can be used to successfully eradicate the fungus and save a diseased tree. Likewise, experienced arborists or tree surgeons can prune out diseased branches, or even infected sections of the stem, to save a tree in the early stages of disease. Disease resistant cultivars of American elm are now available.

Timeline: Insect vectors are most active throughout the growing season (*see elm bark beetles*). Wilt symptoms generally begin to develop during the summer months and early fall.

Range: Statewide.

Fig. 1 Wilted American elm

Fig. 2 Street lined with American elms

Fig. 3 Branch flagging

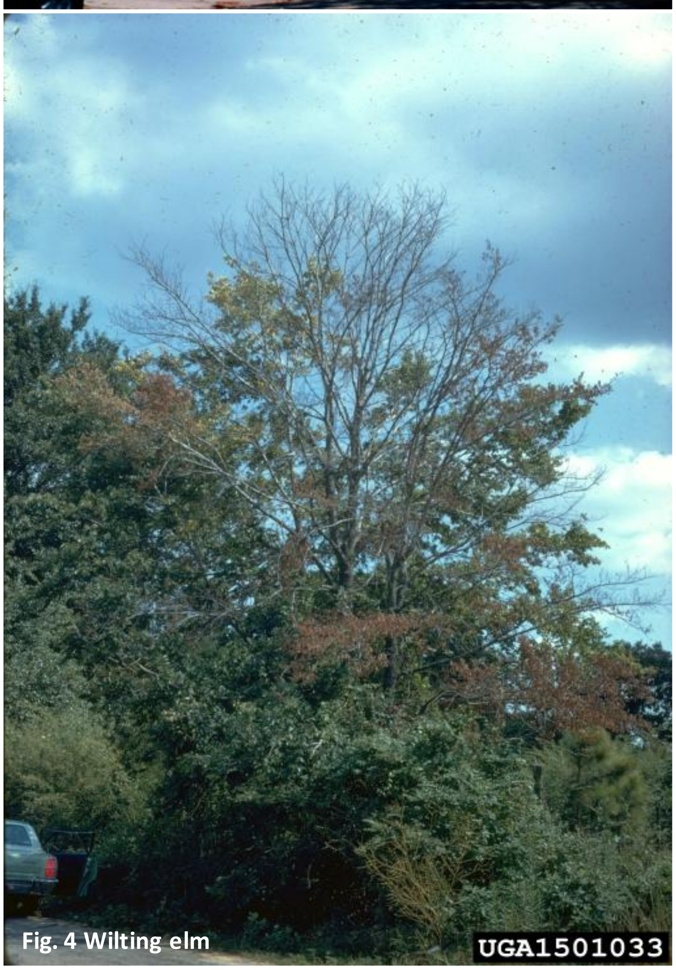


Fig. 4 Wilting elm

Fig. 5 Vascular discoloration in cross section

Fig. 6 Vascular streaking in sapwood

Laurel Wilt

Overview: First discovered in 2002, laurel wilt has rapidly become a disease of serious concern in the southeastern U.S. The laurel wilt fungus can kill mature trees very quickly, is vectored by a small ambrosia beetle from Asia, and is spreading through the southeast at approximately 20 miles per year. It affects plants of the Lauraceae family; most commonly redbay. The disease has become a serious concern because avocado (an economically important crop in Florida) is also susceptible, and the disease threatens the survival of several plant and animal species. Laurel Wilt was discovered in North Carolina in 2011.

Causal Agent: Fungus (*Raffaelea lauricola*) vectored by the redbay ambrosia beetle (*Xyleborus glabratus*)

Hosts: Plants of the laurel family; most commonly redbay, sassafras, and avocado. Also susceptible are swamp bay, silkbay, pondberry (endangered-U.S.), pondspice (threatened-NC), northern spicebush, and California laurel.

Symptoms / Signs: Symptoms of the disease may be similar to drought. Leaves begin to turn olive-grey, then reddish-brown, and begin to droop before wilting completely and turning brown (Fig. 1). Leaves are retained on dead trees for a year or more. Symptoms may start in an isolated branch or in the top of the tree, but will spread throughout the entire tree rapidly (Fig. 2 & 3). Most trees wilt and die a few weeks or months after symptoms first appear.

Discoloration in the outer sapwood is clearly visible in dead or dying trees. Staining will be dark purplish or black; vascular discoloration and be seen by looking at wilted branches in cross section (Fig. 8) or removing the bark to expose the xylem (Fig. 7). Staining in dead trees extends through the roots, stem, and all branches.

Redbay ambrosia beetles are very difficult to detect, especially prior to the tree's death. Small round entrance holes (< 1/32 inch diameter) may be visible on the stems and branches of severely wilted or dead trees. Toothpick-like tubes of sawdust may be expelled from beetle galleries and stick out of dead trees (Fig. 6); sawdust tubes are easily destroyed by wind or washed away by rain. Sawdust may be visible at the base of the tree. The beetle is 1/16 inch long, dark brown or black, and shiny (Fig. 4 & 5). There are many species of ambrosia beetles (native and exotic), many of which attack redbay and can be easily confused with the redbay ambrosia beetle. Suspected redbay ambrosia beetles should be collected and submitted for proper identification.

Disease Cycle: The redbay ambrosia beetle is a "fungus farmer." It creates galleries in dead or dying trees to grow the fungus on which it feeds. The beetle carries the fungus with it from tree to tree, and coincidentally, the fungus that the redbay ambrosia beetle farms is highly pathogenic on the beetle's preferred host tree. This creates a symbiotic relationship in which the fungus kills trees for the beetles to invade, and the beetles farm and carry the fungus to new trees. It only takes one beetle to infect a tree. Beetles cannot successfully attack healthy trees, so it is likely that the fungus is introduced to the tree during failed attempts by beetles to enter. Only after the tree is dead or dying can beetles return to infest the tree and farm the fungus.

Once introduced into the tree's vascular system, the fungus rapidly spreads in the sapwood throughout the entire tree. The tree responds by plugging its vascular system to prevent spread of the fungus, but this limits water movement in the sapwood. Therefore, trees wilt and die rapidly after infection.

Importance: High. The disease threatens the survival of many laurel species including the endangered pondberry. The Palmedes swallowtail butterfly and spicebush swallowtail butterfly require specific laurel species to complete their life cycle. Redbay and sassafras are important wildlife and landscape trees and are an important mid-story species.

Management: There are currently no effective control options. Research is being conducted on systemic insecticides and fungicides. Human movement of infested wood is responsible for the disease's rapid spread through the southeast; without human assistance the disease can only spread approximately 20 miles per year. If laurel wilt is suspected contact the NCFS Forest Health staff immediately.

Timeline: Trees may become infected when temperatures are warm enough for beetle activity. Symptoms usually develop during the growing season, but the tree is evergreen and the disease can be detected year-round.

Range: Eastern North Carolina; potentially statewide in sassafras. It was discovered in North Carolina in 2011.

Fig. 1 Early wilt symptoms

Fig. 2 Wilted redbay

Fig. 3 Wilted redbays

Fig. 4 & 5 Redbay ambrosia beetle

Fig. 6 Sawdust tubes

Fig. 7 Vascular streaking

Fig. 8 Vascular streaking

Heterobasidion Root Disease / Annosus Root Rot

Overview:	Previously called Annosus root rot, Heterobasidion root disease is a serious disease in pine plantations that have been recently thinned. All species of conifers are susceptible. The fungus that causes Heterobasidion root disease infects freshly cut stumps and spreads to living trees through interconnected root systems (root grafts). The fungus attacks the large roots near the base of the tree, limiting the tree's supply of water and nutrients. The rotted roots of diseased trees make them highly susceptible to wind-throw.
Causal Agent:	Fungus (*Heterobasidion annosum*)
Hosts:	All conifers are considered susceptible, including all species of southern pines. Most common in loblolly, slash, and white pines. Longleaf and shortleaf pines, as well as hemlock, are also commonly infected. Annosus root rot is less common in spruces, firs, and cedar.
Symptoms / Signs:	Symptoms first develop 1-3 years after thinning. Crowns may appear thin; needles may be chlorotic, stunted, and tufted at shoot tips (Fig. 1). Trees that have been killed may stay green through the winter, but needles will turn brown the following spring/summer. Wind-throw is commonly observed in stands where Annosus root rot is present (Fig. 2). Rotted roots are unable to provide the necessary structural support. Windthrow may also be the first indication of infection; green and otherwise healthy looking trees have been known to fall over prior to the development of needle symptoms. Roots may be resin-soaked (Fig. 3); white and stringy rot (Fig. 7) may be present in wind-thrown trees. In late winter or early spring, fungal fruiting bodies (conks) may be produced at the base of the tree (possibly under the litter layer) (Fig. 5). The conks are brown on top, white and porous underneath, and have a creamy-white edge (Fig. 6).
Disease Cycle:	Airborne spores are produced by conks in cool weather and germinate on freshly cut stumps and tree wounds. The fungus grows down into the root system and spreads to neighboring trees through interconnected root systems (root grafts). The fungus degrades the cellulose and lignin in large roots, especially around the base of the tree, cutting off the tree's supply of water and nutrients in addition to making the tree susceptible to wind-throw. Spores may be present almost year-round depending on the climate, but are most common during cooler months. Spores can travel for many miles. The disease usually dissipates 5-10 years after thinning.
Importance:	Moderate. This disease is relatively common in North Carolina at low to moderate levels. Severe cases have been observed, and can devastate recently thinned pine stands. In severe cases, landowners may need to decide whether to harvest timber (possibly before rotation age) before maximum losses are sustained, or to allow the disease to progress and allow remaining trees to reach rotation age while accepting some losses.
Management:	Thin stands during summer months when temperature is above 85ºF; spores can only germinate on stumps in cooler weather. If thinning during cool weather, stumps should be treated immediately after cutting with granular borax (or alternative product) to prevent infection (Fig. 4). Treatment with borax is ineffective once infection has occurred. Clearcut stands with greater than 50 percent infection; removal of diseased trees will result in an under-stocked stand. Wide spacing is recommended when planting to increase time to first-thinning, and to reduce the number of thinnings necessary in the stand. Wounding of roots and lower stems should be avoided during logging, fire break installation, and road building because these wounds are also suitable infection courts.
Timeline:	Infection occurs during cooler months (< 85ºF). Conks are generally produced February through May. Symptoms can develop year-round.
Range:	Statewide (Fig. 8). High hazard: sandy or sandy loam soils with at least 65 percent sand in the upper 12 or more inches above a clay layer and with no high seasonal water table. Intermediate hazard: silt and silt loam soils 12 or more inches deep. Low hazard: poorly drained clay and clay loam soils or those with high water tables.

Fig. 1 Declining trees

Fig. 2 Windthrow

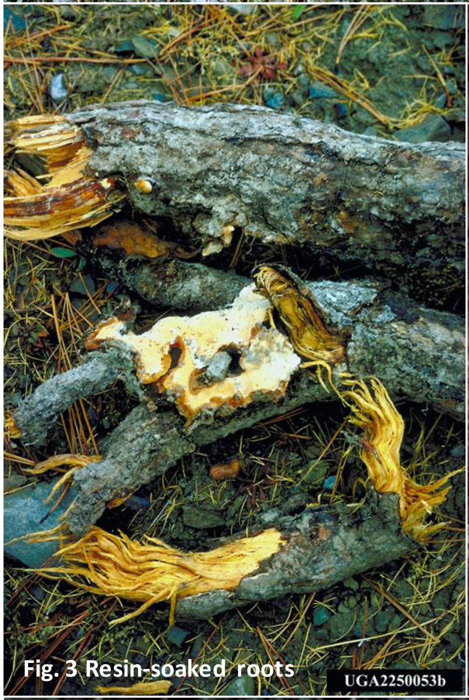


Fig. 3 Resin-soaked roots

Fig. 4 Borax treatment

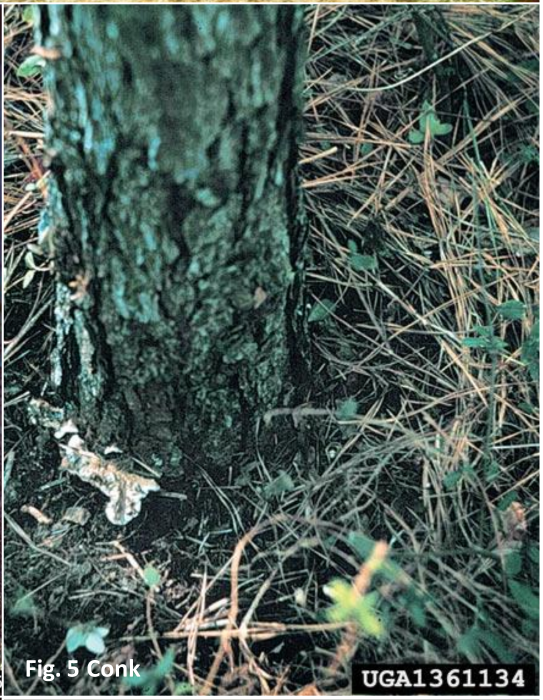


Fig. 5 Conk

Fig. 6 Conk

Fig. 7 Stringy, rotted roots

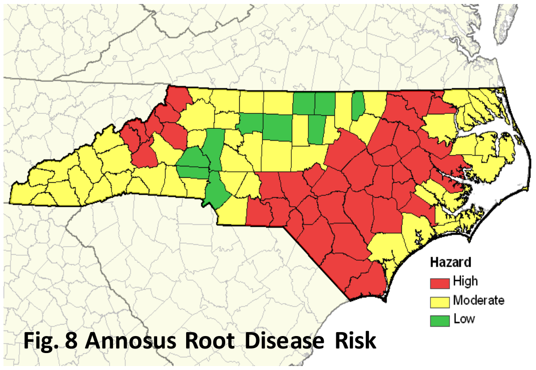


Fig. 8 Annosus Root Disease Risk

Armillaria Root Rot

Overview: Armillaria root rot is a general name for a group of diseases caused by fungi of the genus *Armillaria*. There are many species of *Armillaria* (many of which have only recently been described), but in general they are pathogens of the roots and lower stems of both hardwoods and conifers and are important decomposers of wood. Armillaria root rot is also called shoestring rot because the fungus produces black stringy rhizomorphs below the bark of infected trees. *Armillaria* fungi are commonly referred to as honey mushrooms because they produce large, golden-colored mushrooms around infected trees and stumps. Armillaria root rot is most often a secondary disease of stressed trees, but occasionally the pathogen can attack healthy trees as well. *Armillaria ostoyae* holds the record as the world's largest organism.

Causal Agent: Fungus (*Armillaria* spp.; most commonly *A. mellea* and *A. ostoyae*)

Hosts: Hardwoods and conifers.

Symptoms / Signs: The symptoms of Armillaria root rot often resemble many other diseases and disorders of trees such as drought, decline, Hypoxylon canker, Annosus root rot, and Phytophthora root rot. Growth reduction, chlorotic or scorched leaves, early fall coloration and/or premature leaf drop, branch dieback, wind-throw, and tree death are common above-ground symptoms. Conifers may produce large crops of undersized cones during decline. Trees are often affected in groups.

Armillaria causes cankers (lesions) on the inner-bark and outer-sapwood on the root-crown and lower stem. Cankers may expand slowly and eventually kill large roots; entire stems are not usually completely girdled, but large lesions may cause dieback or death. In conifers, cankers are often pitch-soaked, and resin may ooze and dry on the canker surface. Some cankers do not expand at all if the tree's defense responses are adequate; healthy trees may eventually compartmentalize infections. Callus / wound wood or scars may be visible at the site of old cankers for several years. After a tree dies, the fungus colonizes and causes decay in sapwood.

White mycelial fans (sheets of white fungal tissue) are often visible beneath the bark of cankers of rotted wood (Fig. 1 & 2). Black or brown branched rhizomorphs (also fungal tissue) that resemble fine roots or shoe strings may also be visible beneath bark, on root surfaces, and may even extend into the soil (Fig. 5 & 6). Rhizomorphs may be flattened when found beneath bark, but are cylindrical (< 1/32 inches in diameter) when found on the bark surface or in the soil. Golden-yellow mushrooms may be produced around dead or diseased trees in the fall (Fig. 3 & 4). Many species of *Armillaria* are bioluminescent. Presence of *Armillaria* signs does not necessarily mean the fungus is the cause of death or disease; it is a common wood rotter.

Disease Cycle: Stressed trees are highly predisposed to *Armillaria* root rot. *Armillaria* spreads through a forest via rhizomorphs and airborne spores. Rhizomorphs are made up of densely packed fungal hyphae to form fine root-like structures. Rhizomorphs can grow through the soil (up to 8 feet per year) feeding on organic matter as they go, until they reach the roots of susceptible trees. Rhizomorphs attach to tree roots and penetrate the bark by mechanical force and enzymatic degradation. Airborne spores are produced from golden-yellow mushrooms (honey mushrooms) that grow around the base of diseased trees. Spores infect stumps or wounds on lower stems and exposed root tissue. The hyphae of a single fungus can spread great distances through the soil; the largest organism in the world is an *Armillaria* in Oregon that is over 2500 hundred acres in size.

Importance: Moderate. Armillaria root rot kills many stressed trees; young conifers are frequently attacked on sites previously occupied by hardwoods.

Management: Prevention is difficult; no practical treatment options are available. It is critical to maintain proper tree health. Select the proper tree species for the site; provide adequate water and fertilization if necessary. Avoid mechanical damage and soil compaction. Remove diseased trees and infected root systems if possible.

Timeline: Honey mushrooms are produced in the fall. Other signs may be visible year-round. Symptoms occur during the growing season.

Range: Statewide.

Fig. 1 Mycelial fans UGA1473102

Fig. 2 Mycelial fans UGA4822097

Fig. 3 Honey mushrooms UGA1371018

Fig. 4 Honey mushrooms 5366752

Fig. 5 Rhizomorphs UGA5027093

Fig. 6 Rhizomorphs UGA0364052

Littleleaf Disease

Overview: A type of *Phytophthora* root rot, littleleaf disease is considered to be the most important disease of shortleaf pine in the United States. The pathogen attacks the fine roots of pines, inhibiting their ability to absorb nutrients. The disease is often found in coordination with low soil nitrogen, poor soil drainage, nematodes, and species of *Pythium*. Littleleaf disease usually only affects trees greater than twenty years old; it takes several years for a tree to be killed after symptoms first appear.

Causal Agent: Stramenopile; a fungus-like organism also known as a water mold (*Phytophthora cinnamomi*)

Hosts: Shortleaf pine is highly susceptible; loblolly pine moderately susceptible. Littleleaf disease has also been reported in other southern pine species including Virginia, slash, pitch, and longleaf pines.

Symptoms / Signs: First symptoms are caused by nutrient deficiency due to loss of fine roots. These symptoms include thin crowns, needle chlorosis, stunted needles, and reduced shoot growth (Fig. 1).

As symptoms progress, the crown will look increasingly thin. Needles will become increasingly yellow, then turn brown. Eventually, the tree will lose almost all of its needles except the new growth, giving the shoots a "tufted" appearance (Fig. 2). Prolific production of cones (often stunted) may occur in later stages of disease (Fig. 3 & 4). Branches will begin to die starting in the bottom of the crown, progressing upward. Width of annual growth increments / diameter growth is greatly reduced.

Disease Cycle: *Phytophthora cinnamomi* rarely affects trees less than twenty years old. The pathogen attacks the fine roots that absorb most of the tree's supply of essential mineral nutrients and water. Usually, diseased trees are found in soils that are nutrient deficient and/or poorly drained, or in trees being attacked by nematodes or other pathogenic soil fungi which can weaken the tree's defenses. The pathogen produces motile spores which can swim for short distances, therefore rate of disease spread and risk of infection is highest in soils with poor drainage or that frequently exhibit high soil moisture. Trees are killed slowly, generally over the course of a 1 to 12 year period. On average, trees die 6 years after the first symptoms are observed.

Importance: Moderate. This disease is usually present in North Carolina at low to moderate levels. Trees declining due to littleleaf disease may be more susceptible to attack by bark beetles. The disease is very important for shortleaf pine management.

Management: Avoid planting susceptible species on high-risk sites. Shorten lengths of rotation to harvest trees before they become susceptible. Remove diseased trees. Increase soil drainage through site preparation techniques including break-up of hardpan layers. Inter-plant legumes in susceptible stands to increase available soil nitrogen. Alternatively, fertilize with one ton of 5-10-5 fertilizer + one-half ton of ammonium sulfate per acre for high value trees. Fertilization will delay symptom development for 3-4 years.

Timeline: Year-round. Pathogen is most active during periods of high soil moisture. Symptom progression may be accelerated by periods of drought.

Range: Potentially statewide. It is most common in the piedmont region of North Carolina (Fig. 5).

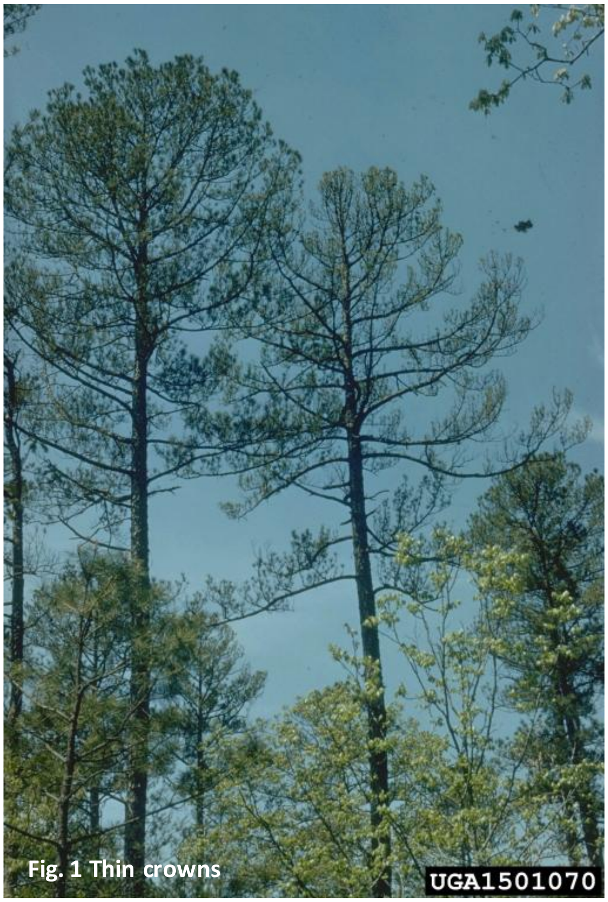


Fig. 1 Thin crowns

Fig. 2 Thin crown and tufts of foliage

Fig. 3 Stunted cones

Fig. 4 Stunted cones

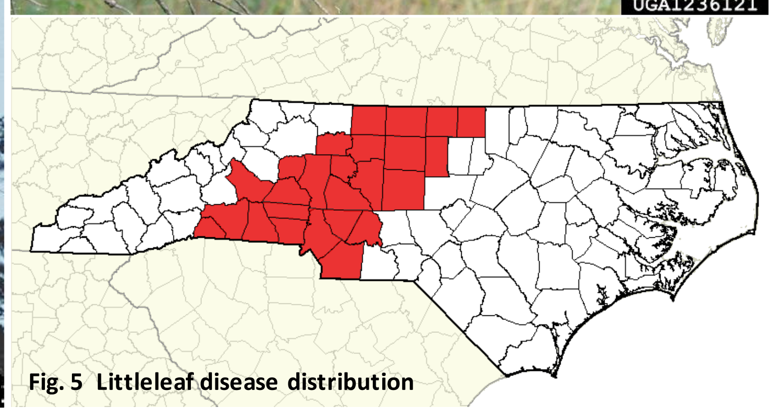


Fig. 5 Littleleaf disease distribution

Phytophthora Root Rot

Overview: Phytophthora root rot is a general name for a group of diseases caused by species of *Phytophthora* belonging to a group of fungus-like organisms. The pathogen attacks the roots of many trees and shrubs, particularly the fine roots that absorb mineral nutrients from the soil. The pathogen prefers poorly drained soil and produces motile spores that can swim through saturated soil for short distances. In North Carolina, the disease is particularly important in Christmas tree production (Fraser firs, Fig. 1), fruit trees, and many ornamentals. (*See also Littleleaf Disease*).

Causal Agent: Stramenopile; a fungus-like organism also known as a water mold (*Phytophthora* spp.)

Hosts: A wide variety of trees an ornamental shrubs including: azalea, rhododendron, dogwood, camellias, yews, deodar cedar, mountain-laurel, heather, juniper, blueberries, Fraser fir, white pine, shortleaf pine, fruit trees, and others.

Symptoms / Signs: Phytophthora root rot can often be difficult to diagnose and laboratory tests are usually required to confirm the presence of the pathogen.

Above-ground, symptoms mimic nutrient deficiency, drought, or decline such as leaf chlorosis, leaf necrosis, wilting, dieback, or death. In Fraser fir, needles will turn yellow-green and may wilt before turning brown. Symptoms often begin in lowest branches progressing upward, or may only affect one side or section of the tree. Plants may decline over several months or several years.

The bark on large roots of infected trees may only be loosely attached; root tissue beneath bark is often discolored red, brown, grey, or black (Fig. 6 & 7). Feeder roots are often fewer in number or even completely absent (Fig. 2). The bark on small roots is easily pulled off the center core; small roots may be mushy, reddish-brown, or black (Fig. 3). The lower stem or root crown of severely diseased plants may be sunken in, swollen, pitch-soaked, or have roughened bark (Fig. 4). On Fraser fir, removal of bark from the lower stem may reveal butterscotch, brown, or black colored sapwood (Fig. 5). Dead or dying trees often occur in groups or in low-lying areas. Seedlings of many trees and shrubs can be killed rapidly by *Phytophthora* under the right conditions; this is known as "damping off." Phytophthora root rot is most often confused with damage caused by soil inhabiting grubs and abiotic disorders.

Disease Cycle: *Phytophthora* overwinters in the soil, infected roots, and other plant debris. The pathogen can lie dormant in the soil for many years. Spore production and subsequent infection occurs in warm and saturated soils. Motile spores can swim through saturated soils for short distances to infect new plants. The pathogen is also easily spread in irrigation water, water runoff, rain-splash, contaminated equipment, and on contaminated plants. The pathogen attacks the fine roots and nutrient-conducting tissue of larger roots and root crowns.

Importance: High. *Phytophthora* species can cause significant and costly damage to landscape trees and shrubs. It is the only serious disease of Fraser fir, and can be responsible for major losses in Christmas tree plantations if soil becomes contaminated and conditions are conducive to spread and infection.

Management: No single practice will prevent Phytophthora root rot; an integrated management approach must be taken. Do not plant susceptible species on sites where the disease has been known to occur; utilize resistant and/or disease-free plants. Obtain plants and soil from reputable sources. Remove and destroy diseased plants (including the root system). Plant in well drained soil; utilize site preparation techniques to improve soil drainage. Promote overall plant health by providing adequate water, fertilization, and maintaining proper soil pH. Avoid over-watering and use of nitrogen rich fertilizers. Crop rotation with resistant plant species is often a successful way to reduce or eliminate soil inoculum. Pesticides are available for specialized applications.

Timeline: Spore production and infection occurs from late spring through fall during saturated soil conditions. Symptoms are most visible during the growing season.

Range: Statewide.

Fig. 1 *Phytophthora*-killed fir

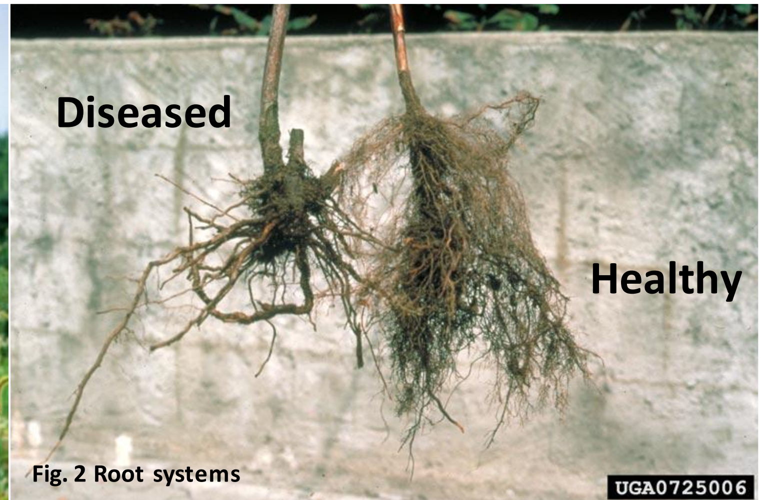


Fig. 2 Root systems

Fig. 3 Rotted roots

Fig. 4 Sunken stem canker

Fig. 5 Vascular discoloration

Fig. 6 Infected root crown

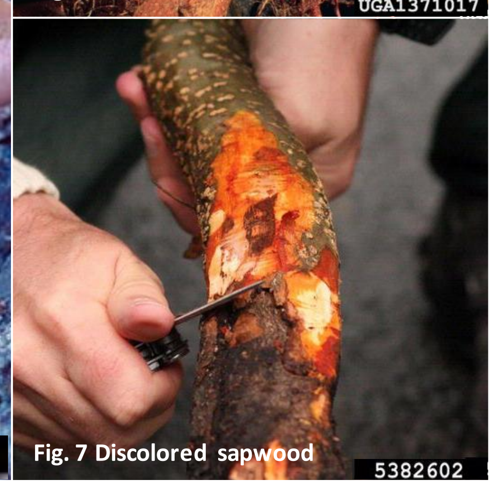


Fig. 7 Discolored sapwood

Procera Root Disease

Overview:	Relatively little is known about Procera root disease, mostly because it was not recognized until the mid-1980s; little research has been conducted on it since. In the past, it was a concern to Christmas tree growers, but over the past two decades it has been found more commonly in stands of white pine. The disease tends to affect trees 3-15 years old; therefore it is becoming a concern for sawtimber production and the establishment of mature white pine stands. The pathogen causes cankers on large roots, the root crown, and lower stem, but smaller roots can also be affected. Trees may die quickly, or over several years.
Causal Agent:	Fungus (*Leptographium procerum*)
Hosts:	Eastern white pine. Occasionally affects Scots and Austrian pines
Symptoms / Signs:	Procera root disease usually affects trees 3-15 years old. Infected trees may exhibit delayed bud-break and reduced candle length (Fig. 1). Trees often begin to die from the top down. Sometimes dieback is slow (one whorl at a time), in other cases (especially younger trees) the entire tree may die suddenly (Fig. 2). In the latter case, trees often begin to turn yellow before turning completely brown. Resin flow may be visible (sometimes obvious) at the base of the tree (Fig. 3 & 5); the trunk may be flattened on the affected side. Removal of the bark may reveal a chocolate-brown or tan canker on the lower stem (Fig. 4), root crown, or large roots, but cankers may not always be visible. Beetle galleries may be found around or within cankers (Fig. 6). Disease centers containing more than a dozen diseased or dead trees have been observed, however, the pattern of disease development is often random within a stand.
Disease Cycle:	Little is known about the disease cycle of Procera root disease. The pathogen does not appear to survive in the soil for long periods of time; rather it survives in infected root systems where it is vectored to neighboring trees by a variety of root-attacking or bark-infesting insects. Large roots are most often attacked and cankers frequently form in the inner bark and sapwood that eventually girdle major roots or the entire stem. Alternatively, small roots may be attacked, leaving little or no evidence of Procera root disease in dead trees. It is believed that this is a secondary disease, requiring certain pre-disposing factors for a successful attack by the pathogen. Wet sites appear to be conducive to disease development and should be avoided when planting white pine, but the disease seems to appear randomly in a stand, even on dry sites.
Importance:	Moderate. Procera root disease may hinder efforts to establish mature white pine stands, kill valuable ornamentals, and prohibit the production of certain Christmas tree species on sites with previous Procera-related problems. In parts of North Carolina, anecdotal evidence suggests most white pines do not live more than 30 years, possibly because of Procera root disease.
Management:	Few management options are available. Avoid planting white pines on wet sites as the disease seems to be more common in these areas. Excessively dry or otherwise poor sites should also be avoided as stressed trees appear to be much more susceptible. Remove and destroy diseased trees, including as much of the stump and root system as possible. Do not plant white pine on or near sites where Procera root disease has been known to occur. Provide adequate water and maintain proper soil pH (do not over-water).
Timeline:	Unknown.
Range:	Statewide.

Fig. 1 Stunted growth

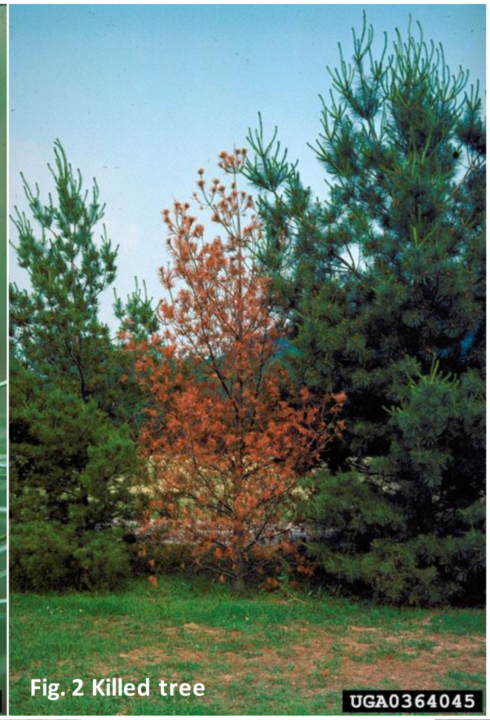


Fig. 2 Killed tree

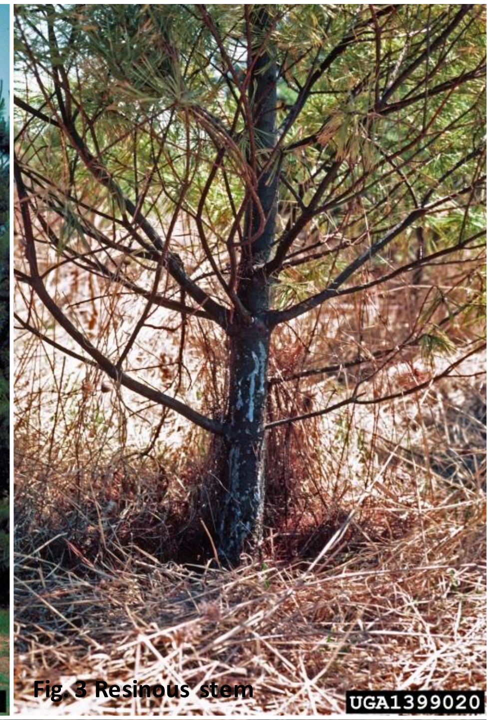


Fig. 3 Resinous stem

Fig. 4 Discolored sapwood

Fig. 5 Resinous stem

Fig. 6 Insect infestation

Disorders and Abiotic Stress Agents

Wind

Trees, being the tallest organisms, are specially adapted to withstand even strong wind events. When well distributed throughout the tree's crown, wind energy is dissipated by the collective movement of all branches swaying out of synchronization. Long and flexible wood fibers lend amazing flexibility over the length of entire stems and branches, which are quite rigid on shorter scales. As a tree grows, small micro-fractures in the wood caused by light to moderate winds actually result in the strengthening of tissues. But strong winds can be a serious threat to a tree's structural integrity, especially at weak points such as branch unions, sites of previous injury, decay pockets, and at points where maximum tension/compression occur. In forest situations, proper stocking and injury avoidance are the best practices to avoid future wind damage. For urban and landscape trees, proper pruning and tree care are important to minimize the risk of limb or stem breakage. Some tree species are more susceptible to wind damage because of weaker wood or the tendency to develop included bark. Overstocked stands that have been recently thinned may be more severely damaged.

Snow / Ice

Tree structure has evolved to support heavy loads at great heights, but there is a limit to the weight capacity of branches that are periodically tested by snow and ice. Tension and/or compression wood develops during the course of a tree's lifetime at points in the stem and branches where bending occurs most frequently and to the greatest degree. In general, hardwoods tend to react to bending by forming more tension wood, whereas conifers produce more compression wood. Unusually severe snow or ice events can exceed the capacity of compression / tension wood, but more commonly, branch or stem breakage occurs at weak points such as branch unions, old injuries, decay pockets, or in branches with included bark. Branches that have developed from epicormic sprouts (suckers) are weakly attached to the stem and are often the first to fail under heavy loads. When possible, proper stocking and pruning will minimize the risk of limb or stem breakage. Stands that have been recently thinned may be more severely damaged, especially if trees have been suppressed for an extended period of time.

Rain

Normally, rain is considered to be beneficial for trees as opposed to a stress agent, however, too much of anything can be bad. Heavy rains can actually damage leaf tissue or cause minor defoliation. Prolonged periods of leaf wetness can increase susceptibility to certain diseases such as anthracnose or needle cast. Splashing rain is a common mode of pathogen transmission for diseases such as fire blight and sudden oak death. Saturated soils also tend to be conducive to root pathogens such as *Pythium* and *Phytophthora*. Shallow rooted trees are susceptible to wind-throw or root-lifting when the surrounding soil remains saturated for a prolonged period of time, especially when strong winds occur. Soils that remain saturated for long periods may also inhibit a tree's ability to conduct many of the essential oxygen-requiring physiological processes that occur in roots, stressing the tree and making it susceptible to secondary stress agents. Excessive rain in the fall may delay the "hardening off" of succulent tissues before winter, leading to an increased risk of late season frost damage.

Lightning

Lightning is an atmospheric discharge of electricity that can exceed 54,000 ºF (many times hotter than the surface of the sun). Lightning tends to be "attracted" to objects on the ground with a slight positive charge that are nearest to the negatively charged storm clouds above. This makes trees an ideal target for lightning strikes. The type of damage a lightning strike will cause is difficult to predict. In some cases, the damage may be obvious such as the classic vertical stripping of bark (that may be continuous or discontinuous) that may spread straight down the stem or may spiral around the circumference of the tree. In other cases the damage may be more extensive and the tree will appear as if it exploded from the inside. Many lightning strikes go undiagnosed however because they do not cause obvious physical signs. Instead, the tree's vascular system may become super-heated and permanently damaged by the strike. Vascular system damage may be widespread (even extending into the roots) or may occur in relatively localized areas of the tree and can mimic drought or disease symptoms.

Hail

While a relatively uncommon event, hail poses a significant threat to tree health. Hail forms when super-cooled water droplets collide with tiny ice crystals. Strong updrafts produced during severe thunderstorms can keep hail particles suspended in the atmosphere for long periods of time allowing them to grow to sizes in excess of several inches in diameter. The speed at which hailstones fall varies with size; a small stone can reach speeds of around 25 mph, but larger stones can hit the ground at speeds in excess of 200 mph! Even a small, relatively slow moving hailstone can cause severe damage to a tree. Foliage is easily bruised, shredded and/or stripped from trees during hail storms. Hailstone impacts on the stem, branches, and twigs can easily kill the underlying cambium tissue, resulting in a necrotic canker. Widespread cankers can cause branch dieback and severely stress a tree, making it susceptible to attack by secondary insects and pathogens. Wounds caused by hailstone impacts often serve as infection courts for many bacterial and fungal diseases.

Storms

Severe storms expose trees to a combination of many of the most destructive atmospheric stress agents in a short period of time. It is not uncommon for trees to experience heavy rains, saturated soils, strong winds, snow, ice, hail, and/or lightning during a single storm event. Severe damage or mortality often cannot be avoided during the worst storms, but proper tree care starting with the right species selection for the site, appropriate stocking density, and/or pruning when appropriate can minimize damage during less severe events. Large trees should never be “topped”; topping can cause extensive decay pockets and induce epicormic sprouting that gives rise to weakly attached branches that easily break during storms. Care should be taken to regularly examine trees that pose potential hazards to people or structures. Fruiting bodies, holes, or sunken areas on the main stem may indicate areas of decay or weak points that may fail during a storm. After large storm events, trees should be assessed for immediate damage, and be monitored for several years for secondary insects and diseases.

Flooding

Although some tree species are tolerant of periodic or even prolonged flooding, most tree species are severely stressed by flood events. Roots require oxygen for cellular respiration, which is the process of metabolizing sugars to produce energy. The energy produced from respiration is used by trees to power a wide variety of physiological processes necessary to stay alive. During floods, tree roots become starved of oxygen, and therefore cannot undergo cellular respiration. If flooding is prolonged, the entire root system can be severely damaged, eventually leading to decline or death of the tree. Flood tolerant species have evolved mechanisms to transport oxygen from the crown of the tree into the roots, while flood intolerant species lack this oxygen transport mechanism. Flooding while trees are dormant is usually less damaging that flooding that occurs during the growing season. Flood damage symptoms may take years to develop and are difficult to diagnose because they resemble many other root disorders and diseases. Be aware that prolonged soil saturation can have the same effect as floods.

Drought

Water is a critical component of nearly every physiological process in plants; without water, trees will rapidly wilt and die. On average, trees require 1 inch of water per week. A large mature oak can lose nearly 400 gallons of water on a hot summer day through transpiration. Fortunately, trees have vast root systems that, using mychorrizal associations, can access water from the small spaces between soil particles. Trees respond to short term water shortages by closing small pores in the leaf surface called stomata and minimizing transpirational water loss. Longer periods of drought can cause wilting and browning of foliage, embolisms in the tree's vascular system which further inhibit water translocation, dieback of the tree's crown, and eventually death. Drought symptoms will first appear where water is lost at the highest rates (foliage) and at points farthest from the water supply (leaf tips, inter-veinal leaf tissue, and the upper crown). It may take a tree several years to fully recover from prolonged drought. Drought stress can make trees highly susceptible to secondary stress agents.

Salt Damage

Trees can be damaged by salt that sprays or drifts onto foliage or by salt that leaches into the soil. Salt damage is most common in coastal areas, particularly after large storms, and along roadways where de-icing salts are commonly used. Tree species vary in sensitivity to salt in the soil or on foliage, and salt damage severity can vary from year to year depending on temperatures, rainfall, and timing of salt exposure. High levels of salt in the soil can inhibit a trees ability to absorb water and mineral nutrients and may kill fine roots and root hairs. Excessive salt can also cause the soil to break down, leading to poor aeration and permeability. When salt contacts succulent green tissues such as the foliage and buds, water can be drawn out of these tissues. The result is the desiccation and death of leaf cells and common salt injury symptoms such as leaf and needle browning and premature defoliation. Prolonged salt exposure can lead to decline symptoms such as foliage chlorosis, growth reduction, abnormal growth patterns, thin crowns, dieback, and even mortality.

Frost / Freezing

During freezing temperatures, ice crystals form inside of plant cells that rupture the cellular membrane, resulting in death of frozen tissues. Plants have developed many adaptations to avoid freeze damage. For instance, deciduous species shed their leaves and “harden off” succulent tissues before the first frost to avoid damage, and the cells of pine needles expel water into intercellular spaces to avoid intracellular ice crystal formation. However, early frosts in the fall or late frosts in the spring can catch trees off guard and unprepared for freezing temperatures.   Newly expanding leaves in the spring are the most susceptible, as are actively growing tissues in the fall such as shoots that have not adequately hardened off. Freeze damaged tissues may appear bruised and water soaked, eventually turning brown or black. Dead tissues may eventually fall out of leaves, giving foliage a “shot-holed” appearance. Excessive rainfall in the fall can encourage trees to continue to put on new growth that may not adequately harden off before the first frost.

Heat

The vascular system of a tree, which is responsible for transporting water and nutrients, and the cambium, which is responsible for diameter growth, lie just beneath the bark. Combined, the vascular system and cambium are usually less than ½ inch thick. Bark is a relatively good insulator, however, intense heat can easily damage this thin layer of vital tissues and cause severe injury or death. Trees with thin bark are more susceptible to heat injury on the stem, but even thick-barked species can be damaged. Avoid placing trees in close proximity to surfaces that absorb and radiate intense heat such as asphalt or dark rocks. Radiant heat from these surfaces can easily "cook" the living cells of the vascular system and cambium on a hot summer day. Succulent tissues such as leaves and young shoots are particularly susceptible to intense heat. The living cells of these tissues can be killed by excessive temperatures, or rapid water loss through transpiration may exceed the trees capacity resulting in wilting or leaf scorch. This is frequently seen on low branches over parking lots.

Air pollution

The foliage of trees, particularly hardwoods, is very susceptible to air pollutants including sulfur dioxide, fluorides, and oxidants such as ozone. These pollutants can be absorbed by leaf tissues, and if concentrations are high enough, will kill cells in a few hours or days. This can stress trees and lower overall tree health. Well defined concentration gradients of pollutants may exist downwind of pollution point sources, and in these cases, injury is most severe near the pollution source and will diminish as distance from the source increases. In other cases, regional sources of these pollutants can result in uniform and widespread distribution of air pollutants over large geographical areas. In broadleaf species, ozone damage will cause leaf stippling or unusual pigmentation patterns. The stippling may be red, purple, brown, or black, and can be restricted to certain areas of the leaf or appear uniformly over the entire leaf surface. Ozone can cause chlorotic mottling and tip burn in conifers. Sulfur and fluoride injury usually results in interveinal and/or marginal necrosis of leaf tissue.

Fire

While some tree species are adapted to survive low to moderate intensity fires, excessively high temperatures can damage even the most fire-adapted trees. Because of the proximity of the vascular system and cambium to the bark surface, these vital tissues can be easily damaged or killed if not protected by a thick layer of insulating bark or if fire temperatures become excessive. In addition, foliage, buds, and near-surface roots can be damaged or killed during fires, further stressing trees and making them susceptible to secondary stress agents. Frequently, secondary insects such as ambrosia beetles will invade damaged tissues shortly after a fire event. If trees are severely stressed, opportunistic insects such as *Ips* engraver beetles or southern pine beetles may move in. Frequent, low intensity burns are less likely to injure or kill trees. Intense fires generated by heavy fuel loads, dry conditions, and strong winds are more likely to exceed the capacity of the bark to insulate. Fire injury may show up immediately, but often the effects are not noticed until many years after the damage occurs.

Mechanical Damage

Mechanical damage refers to the physical injury of a tree and is a term usually reserved for those injuries caused by people or animals. Woodpecker feeding sites, deer rubs, and beaver and rodent feeding are some examples, but people tend to be far more destructive. Examples of human caused mechanical injury include weed-eater and lawnmower damage, root injuries, nailing objects to trees, tying ropes around the stem or branches which eventually girdle the tree, pruning, equipment impacts during logging or construction, and acts of vandalism such as name carving or intentional girdling. Trees do not have the ability to "heal"; they can only compartmentalize injuries such as these. Repeated injuries or severe damage can lead to decay, disease, localized dieback, or even mortality. In most cases, mechanical damage is completely preventable, and requires little more than planning and preparation when using equipment around trees. For instance, mulching around trees eliminates the need to mow up against the stem; and the use of "bumper trees" along skid trails can minimize damage to valuable trees during logging operations.

Root Injury

The vast majority of a tree's root system is present within 24 inches of the soil surface. While frequently forgotten because they are out of sight, roots are critical because they absorb water and mineral nutrients from the soil, store carbohydrates, and anchor and support the tree. Because of their proximity to the soil surface, roots are easily injured by human activities. Often these injuries are accidental such as those caused by lawnmowers and soil compaction. In other cases they may be intentional, such as when roots are cut to install irrigation lines, sidewalks, utility lines, or during construction projects. Small diameter "feeder roots" can be replaced by a tree when they are damaged, however the larger "buttress roots" that emerge from the root collar only develop early in a tree's life. Damage to large roots can seriously impair a tree's ability to obtain adequate water or remain anchored in the ground properly. But even damage to small roots can impair tree health. Root injuries are often invaded by pathogenic organisms and/or insects, and may act as the entry points for decay.

Herbicide Damage

When used correctly, herbicides can be a valuable vegetation management tool. However, improper use or failure to heed all herbicide label instructions and warnings can result in herbicide injury to non-target plants. Symptoms of herbicide damage vary widely with the herbicide and formulation used, time of year the product was applied, and the plant species affected. The most common symptoms of herbicide injury can include chlorosis, dieback, epicormic sprouting, abnormal growth patterns, stunting, wilting, death, and/or the cupping, strapping, curling, or abnormal thickening of foliage. Often, more than one plant species will be affected when herbicides have been used improperly, although some plants can be especially sensitive to certain types of herbicides. Herbicide injury often results when chemicals drift on to non-target plants, are applied to stressed or otherwise unhealthy plants, or when residual chemical in the soil remains present and active for longer than expected. Herbicide injury can often be diagnosed by an expert based on symptoms alone, but positive confirmation can only be achieved through expensive laboratory testing.

Nutrient Imbalances

Nutrient imbalances occur most commonly when there is a macronutrient or micronutrient deficiency in the soil, but may also occur, for example, when excess nutrients are present, when nutrients are unavailable to the tree because of improper soil pH, or when there is a problem with root system structure or function. The most obvious symptoms of a nutrient imbalance are chlorotic foliage, possibly accompanied by growth loss or even deformed growth. Different tree species will react differently to nutrient imbalances, but there are many useful patterns that can be used to narrow down possible problems. For instance, symptoms of deficiencies of mobile nutrients such as N, P, or K will show up in new growth, while deficiencies of immobile nutrients such as Ca, Cu, Mn, or Zn will cause symptoms in older tissues. Color of foliage alone may be enough to determine which nutrient is lacking. Diagnosing specific nutrient imbalances can be difficult using symptoms alone so chemical tests of soil and / or plant tissues are usually recommended.

Frost Cracks

A frost crack is a form of bark damage sometimes found on thin-barked trees. A frost crack is a vertical fracture or crack, usually on the south-facing side of a tree's stem. Frost cracks originate from some sort of weakness in the bark, often an old wound that has since disappeared from the bark surface. During winter months, the inner bark and outer xylem can expand and contract under the widely fluctuating temperatures of cold nights and warm sunny days. Surface bark may cool and contract and / or warm and expand faster than underlying wood, stressing weak points in the stem. Wood that is in some way damaged does not flex to the same degree as healthy wood, resulting in a sudden rupturing of the bark, sometimes with an audible report likened to that of a rifle. These cracks may heal in the summer and reopen again during the winter, so that successive cracking and callus formation over a number of years results in the formation of 'frost ribs' on the sides of affected trees. Frost cracks may act as sites of entry for wood decay organisms and insects.

Sun Scald

Sun scald occurs during the winter months, most frequently on thin-barked trees on the south or southwest facing side of the stem. During warm winter days, sunlight directly contacting the bark may warm the bark enough to bring the living cells of the phloem and cambium out of dormancy. As the sun sets and temperatures rapidly cool, these living cells can freeze suddenly, resulting in the death of large vertical patches of inner bark. During the spring, bark that has been killed by sun scald may slough off, revealing the full extent of the injury. Trees will attempt to form callus tissue over these large open wounds, but frequently these new tissues are killed the following winter, creating perennial open wounds that never fully "heal over." Commercially available tree wraps or crepe paper can be used to insulate the bark from the warm winter sun, and white paint is often applied to the stems of susceptible tree species in orchards and landscape settings to reflect winter sunlight. Using these protective measures after injury has occurred is the only option available to allow the tree to recover.

Soil Compaction

Soil compaction occurs when heavy loads compress soil particles together causing the loss of natural soil structure and pore space. Compaction can occur over a long period of time by frequent light loads passing over the site (e.g. a walking path), or can occur instantly with a very heavy load. Wet soils are particularly susceptible to soil compaction. Water is not absorbed readily by compacted soils, leading to chronic runoff and erosion issues. Water and oxygen cannot penetrate as deeply into compacted soils, and therefore roots are unable to get the water and oxygen needed for growth and survival. Heavily compacted soils can also inhibit root growth if they are exceedingly dense. Soils vary in their capacity to become compacted and return to a normal state. Clay soils are particularly susceptible to severe compaction and may never fully recover without mechanical assistance. Avoid using heavy machinery within the drip line of trees. In areas with frequent or heavy traffic, a layer of mulch 1-3 inches thick will provide some protection.

Soil Grade Changes

The vast majority of a tree's root system occurs within the upper 24 inches of the soil surface. Within this region water and oxygen are most available. Grade changes occur when soil is either removed from or added to the soil surface. Grade changes can occur naturally (e.g. during flooding), but most often they are a result of grading and excavating by people. When soil is removed around a tree, most of the root system responsible for water, mineral, and oxygen absorption is also removed. The remaining root system is unable to support the tree's needs, and therefore, decline or death can result. Likewise, tree health can be adversely affected when soil is added on top of a tree's root system. Additional soil starves the root system of water and oxygen and may cause soil compaction in the root system region. Usually the affects of grade changes take years to develop in trees. If grade changes are necessary, they should be avoided within the drip line of trees. Use of retaining walls to either keep added soil away from the tree, or to protect the root system when soil is removed is a commonly utilized practice, but walls should be placed as far from the tree as possible.

Improper Pruning

Proper pruning is an important part of tree care in urban, landscape, and ornamental trees. When done properly, pruning wounds are compartmentalized by the tree and can benefit tree health in a variety of ways. However, improper pruning can injure trees, slow compartmentalization, and lead to insect or disease problems. Pruning should be done with the proper tools; use of the three-cut method ensures the cut is made outside the branch collar with no remaining branch stub or bark tearing. Cutting within the branch collar can cause decay in the main stem, and leaving a branch stub can significantly slow compartmentalization. Bark tearing occurs when an undercut is not made on the branch being removed and results in a larger wound that can allow decay fungi to enter. Several important tree diseases are caused by pathogens that can enter the tree through pruning wounds. Care should be taken to sterilize pruning tools and only prune during seasons when the risk of infection is low. Do not apply pruning paint to the wound unless oak wilt is known to occur in the area.

Deep Planting

When planting large-caliper trees such as balled-and-burlapped or containerized saplings, care should be taken to ensure the root flare (the point at which the stem begins to flare out into the root crown zone) is level with the soil surface. Planting trees too deeply can cause a wide variety of problems including disease, bark and stem decay, deformed or girdling roots, and can starve the root system of water, nutrients, and oxygen. Trees planted too deeply can suffer from decline and eventual death. Typically, problems associated with deep planting do not develop for many years, therefore trees usually decline and die just as they reach maturity after years of investment and care. Once a tree has been planted too deep and is established, there is little that can be done to reverse the effects. Follow appropriate tree planting guidelines. Often trees from nurseries will already be planted too deeply in their containers, so be sure to remove soil from containers or the root ball until the root flare is exposed. The root flare should be level with the soil surface when planting is complete.

Improper Mulching

Mulch, when applied properly around trees, can provide many benefits including improved soil moisture retention, reduced soil compaction, reduced competition from weeds and turf, reduced risk of wounding by lawn care equipment, slow release of important nutrients as the mulch decomposes, and improved appearance. Mulch that is applied too thickly or piled high on the tree's stem can have the same effect as deep planting or grade changes. A thin layer of mulch 1-3 inches thick can be applied around the base of a tree at the time of planting, and can be reapplied as needed every few years. Using thick layers of mulch can starve the tree of water and oxygen. Mulch piled high onto the stem can cause disease problems, stem and bark decay, and the formation of abnormal root systems. Extend the mulch zone as far out from the tree as possible. Using natural materials such as bark or shredded wood mulch provide the benefit of some added nutrients, but tend to break down more quickly. Artificial mulches last longer, but can for instance, reflect excessive heat onto the tree's stem. Use local sources of mulch.

Included Bark

Normally stems and branches grow in such a way that bark is confined to the surface of the tree. However, some tree species have a tendency to form multiple stems or develop improper stem/branch unions which can trap bark between adjacent stems and/or branch tissue. This union is relatively weak in strength, and can eventually fail when the tree grows large enough, particularly during storms. Improper pruning can also result in multiple stemmed trees that are prone to included bark formation. Trees that form branches with narrow branch angles are also particularly susceptible. Proper pruning, including the removal of multiple stems, co-dominate leaders, and branches with narrow branch angles, can reduce the risk of included bark formation. Mature trees with large regions of included bark should be inspected frequently for hazard potential. Cable and bracing techniques can be used to strengthen the weak regions in large, valuable trees with included bark.

Girdling Roots

Girdling roots are roots that completely or partially encircle the main stem of a tree. As girdling roots and the stem increase in size, the root tissue can strangle the underlying vascular system of the tree's stem. Eventually, the part of the stem that has been girdled will die. Girdling roots that completely encircle the stem can eventually cause tree death. Girdling roots form for a variety of reasons. Some tree species have a tendency to naturally form girdling roots, but in most cases they result from improper tree care. For instance, trees grown for extended periods in containers may develop girdling roots that can eventually kill the tree many years later. Trees in containers or burlap balls should be inspected for girdling roots before transplanting. Compacted soils, deep planting, grade changes, and root system obstructions can also lead to the formation of girdling roots. Once the effects of girdling are observed, it is usually too late to fix the problem. Girdling roots, when discovered early, can be cut and removed before they completely strangle the stem.

Genetic Disorders

Trees, just like people, are all unique individuals. Occasionally, genetic variations may occur in an individual tree that in some way distinguishes it from the surrounding population. For instance, genetic variations may make trees more disease resistant (or susceptible), possess faster growth rates, or be especially drought resistant. Genetic variations contribute to the evolution of a tree species through natural selection. Sometimes genetic variations arise in a tree that can have a dramatic effect on the tree's appearance or health. For instance, occasionally mutations occur that cause unusual leaf pigmentation called "variegation." Variegated leaves have unique patterns of green and chlorotic foliage, and can even be propagated and resold as unique cultivars. Total lack of pigmentation is called "albinism." While frequently beautiful and always unique, these genetic mutations can negatively impact tree health. Severe variegation or albinism can cause leaves to be intolerant of direct sunlight, or make them more susceptible to foliar insects and pathogens.

Diagnosing Disorders of Trees

Diagnosing tree problems can be difficult. Symptoms and signs can be subtle or only visible using special techniques, important information can be missing, there can be multiple contributing stress agents that make conclusive diagnoses problematic, secondary pests may obscure the primary stress agent, and beginners may lack a familiarity with the common symptoms and signs of biotic and abiotic stress agents common in their area. However, the major difficulty in diagnosing tree health issues is usually not insufficient expertise in forest pathology or entomology; there are many resources available that can assist with the identification of specific pests. Rather, inexperience with proper diagnostic methodology puts beginners at a disadvantage. But diagnosing tree problems can be fun and rewarding if an ordered, scientific approach is utilized and observation skills are practiced and improved. Of course, familiarity with basic forest pathology, entomology, tree physiology, tree anatomy, dendrology, and silviculture are essential to make correct diagnoses.

The following is an ordered approach to tree disorder diagnosis that beginners and experienced foresters alike may find useful. The "Ten S's of Tree Disorder Diagnostics" is a list of information that should be collected and considered every time a diagnosis is undertaken. Careful observation and collection of this information can either lead to a correct diagnosis, or considerably reduce the potential causes of a tree disorder. In some cases, samples must be collected and submitted to a diagnostic lab for additional assistance or definitive confirmation of a diagnosis made in the field. In other instances, careful observation in the field followed by consultation of diagnostic resources such as forest disease and insect texts or forest health websites may be sufficient to identify the causal agent.

*** The Ten S's of Tree Disorder Diagnostics ***

Host Factors

1) ***Species.*** The first diagnostic step should always be the identification of the tree species affected. Many disorders, especially those caused by biotic stress agents such as insects and pathogens, are species specific. In fact, most insects and pathogens a have a very narrow host range, and may be capable of attacking only one or a few tree species or cultivars. Identification of the tree species can effectively eliminate the vast majority of potential insect and disease problems, and narrow the list of suspected agents to a manageable level. Many tree species vary in response to abiotic disorders as well. Familiarity with the specific sensitivities of tree species to abiotic stresses may help narrow the focus of an investigation. Other abiotic disorders are less species specific. In general, if only one tree species (or a number of closely related tree species) is affected while other species are not harmed, it is likely that a biotic stress agent is at work. If many or all tree species in an area are affected, then abiotic causes should be investigated. Familiarity with tree species can also indicate what is normal, and what is abnormal. Often, obvious clues to the stress agent at work are overlooked because they are not recognized as abnormal. Alternatively, significant concern can be generated when the traits of perfectly healthy plants are confused with a disorder.

2) ***Sex.*** Many tree species are ***dioecious***, meaning that they have separate male and female individuals. Even ***monoecious*** species that lack individuals with a specific gender have separate male and female reproductive organs. Examples of dioecious species include ash, maple, sumac, persimmon, holly, cedar, juniper, Osage orange, poplar, willow, and ginkgo. Many tree disorders only affect male or female individuals, or alternatively, only male or female plant parts. At times, determination of tree gender can be difficult, especially when trees are young or dormant. During the growing season, reproductive structures such as flowers, fruits, and cones can indicate the sex of a tree.

3) ***Stock.*** Knowledge of where a plant came from can provide important information when tree health declines. If possible, the seed source, nursery of origin, and provenance should be identified. Many pathogens can be spread in seeds or on seedlings. If a particular nursery or seed source has had a known problem with a specific pest, identification of plantings that used those plant materials can be identified and monitored for health issues. Some landscape nurseries are reputable and produce quality plants for use in ornamental and shade tree situations, but quality control may not be a top priority in others. Familiarity and experience with a nursery and the plant materials provided by them can indicate where potential problems may arise. ***Provenance*** indicates where a plant, or its genes, originated. Subtle variations in a variety of tree characteristics may be present across the large natural ranges of many

tree species. A tree with northern provenance may lack heat and drought tolerance and do poorly when planted at the southern end of the species range. Alternatively, a tree from the south may lack the structural strength to survive ice storms that may be more common in the northern portion of its species range. Therefore, the provenance of a tree may provide important clues as to tree health problems.

4) ***Size.*** Many forest pests only attack trees of a certain size or age, or may only attack certain portions of a tree that meet a size preference. Some insects and pathogens only attack seedlings, while others prefer stands of over-mature timber. Certain insects prefer to attack the lower portion of the main stem, while others attack only the small twigs and branches high in the crown. Many trees species are plagued by pest attacks for their first few years of life, or until they reach a certain height, and then become pest free once a threshold is exceeded. Trees of a certain size may also be exposed to unique microclimates that make them more susceptible to attack. Small trees in dense stands may be suppressed, have poor air circulation to facilitate drying of foliage, are close the ground where spores from many pathogens are produced, etc. Large trees are more prone to lightning strikes and high-winds, and are more likely to suffer severe harm from root injuries. Abiotic disorders such as girdling roots and compartmentalized injury may be present when a tree is planted, but tree health may not decline until the tree has grown for many years.

5) ***Symptoms***. Symptoms are a plant's response to a stress agent and the injury it is causing. Some symptoms are very general and are produced in response to many stress agents, while other symptoms are very specific to certain pests or abiotic disorders. Frequently, unhealthy trees will have more than one symptom. Familiarity with the various types of symptoms and an ability to identify all symptoms present is essential for proper diagnoses. When taken together, a set of symptoms can often indicate the cause of the disorder. Common symptoms include:

Stunting	Galls	Flagging
Chlorosis	Discoloration	Leaf Cupping
Necrosis	Decay	Scorch
Weeping	Lesions	Water Soaking
Dieback	Leaning	Swelling
Wilting	Abnormal Fruiting	Resin Soaking
Defoliation	Callus	Pitch Tubes
Hypotrophy	Sprouting	Foliage Shedding
Hypertrophy	Witches Brooms	Tufting

Stress Agent Factors

6) ***Signs***. Signs are a direct observation of the stress agent itself or evidence of its activity. If a sign can be located and collected, a diagnosis can often be achieved quite readily. However, the presence of a stress agent does not necessarily imply that it is the causal agent responsible for the observed decline in tree health. Many signs on dead or dying trees may be from secondary stress agents that are present only because a predisposing factor or primary pest has already weakened the tree significantly. Some examples of signs are:

Insects	Exoskeletons	Smog
Pupal Cases	Spores	Soil Test Results
Mushrooms	Rhizomorphs	Hardpan
Fruiting Bodies	Charcoal	Frass
Galleries	Tents/Webbing	Egg Niches
Entrance Holes	High Water Marks	Bite Marks
Exit Holes	Wounds	People

Environmental Factors

7) ***Season***. The symptoms and signs of many stress agents appear at specific times of the year. Pests, such as insects and pathogens, have life cycles that are closely tied to host ***phenology,*** which is the timing of plant growth and development throughout the year, and environmental conditions such as light, temperature, and rainfall, which vary by season. Symptoms or signs that may be similar for many different stress agents can be distinguished by the time of year during which those stress agents produce those symptoms or signs. Alternatively, many pests only produce visible life stages at a certain time of year. If a stress agent is suspected, but cannot be verified, a return visit when the suspected pest will be visible can confirm the diagnosis.

8) ***Site***. Site is often a major contributor to forest health issues because many predisposing factors originate from site conditions. There is often a tendency to look only at the tree for symptoms and signs, but close inspection of the surrounding area may reveal the cause of the problem. Both abiotic and biotic components of the surrounding forest may contribute to tree disorders. Some examples of site characteristics to consider include:

Slope	Disturbance	Species Composition
Aspect	Exposure	Alternate Hosts
Soil Characteristics	Light	Climate
Elevation	Strata	Site Preparation
Proximity	Forest Type	Microclimate

9) ***Spread***. Patterns in the distribution of symptoms and trees affected in the landscape can be important indicators of tree disorders. Where and when did the problem start? How fast is it changing (if at all)? Where is the problem most severe? Has the problem disappeared in one area but appeared in another? How many tree species are involved? What else in the landscape follows the same pattern: roads, field edges, elevation, soil type, prevalent wind direction, recent disturbance, management activities? Is the problem randomly distributed or does it follow an organized pattern?

10) ***Stand History***. The history of a forest stand or single tree is often the most important information when diagnosing a tree problem (and often the most difficult to obtain). Stand history may provide important information as to predisposing factors that may have been present in the past. Frequently, tree problems become visible long after the evidence of a predisposing factor has disappeared. In other cases, the stress agent itself may have been noticed and ignored by a landowner or homeowner because it was not recognized as a potential problem. In many cases, detailed knowledge of stand history can provide enough information to significantly narrow the list of potential stress agents. Consider previous crops grown on the site, past root damage, thinning operations, pesticide applications, fertilizer applications, age of the stand, planting method, pruning activity, grade changes, past weather events, fires, and long-term trends in the forest.

Pest Management

Insects and diseases claim more timber each year than any other forest menace. Some of this loss is a natural part of the forest's natural cycle; however, forest health can decline if this natural cycle is thrown out of balance. We value and rely on forests for a wide variety of resources that can be threatened by forest pests, and therefore it is important to monitor forest health and intervene when those resources are at risk. Proper forest management, early detection, and protective measures can prevent or reduce the effects of insect and disease problems; while more intensive management and control options are available when required.

Forest pest management can be difficult for a number of reasons. Trees are generally a low-value crop per acre; to make a forest profitable one cannot afford the cost-intensive control options that are frequently utilized for other agricultural crops. In fact, complete control or eradication of forest pests is, with few exceptions, difficult or impossible to achieve. Trees are grown on vast acreages making monitoring difficult, access problematic, and management/control of pests very expensive. Unlike an annual crop that matures within a single growing season and may only be exposed to a few pests or environmental stressors, trees are long-lived and exposed to many stress agents over the course of their lifetime. They are also very large organisms, so close examination of an entire tree including its leaves, branches, roots, and internal structures, is impossible. Chemical applications that require thorough coverage over the entire plant are limited to young trees or small cultivars. Trees do not heal; rather they compartmentalize their wounds. Compartmentalization is an effective way to contain injured, diseased, or dead tissues, but these "walled-off" pockets of wood and decay can lead to tree health problems years after the initial damage occurred. Trees are the largest organisms in forest communities, and any treatments or control options may adversely affect other organisms in the vicinity. Injury to non-target organisms is a major concern in forest health management. Finally, there are relatively fewer chemical control options available for forestry use than in agriculture or landscape management. Because of these difficulties, forest managers must use an Integrated Pest Management approach when dealing with forest pests and other stress agents.

Integrated Pest Management (IPM) is an environmentally friendly and cost effective approach that utilizes a variety of preventative measures, cultural controls, and direct control measures to promote plant health. No single activity in an IPM program is effective on its own; rather, all of the components of the program contribute to plant health and when used together, effectively keep pest problems below a tolerable threshold. The first and most important step in establishing and maintaining a healthy forest is proper forest management. Planting the appropriate tree species for the site, managing competing vegetation, maintaining appropriate stocking, minimizing injury and stress, and adhering to sound silvicultural methods is the first step in preventing disease and insect problems, and minimizing the impacts of stress agents. In urban forests, proper tree care including water, fertilization, pruning, mulching, and correct species selection will promote long-lived trees that provide many benefits.

An important component of proper forest management and tree care is monitoring the health of the forest and trees within it. Because of the difficulties encountered when managing forest health problems (as discussed above), it is best to detect and mitigate problems early and when they occur at small, localized levels. When an outbreak or epidemic occurs, foresters are often left with very few effective control options. An awareness of the health of your forest, the health of trees in the surrounding area, past predisposing factors, and any changes in the forest community that could throw the natural cycle out of balance is critical to prevent widespread and severe damage by pests.

Foresters have a variety of methods at their disposal to prevent, manage, and control pest problems. The following approaches can all be used as part of an integrated pest management program:

1) ***Exclusion***, otherwise known as quarantine, targets the introduction of forest pests. Quarantines may be difficult to establish, but are usually the cheapest method of pest control. Quarantines are only effective when the pest is not already present in an area, and when natural or artificial boundaries can be established that can effectively prevent introductions. Internal quarantines are utilized to keep a pest inside of the area where the pest is already established. Laws and regulations forbid the export of potentially infested material out of the quarantine zone without certification. External quarantines are enacted in areas free of a certain pest and prevent the importation of potentially infested materials into the pest-free zone. Quarantines can be enacted at city, state, regional, and international levels, but can also be utilized on much smaller scales. For instance, growers can inspect seedlings at the time of planting for disease or insect problems carried in on nursery stock, and effectively exclude those pests from becoming introduced into the stand. Use of soil-less planting media in containerized nursery stock may prevent the introduction of soil-borne pathogens, and use of only local seeds and plant materials can avoid the establishment of non-native pests.

2) ***Eradication*** is utilized when a quarantine has failed. The ultimate goal of eradication is to completely eliminate the pest from an area so that an external quarantine can be established. But complete eradication is only possible when pest populations are small, or when the pest is highly sensitive to control measures. In forestry, this is rarely the case, so eradication is also referred to as ***sanitation***. Sanitation seeks to reduce the pest population below acceptable levels, but usually does not result in complete elimination of the pest. Sanitation and eradication can be achieved through fumigation, crop rotation, destruction of infested/infected plants or plant parts, and destruction of potential hosts.

3) ***Protection*** is utilized to protect susceptible plants from attack, injury, or disease when a pest is present. Also known as prophylactic treatments, protective measures must be in place before the tree is attacked by the pathogen or insect. Typically, prophylactic treatments consist of a ***protectant pesticide*** that is sprayed onto the surface of the plant to prevent an infestation/infection from occurring. Protectant pesticides, because they reside on the plant surface, tend to wash off over time and must therefore be applied periodically while the pest is present. However, some protectant pesticides have systemic properties that allow the chemical to be taken up into the plants vascular system where it may provide long-lasting protection. Protectant pesticides tend to be very effective, but are also among the most expensive control measures because of the need to constantly apply them, and the most likely to cause environmental damage or harm to non-target organisms. Because protectant pesticides need to be applied often and in large quantities, there is also an increased risk that the pest population will develop resistance to the chemical.

4) ***Cures***, or therapeutic treatments, are available in certain cases that limit the damage to a tree that has become infected/infested by a pest, and may potentially eradicate that pest from the plant so further damage does not result. Cures cannot heal the tree, but they may allow recovery if the pest population is incapacitated, reduced, or eliminated. Therapeutic treatments usually come in the form of systemic pesticides that are injected into or taken up by the plant; translocation of the pesticide throughout the infested/infected plant is necessary for adequate control. The benefit of cures is that they can be applied only when needed (after the plant has been attacked), as opposed to prophylactic measures which must be continually applied to prevent an attack from occurring in the first place. This makes them more environmentally friendly, potentially more cost effective (over the long term), and reduces the risk of resistance development in the pest population. However, there are relatively few therapeutic options available in forestry, and they tend to be reserved for high-value trees (landscape trees and ornamentals) because of their high cost per plant.

5) ***Incomplete Resistance***, also known as horizontal resistance or polygenic resistance, is a type of resistance that does not prevent infection/infestation from occurring, but limits the number of attacks or the extent of damage that occurs to the host. Trees with incomplete resistance may not be attacked by beetles as frequently as highly susceptible tree species, may have fewer infections by pathogens, or may have less severe symptoms/signs resulting from those attacks. Incomplete resistance is controlled by many plant genes; each gene partially contributes to plant defenses, but alone they provide little protection. Overall, incomplete resistance is the best possible control option available if it is sufficient to keep damage below acceptable thresholds. The protection it provides is inexpensive, long-lasting, and durable. However, it does permit some damage to occur, and it is difficult to develop this type of resistance. Because many genes are involved, it can take many years (or generations) of plant breeding to achieve desirable results.

6) ***Complete resistance***, also known as vertical resistance or monogenic resistance, is a type of resistance that either prevents infection/infestation completely, or prevents any damage from occurring after an attack occurs. Complete resistance is controlled by a single plant gene that confers 100 percent protection to the plant from a specific pest. Obviously this type of resistance is highly desirable, and can actually be developed quickly through genetic engineering. Occasionally, completely resistant individuals can be found in nature, and used to develop resistant plant varieties. However, initial development of a completely resistant plant variety can be very expensive. In addition, because complete resistance is only controlled by one gene, there is an increased risk that the pest population will evolve mechanisms to overcome that resistance, in which case the variety would become completely susceptible.

7) ***Avoidance*** is perhaps the cheapest and most effective option available to control pest problems, but there are few applications of avoidance available in forestry. The key to avoidance is to make the host unavailable or the environment unsuitable for pest attacks. For instance, plants can be planted earlier/later in the growing season to avoid the time of year when spores from a pathogen are produced. But because trees are long lived organisms, this type of avoidance is difficult to achieve in forestry. However, examples of avoidance include planting trees in microclimates where the environment is not suitable for infections to occur, or delayed planting of seedlings to allow pest populations to dissipate from a stand.

Non-native Invasive Species

Non-native species or ***exotic species*** are organisms that have been introduced to regions outside their natural or historical home ranges. Typically, the term "exotic" or "non-native" brings to mind organisms from other countries or continents, however, exotic organisms can originate within the same country if they have historically not existed throughout that country (e.g. a species native to the west coast of the U.S. would be considered exotic on the east coast). Non-native species present a unique threat to forest health because they have the potential to become invasive. ***Invasive species*** are organisms that multiply and spread rapidly, displacing other organisms to the detriment of ecosystem health and stability. Invasives can be native (e.g. weeds) or non-native, but typically exotic invasives are much more damaging to forest health than native invasives, which are usually nuisances. ***Non-native invasive species*** include plants, animals, and microorganisms outside their native home range that cause significant injury to, displace, or kill native species. Throughout recent history, non-native invasives have wreaked havoc in our nation's forests. Chestnut blight, caused by a fungus that girdled and killed millions of American chestnuts throughout the eastern U.S. in the early 1900's, was one of the first major non-native invasives to attack our forests, and highlighted the threat posed by exotic organisms. Since that time, thousands of non-native organisms have been introduced to our country, many of which have or continue to threaten or exterminate native tree species and destroy our forest ecosystems.

Exotic species have the potential to become extremely invasive and destructive for a number of reasons. When introduced to a new area, exotic organisms are often freed from the predators, parasites, competition, and/or environmental constraints that kept their populations in check within their native home range, allowing rapid population growth and unimpeded spread through the landscape. New host/prey species are available in the invaded region that did not evolve along with these non-native invasives, and they may therefore lack the defense responses necessary to fend off an attack, or may be unable to sufficiently compete to avoid being displaced. The population size of newly introduced invasives is generally small, while the challenges faced in the new region may be substantial. This creates a genetic bottleneck, that when combined with significant selective pressure, can promote rapid adaptation in the pest population and results in new strains or subspecies of the invader that are optimized for their new environment.

Fortunately, although many exotic organisms may be introduced to the U.S. each year, not all of them become problematic. The process of invasion by exotic organisms involves several stages, each of which places a constraint on potential invaders and may prevent their development into a highly damaging invasive species.

1) ***Introduction*** is the first step in the invasion process, when an organism arrives in a new region. Introductions can occur naturally, as a result of gradually shifting home ranges due to climate change or continental shift for instance. But natural introductions can also occur more rapidly, due to sudden transport of the organism over long distances, for example in a storm or flood. Exotic organisms can also be carried, or ***vectored***, by other organisms that are capable of travelling long distances. Microorganisms and plant seeds ingested in one region can be carried in the digestive tract of migrating animals and released in new regions for instance. More commonly, exotic organisms are introduced through the action of humans, either accidentally or purposefully. With today's modern global economy, boats, airplanes, vehicles, and the goods they carry come from all corners of the globe. Exotic organisms frequently hitch rides on those vehicles or within the products being transported. Detection of these hitch hikers is often difficult or impossible. But there are also many instances where people knowingly introduce an exotic organism (often with good intentions), only to find that the organism is invasive and destructive. However, not all introductions are successful and many exotic organisms are unable to survive in their new environment.

2) ***Establishment*** occurs when an introduced non-native organism is able to survive and reproduce in its new environment. An established organism is generally already suited for its new environment, and is therefore likely to have originated in a place with a similar climate. To become established, the organism must be able to obtain everything it needs to survive, complete its life cycle, and reproduce (e.g. susceptible hosts must be available for exotic parasites), and must have a climate that the organism can tolerate. If either of these requirements is not met, the organism will not survive. Established organisms typically prey on, parasitize, or displace native organisms with potentially damaging side effects to a forest ecosystem. In some cases, non-natives may establish themselves in an unoccupied niche and cause little harm or alterations to the ecosystem.

3) ***Spread*** of non-native organisms occurs after establishment. If the organism is able to spread rapidly through the landscape, it has a high probability of becoming invasive. Resources must be available and the climate

must be suitable to sustain the spread. As the organisms range expands, the population will grow and increasing numbers of native organisms will be injured, killed, or displaced. The rate of spread is determined by many factors including the method or movement/spread, rate of reproduction, landscape characteristics, competition, predation, disease, and environmental constraints. Often, exotic organisms spread relatively slowly through the landscape, but with human assistance, they may spread more quickly. Many forest pests of concern today have spread rapidly and caused wide-spread damage because of a series of new human-assisted introductions that stem from a single, newly-established, localized population.

4) ***Impact*** of non-native invasives results from the interactions that occur when invading organisms prey on, parasitize, displace, or compete with native species. Occasionally native species form symbiotic relationships with exotic organisms that favor both populations (but are not always beneficial for the forest ecosystem as a whole). The long-term impact of non-native invasives is difficult to predict because of the complex interactions occurring within the forest ecosystem. The displacement or eradication of a single native species can set off a chain reaction of negative impacts on other organisms in that community. A cascade of changes in the biotic composition of a forest can impact abiotic components such as water quality and soil stability. Exotic organisms can even hybridize with native species, with potentially disastrous consequences. Even if serious ecological damage does not occur, exotic organisms can become a serious nuisance to humans and to forest management.

5) ***Naturalization*** is the eventual result when an organism spreads into a new region. At some point the organism will reach a natural equilibrium with the native biotic and abiotic components in its new environment; however, the ecosystem is usually significantly altered as a result. Over time, populations of non-native invasives that exploded during their initial spread through a new region, will begin to fall as resources run out, predator and parasite populations increase, and native species adapt to the presence and impact of the new organism. Exotic organisms must also adapt and evolve to their new environment; naturalized population frequently become significantly different from populations in their native range.

Management of non-native invasives is often difficult and presents unique challenges not posed by native pests. Because non-native invasives are freed from significant competition, predation, and parasitism, they often spread at a rate that exceeds our ability to manage or control them. The most effective means of control is to prevent introductions in the first place using quarantines and encourage the use of native plants. After exotic organisms are introduced and become established, eradication of the new organism is only possible when the population is localized and caught relatively early. Once the organism begins to spread through the environment, focus must be shifted to other methods of pest management such as protective and therapeutic treatments, resistance development, and avoidance. If natural barriers are available, or effective artificial barriers can be established, spread of the organism can be halted. In extreme situations where exotic organisms threaten the survival of a native species, seed conservation efforts or establishment of endangered populations in regions free from the invader may be the only way to save the species.

A potentially effective management tool used to control non-native invasives is biological control (also known as biocontrol). ***Biocontrol*** is the use of organisms that can prey on, parasitize, or displace the pest of concern. Although biocontrol options are usually incapable of completely eradicating a pest, they can significantly depress their populations and minimize their impact. When utilized properly, biocontrol options tend to be environmentally safe, have few non-target effects, and are relatively inexpensive once the bio-control organism becomes established. However, biocontrols are often times unavailable for non-native invasives because the invader is free from its native predators, parasites, and competitors. Therefore, biocontrol agents for non-native invasives need to be sought out in the native range of the exotic pests, imported, and released into the invaded area. Unfortunately, the importation and release of biocontrols presents its own challenges and difficulties. Care needs to be taken to ensure the biocontrol specifically attacks the exotic pest of concern, and cannot cause damage to native species. There is a significant risk that introduction of additional exotic species for biocontrol purposes can result in new non-native invasives.

Diagnostic and Laboratory Services

North Carolina Forest Service – Forest Health Branch

The North Carolina Forest Service – Forest Health Branch provides diagnostic assistance when forest health problems are encountered. Homeowners, landowners, and consulting foresters are encouraged to first contact their county forestry staff for assistance with tree health issues. Cases may then be forwarded to NCFS Forest Health staff, who are specially trained in forest health issues, when necessary. Forest Health personnel provide assistance throughout the state; offices are located in Raleigh, Clayton, Goldsboro, and Morganton. On-site visits, inspections, and consultations can usually be conducted within one week. Pictures can also be emailed to the Forest Health Branch, and assistance for minor problems can often be provided over the phone/email. If a non-native invasive insect, disease, or weed of concern is suspected, the Forest Health Branch should be contacted immediately.

North Carolina State University – Plant Disease and Insect Clinic

The Plant Disease and Insect Clinic at North Carolina State University provides disease diagnostic and insect identification services to help grow healthy plants and crops. Extension specialists from Plant Pathology, Entomology, Horticulture, Crop Science and Soil Science diagnose problems on the samples received. Samples can be dropped off or mailed/shipped to the diagnostic lab with the proper submission form and documentation. In addition, pictures of plant problems can be submitted online. The Plant Disease and Insect Clinic's website is a good source of information on common plant diseases and insect problems, and has all of the instructions and sample submission forms for its diagnostic services. Samples can be submitted to the clinic by landowners/homeowners directly for around $30. Samples can also be submitted by NCFS or NCSU extension personnel at a reduced rate ($20). Digital pictures can be submitted through an electronic database and will be assessed free of charge. For more information, see the Plant Disease and Insect Clinic's website at: http://www.cals.ncsu.edu/plantpath/extension/clinic/

North Carolina Department of Agriculture and Consumer Services – Plant Tissue Analysis

Plant tissue analysis is conducted to determine if plants contain the concentrations of essential nutrients necessary for optimum growth. Results help growers monitor nutrient uptake and correct imbalances or deficiencies before they negatively impact plant health. In some cases, plant tissue analysis may indicate nutrient deficiency issues that soil analyses alone cannot reveal. Therefore, when nutrient imbalances are suspected, it is recommended that both soil samples and plant tissue samples be submitted to the North Carolina Department of Agriculture –Agronomic Division. Plant tissue analysis along with interpretations of results and recommendations are available for a small fee. Instructions for sample collection and submission, in addition to information on nutrient imbalances, nutrient analyses, and report interpretation guides are available at: http://www.agr.state.nc.us/agronomi/uyrplant.htm

North Carolina Department of Agriculture and Consumer Services – Soil Analysis

Soil analyses are useful for determining the right tree species for a site and prescribing soil amendments, fertilizers, or management activities for a stand. Use of soil analyses can lead to improvements in tree survival and stand productivity, reduce costs and improve the effectiveness of management practices, and protect the environment. Soil tests can also provide valuable information on what types of forest health problems may occur on a site, and what pests should be monitored for. When tree health declines, diagnostic soil analyses can determine if an imbalance in the level of nutrients, salts, or heavy metals is present. Soil samples can be submitted to the North Carolina Department of Agriculture – Agronomic Division either by mail or in person. Normal soil analyses are free; diagnostic analyses or special testing may be conducted for a small fee. Information on soil testing, instructions for sample collection and submission, and guides for interpreting soil test results are available at: http://www.ncagr.gov/agronomi/sthome.htm

NOTE: all charges and rates are correct on the date of publication and are subject to change

Sample Collection Guidelines

Not all forest health problems can be diagnosed in the field. Sometimes it is necessary to collect samples, examine them closely indoors or under magnification, and to compare them with identification keys, insect or disease manuals, and/or online resources. In other cases, it may be necessary to collect and ship samples for identification by a specialist or submit them to a laboratory for diagnosis or assessment. In North Carolina, there are several services available to the public for the diagnosis of plant disorders, insect identification, soil analysis, and plant nutrient analysis.

Samples must be collected and stored properly to be useful for these more detailed investigations. Improper sampling and storage techniques may result in the loss of important specimen parts, may cause deterioration of key characteristics, and/or render the sample unsuitable for laboratory tests. In addition to the sample itself, there is a specific set of information that must be provided along with samples when they are submitted to specialists for assistance. Utilization of the following tips and guidelines will ensure that field samples are collected, stored, and shipped properly.

General Tips

1) ***Fresh samples are better than old ones***. When plant material is collected in the field, place it into a cooler with ice packs for short term storage. Do not allow the plant to get wet or to dry out. Samples should be shipped as soon as possible after collecting. Avoid shipping at the end of the week; samples that arrive at the end of the week or over the weekend may be significantly deteriorated by the time they are examined.
2) ***Living specimens are better than dead samples***. If possible, insects (especially larvae) can be collected and shipped alive. If the insect is feeding on a plant, include some plant material in the shipment to increase its chances of survival. Plants that can be shipped with root systems and surrounding soil in tact can survive for several days. Microorganisms are more likely to survive until they can be examined in the laboratory if they are kept cold (not frozen).
3) ***Collect as much as possible***. For plant problems, send several specimens including dead, dying, and even healthy examples. Small plants can be dug up and sent with roots and soil attached. Do not remove foliage from a tree; instead, collect symptomatic twigs or branches with foliage attached. Roots (preferably with soil) should be sent whenever possible. For insects, collect several specimens and all available life stages when possible, and include infested plant material when appropriate.
4) ***Keep soil and water off of foliage***. For small plants collected in their entirety, wrap the root ball and attached soil in a plastic bag tied off tightly at the bottom of the stem. If the soil is dry, mist or water lightly to keep the plant from drying out. Excess water should be drained or blotted off. Wrap foliage in newspaper or paper towel to keep dry. Do not seal plants in air tight plastic bags because excess moisture can build up; loosely tied paper or plastic bags are preferred.
5) ***Be aware of quarantines.*** It may be illegal to ship certain species of plants, insects, or microorganisms out of quarantined areas. Quarantines may also prohibit the shipment of soil out of areas infested with certain species of noxious weeds. Quarantines are usually established by the state or federal government. Be aware of quarantines established in the county the collection is made, and do not ship quarantined materials out of the quarantine zone. Lists of internal quarantines currently established in North Carolina are available from the North Carolina Department of Agriculture (NCDA) and/or the U.S. Department of Agriculture - Animal and Plant Health Inspection Service (USDA APHIS).
6) ***Collect as much information as possible***. Collection of the sample itself is only the first step. When submitting a sample, provide as much information as possible. A detailed write-up or list should be included with every sample with the following information, and any other information you feel may be important:

Collector's Name
Date Collected
Location Collected
Landowner/Homeowner Info
Plant Species
Plant Age
Description of Submitted Sample
Description of Symptoms
Timeline of Symptom Development
Description of Signs
Description of the Site (and map)
Recent Pesticide/Chemical Applications
Recent Activities (e.g. Pruning, Irrigation, Fertilization, Thinning)
Recent Disturbances
Number of Plants Affected
Size of Area Affected
Pictures of Plant and Surrounding Area

Small Plants

1) Select a number of plants with a range of symptoms. Include a range of healthy, symptomatic, and recently killed plants.
2) It is important to select symptomatic plants at the edges of the area being affected.
3) Dig up the entire plant. Keep as much of the root system and surrounding soil intact. Do not pull plants from the ground.
4) Mist or lightly water the root system if it is excessively dry. Excess water should be drained or blotted off.
5) Place plant in a pot if possible. Wrap the soil and roots in a plastic bag tied off tightly at the lower stem.
6) Wrap foliage lightly in newspaper or paper towels.
7) Place the entire plant in a loosely sealed plastic or paper bag.
8) Ship as soon as possible using the shipping guidelines described below.

Foliage Diseases

1) Select several small twigs or branches with foliage attached. Include examples of twigs/branches with a range of healthy, symptomatic, and/or recently killed foliage.
2) Strip away bark from several affected twigs or branches that will not be shipped and examine the sapwood for discoloration or streaking; if observed, include larger branch or stem samples with vascular symptoms (*see vascular samples*).
3) Cut branches or twigs with a sharp, by-pass type pruning shear or lopper. Do not tear or break off twigs and branches.
4) Cut branches to length (if necessary). If the sample is wet, blot it dry. Wrap foliage lightly in newspaper or paper towels and seal in a plastic bag.
5) Place sample in a cooler with ice or ice packs. Store in a cool dry place.
6) Ship as soon as possible using the shipping guidelines described below.

Vascular Diseases

1) Select several small branches that are wilting, discolored or dying (do not select dead branches).
2) Strip away bark from affected branches and examine the sapwood for discoloration or streaking; if observed, include branch samples with vascular symptoms.
3) Cut branches with a sharp, by-pass type pruning shear or lopper. Do not tear or break off branches.
4) If the entire tree is affected and expected to die, examine the sapwood of the main stem. If discoloration or streaking in the xylem is observed, removed a large chunk of the sapwood (preferably with bark attached) using a saw or ax.
5) Seal branch and/or stem samples in a plastic bag. Do not allow samples to dry out.
6) Place sample in a cooler with ice or ice packs. Store in a cool dry place.
7) Sterilize the cutting edge of the tools used to take the sample using alcohol or bleach before using again.
8) Ship as soon as possible using the shipping guidelines described below.

Cankers, Galls, Swellings, and Weeping

1) Symptomatic branches should be cut with a sharp, by-pass type pruning shear or lopper. Do not tear or break off branches.
2) Symptomatic areas on the main stem should be cut out or the entire stem section removed using a saw.
3) Seal branch and/or stem samples in a plastic bag. Do not allow samples to dry out.
4) Place sample in a cooler with ice or ice packs. Store in a cool dry place.
5) Sterilize the cutting edge of the tools used to take the sample using alcohol or bleach before using again.
6) Ship as soon as possible using the shipping guidelines described below.

Large Trees

1) Because large trees cannot be submitted, pictures of the entire tree, close-ups of symptoms, and the surrounding area should be submitted along with samples.
2) Collect symptomatic foliage and branches as described above.
3) If the tree is expected to die (or has recently died) collect a section of the main stem near the soil line, or if possible, the entire root crown region (lower stem and upper roots). Seal in a large plastic bag.
4) Collect root samples if possible, including large buttress roots if the tree is expected to die. Seal in a plastic bag.
5) Collect a large soil sample containing fine roots. Seal in a plastic bag.
6) Place samples in a cooler with ice or ice packs. Store in a cool dry place.
7) Sterilize the cutting edge of the tools used to take samples using alcohol or bleach before using again.
8) Ship as soon as possible using the shipping guidelines described below.

Mushrooms, Conks, and other Fruiting Bodies

1) Hard, perennial conks can be broken off the tree and stored in a loosely sealed plastic or paper bag.
2) Mushrooms and other soft fruiting bodies should be blotted dry and sealed in a plastic bag.
3) If possible, collect mushrooms or conks with surrounding soil or plant tissue attached.
4) For mushrooms, take note of the plant species in the surrounding area.
5) Place samples in a cooler with ice or ice packs. Store in a cool dry place.
6) Ship as soon as possible using the shipping guidelines described below.

Insects

1) Most adult insects can be collected and placed immediately into a vial containing 70 percent alcohol.
2) Sapsucking insects such as mites, scales, aphids, thrips, and adelgids should be submitted alive on infested branch, twig, or foliage samples (*as described above*).
3) Adult butterflies and moths can be collected and killed in a container containing ethyl acetate or placed in a freezer; package lightly in soft tissue paper inside a solid container. Placing moths or butterflies in alcohol will destroy them.
4) Larvae, when possible, should be submitted in or on the plant tissues upon which they are feeding in a sealed plastic bag. Otherwise, they should be placed in a vial of 70 percent alcohol.
5) Grubs can be dug up and submitted with several cups of soil sealed in a plastic bag.
6) Place samples in a cooler with ice or ice packs. Store in a cool dry place.
7) Do not allow insects to overheat; they will soften and begin to decompose rapidly.
8) Ship as soon as possible using the shipping guidelines described below.

Shipping Guidelines

1) Mail or deliver samples as soon as possible after collecting. Avoid shipping at the end of the week; samples that arrive at the end of the week or over the weekend may be significantly deteriorated by the time they are examined.
2) Soft plant tissues, mushrooms, vascular tissue, samples containing microorganisms, and living insects should be shipped overnight/next day when possible.
3) Avoid shipping wet samples; drain or blot excess water. Do not seal samples in plastic bags for more than a few days.
4) Ship samples in a Styrofoam cooler containing ice packs sealed in a plastic bag (in case of leakage) when possible.
5) Pack samples in a sturdy box adequately filled with packing material such as newspaper. Do not crush samples.
6) Seal any liquid containing items (ice packs, vials, wet soil) in a leak-proof plastic bag or container.
7) Include all relevant documentation and pictures in a sealed plastic bag.

Photographing Tree Disorders

When the cause of a tree disorder cannot be identified, it is not always necessary to collect and submit samples to a diagnostic lab or to have a specialist visits the site to determine the cause of the problem. Digital photographs can be taken while on-site, and submitted electronically to NCFS Forest Health staff, the NCSU Plant Disease and Insect Clinic, or other specialists for assistance. It is also a good idea to submit photos with plant, disease, or insect samples because they can provide additional information about the appearance of the tree, the site, and potential causal agents that samples alone may not provide. Like sample collection and submission, there are guidelines that should be followed when using photographs for diagnostic purposes to maximize their usefulness.

1) ***Take many pictures***. You can never take too many pictures; often important clues may not be visible from all angles, all locations, and at all distances from the tree. A single picture is almost never enough; instead, a set of pictures should be taken that capture a range of scales including the overall site, the area immediately surrounding the tree, a view of the tree from all directions, overall symptoms, close-ups of affected areas, close-ups of groups of symptoms/signs, and even close-ups of individual symptoms/signs such as a single leaf, leaf spot, insect, or exit hole.
2) ***Scale is very important***. Every picture should be taken with an object in the frame that provides a scale reference. When taking a picture of a tree, a nearby house or person in the frame is usually sufficient. Horizontal distances can be indicated by flags/flagging laid out at set intervals. Close up photos should always include a ruler when possible. If a measuring stick or ruler is not available, some other object can be substituted if its size is generally standard (e.g. a coin, pencil, pocket knife, etc.) Sizes and distances that may seem obvious on site may be difficult to determine in a two-dimensional image with no scale references.
3) ***Show progress***. Photographs provide information about a single moment in time, but symptoms and signs change. If possible, take a series of pictures that captures important changes. Some symptoms change relatively quickly, so a series of pictures over the course of a few days may be useful. Other symptoms change slowly, so pictures taken over several years may be necessary to demonstrate the problem. When taking a series of photographs, it is best to take them from the same location at the same time of day. When a time series is not possible, a good substitute is to take pictures of other plants in the surrounding area that may be afflicted with the same problem, but are at different stages of symptom progression. Take pictures of plants that are healthy, lightly impacted, heavily impacted, and even dead.
4) ***Focus please***. Blurry or grainy images are virtually useless, especially in close-ups or when looking at fine details. Move plant tissues or other items to be photographed into lighted areas when possible. Flashes are useful for providing some light, but may bleach-out important details. Use a tripod or other solid object to rest the camera on to steady shaky movements. Use the shortest shutter speed possible without allowing pictures to become too dark. Use optical zooms only; digital zooms only reduce image quality (digital zooming has the same effect as magnifying/zooming in on the computer screen, so it is unnecessary in the field). Higher image resolutions are best.
5) ***Learn to use your camera's macro setting***. Most digital cameras today come with a macro setting that allows the camera to focus on very close objects. In standard setting, pictures taken less than a foot (sometimes more) from an object will be out of focus. Switching to the macro setting allows you to hold the camera only inches from the object you want to photograph and provides excellent details of small features. Close-up pictures taken using the macro setting need to be taken in a well lit area (without a flash), but are an excellent way to provide quality images of leaves and insects for example. If a macro setting is not available, hold the camera only as close as the object will remain in focus; if the image quality is sufficient, the photo can be examined under magnification later. Blurry images taken close up with a standard camera setting cannot be used.
6) ***Label your pictures.*** Just as with sample collection, photographs alone provide limited information. Photos should be submitted with all of the same information samples are submitted with (*see Appendix E*). In addition, each photo should be labeled with a description of the image including what you are trying to show and where the picture was taken from.
7) ***Don't downsize***. When sending digital photographs electronically, it is often tempting to reduce picture size. This has the same effect as reducing image resolution. Send the largest file sizes possible. If many pictures need to be sent, first send a set of reduced-size images, but make the original full size images available on request.

Diagnostic Tools of the Trade

When attempting to diagnose a tree disorder or when identifying specific insects or diseases, it is useful or necessary to have certain tools and equipment available on-site. When conducting a tree inspection or diagnosis, many foresters come prepared by carrying a bag of commonly used tools and sample collection equipment. The following is a list of tools and equipment that you can include in your own diagnostic bag. The time and effort it takes to gather and organize this equipment will be rewarded when you show up at a site prepared and professional.

You may find it useful to store this equipment in a crate, backpack, shoulder bag, or even a tackle box. Smaller items can be carried with you in a bag or small tool tray; larger items can be stored in a designated container in your vehicle and removed when necessary.

Tools
Duck-billed Spade (Drain Spade)
Garden Spade
Hand Trowel
Hatchet
Machete
Draw Knife (Bark Knife)
Handsaw
Pruning Shears
Loppers
Pole Saw / Pruner
Pocket Knife
Tool Disinfectant
Rope
Binoculars

Dissecting Kit
Forceps (Various sizes)
Small Scissors
Pointed Probes
Razor Blades / Scalpels
Hand Lens / Magnifying Glass
Small Brush

Measurement Tools
D-Tape
Ruler
Clinometer
Increment Borer
Increment Core Case
Compass

Reference Material
Pest Control Manual
Insect Identification Guide
Disease Identification Guide
Weed Identification Guide
Tree Identification Guide
NC Agricultural Chemicals Manual
Pamphlets/Brochures
Business Cards

Sample Collection
Glass Vials (Various sizes)
Plastic Vials (Various sizes)
Kill Jars
Plastic Sealable Bags
Paper Bags
Paper Envelopes
Small Plastic Containers
Bottle of 70 percent Alcohol
Small Cooler
Ice Packs
Soil Sample Boxes
Butterfly / Insect Net
Duct Tape
Clear Tape

Data Collection
Notepad
Sticky Labels
NCDA Soil Sample Forms
NCSU Insect and Disease Clinic Forms
NCDA Plant Tissue Analysis Forms
NCDFR Pest Control Worksheets
Permanent Markers
Pencils
Flagging Tape
Colored Marker Flags
GPS Unit
Digital Camera

Personal Protection Equipment
First Aid Kit
Leather Gloves
Protective Eyewear
Hard Hat
Latex Gloves
Hand Sanitizer
Poison Ivy Soap & Treatment
Sting Relief Pads
Rubber Boots
Bottled Water

Additional Resources and Selected References

Forest Health

National Forest Health Monitoring Program
This site provides information on forest health monitoring surveys nationwide.
http://fhm.fs.fed.us

USDA Forest Service – Forest Health Protection
A part of the State and Private Forestry Deputy Area of the USDA Forest Service.
http://www.fs.fed.us/foresthealth/

USDA Forest Service Publications
An extensive collection of General Technical Reports, Resource Bulletins, Research Papers, and Research Notes.
http://www.na.fs.fed.us/pubs/index.shtm

USDA Animal and Plant Health Inspection Service (APHIS)
Information on non-native invasives and other forest threats, quarantines, and regulations.
http://www.aphis.usda.gov/

USDA Forest Service Forest Health Technology Enterprise Team (FHTET)
Information technology and treatment technology related to forest health issues.
http://www.fs.fed.us/foresthealth/technology/

North Carolina State University Cooperative Extension – FEOP
The Forestry and Environmental Outreach Program brings the academic knowledge and applied research provided by the College of Natural Resources and NC Cooperative Extension Forestry to the citizens of North Carolina.
http://www.ces.ncsu.edu/nreos/forest/feop/

North Carolina Department of Agriculture & Consumer Services, Plant Industry Division
Information on non-native invasives and other forest threats, quarantines, and regulations, and pesticide use.
http://www.ncagr.gov/plantindustry/

North Carolina Department of Agriculture and Consumer Services, Structural Pest Control and Pesticide Division
Administers and enforces North Carolina's Pesticide Law. Provides training and certification for safe use of pesticides.
http://www.ncagr.gov/SPCAP/pesticides/index.htm

Eastern Forest Environmental Threat Assessment Center
Provides a resource for cutting edge research, technology and tools that address emerging forest threats.
http://www.forestthreats.org/

Forestry Images
A source for Forest Health, Natural Resources & Silviculture Images. A joint project of the University of Georgia and the USDA Forest Service.
http://www.forestryimages.org/

Forestry Insect and Disease Leaflets (FIDLs)
Each FIDL provides information about one insect or disease affecting forest trees in the United States. FIDLs describe their subject's distribution, appearance, life cycle, symptoms, and management.
http://www.fs.fed.us/r6/nr/fid/wo-fidls/fidls-info.shtml

North Carolina Forest Service
State forest health information and assistance.
http://www.dfr.state.nc.us/

Forest Entomology

The Bugwood Network
Images and information in important forest and agricultural insects.
http://www.bugwood.org/entomology.html

Insects of Trees in the South
Online version of: Anonymous. 1989. Insects and Diseases of Trees in the South. USDA For. Serv. Prot. Rept. R8-PR16. 98 pp.
http://www.forestpests.org/insects.cfm

BugGuide
Identification, images, & information for insects, spiders and their kin.
http://bugguide.net/

Insects that Feed on Trees and Shrubs
W.T. Johnson and H. H. Lyon. 1991. Cornell University Press, Ithaca, New York. 575 pp.

Introduction to Forest and Shade Tree Insects
P. Barbosa and M.R. Wagner. 1989. Academic Press. 639 pp.

Forest Pathology

Forest and Shade Tree pathology
Information on important forest diseases.
http://www.forestpathology.org/

Diseases of Trees in the South
Online version of: Anonymous. 1989. Insects and Diseases of Trees in the South. USDA For. Serv. Prot. Rept. R8-PR16. 98 pp.
http://www.forestpests.org/diseases.cfm

Diseases of Trees and Shrubs
W. A. Sinclair and H. H. Lyon. 2005. Cornell University Press, Ithaca, New York. 659 pp.

Diseases of Shade Trees
T.A. Tattar. 1989. Academic Press, New York. 376 pp.

Forest Pathology
J.S. Boyce. 1961. McGraw-Hill, New York. 527 pp.

Introductory Mycology
C.J. Alexopoulous and C.W. Mims. 1979. John Wiley and Sons, Inc., New York. 632 pp.

Non-native Invasives

Center for Invasive Species and Ecosystem Health
Information on important exotic plants, insects, and microorganisms
http://www.invasive.org/

Invasive Exotic Plants of North Carolina
Online version of: C. Smith. 2008. Invasive Plants of North Carolina. North Carolina Dept of Transportation. 189 pp.
http://www.ncdot.org/doh/preconstruct/pe/neu/NEUProcedures/NCDOT_Invasive_Exotic_Plants.pdf

Nonnative invasive plants of southern forests: a field guide for identification and control
Online version of: J.H. Miller. 2003. Nonnative invasive plants of southern forests: a field guide for identification and control.
http://www.treesearch.fs.fed.us/pubs/5424

Going Native
Information on landscaping with native plants and invasive exotic plants in the southeastern U.S.
http://www.ncsu.edu/goingnative/

Tree Physiology and Anatomy

Physiology of Woody Plants
T.T. Kozlowski and S.G. Pallardy. 1996. Academic Press, New York. 411 pp.

Anatomy of Seed Plants
K. Esau. 1977. John Wiley and Sons, Inc., New York. 576 pp.

A New Tree Biology: Facts, Photos, and Philosophies on Trees and Their Problems and Proper Care
A.L. Shigo. 1989. Shigo and Trees, Associates, Snohomish, Washington. 132 pp.

Image Citations

Images contained within this publication originating from the Bugwood Network Image Archives (ForestryImages.org, IPMImages.org, Invasive.org, and InsectImages.org) are made available under a Creative Commons license. Individual photographers retain all rights to images included in the archive. For license terms visit Creative Commons at http://creativecommons.org/. Images contained within this publication may not be used for commercial purposes unless permission is granted by the photographer or copyright owner.

Cover

Design by Ryan Blaedow, North Carolina Forest Service
Oak: Rainbow Treecare Scientific Advancements, Minnetonka, MN
Two-lined Chestnut Borer: Pennsylvania Dept of Conservation and Natural Resources

Forest Protection Introduction

Tree Stress Agents: Illustration by Ryan Blaedow, North Carolina Forest Service

Forest Entomology Introduction

Clerid Beetle: David Cappaert, Michigan State University, Bugwood.org
Gypsy Moth Egg Masses: Manfred Mielke, USDA Forest Service, Bugwood.org
Eastern Hercules Beetle: Allen Bridgman, South Carolina Department of Natural Resources, Bugwood.org
Insect Anatomy (Side View): Illustration by Gary Blaedow, West Allis, WI
Mouthparts: Illustration by Gary Blaedow, West Allis, WI
Insect Anatomy (Top View): Illustration by Gary Blaedow, West Allis, WI
Metamorphosis: Illustration by Gary Blaedow, West Allis, WI
Cecropia Moth Caterpillar: Ryan Blaedow, North Carolina Forest Service
Cecropia Moth Adult: Daniel Herms, The Ohio State University, Bugwood.org
Eastern Tent Caterpillar: Lacy L. Hyche, Auburn University, Bugwood.org
Beetle Galleries: Ronald F. Billings, Texas Forest Service, Bugwood.org
Wood Borer Gallery: Lacy L. Hyche, Auburn University, Bugwood.org
Aphids: Whitney Cranshaw, Colorado State University, Bugwood.org
Frasier Fir Stand: Ronald F. Billings, Texas Forest Service, Bugwood.org
Pales Weevil: USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org
Tip Moth Damage: A. Steven Munson, USDA Forest Service, Bugwood.org

Scale Insects

Fig. 1 Gerald J. Lenhard, Louiana State Univ, Bugwood.org
Fig. 2 R. Scott Cameron, Advanced Forest Protection, Inc., Bugwood.org
Fig. 3 John A. Weidhass, Virginia Polytechnic Institute and State University, Bugwood.org
Fig. 4 Andrew J. Boone, South Carolina Forestry Commission, Bugwood.org
Fig. 5 Raymond Gill, California Department of Food and Agriculture, Bugwood.org
Fig. 6 US National Collection of Scale Insects Photographs Archive, USDA Agricultural Research Service, Bugwood.org
Fig. 7 US National Collection of Scale Insects Photographs Archive, USDA Agricultural Research Service, Bugwood.org
Fig. 8 US National Collection of Scale Insects Photographs Archive, USDA Agricultural Research Service, Bugwood.org

Aphids

Fig. 1 R.J. Reynolds Tobacco Company Slide Set, R.J. Reynolds Tobacco Company, Bugwood.org
Fig. 2 Whitney Cranshaw, Colorado State University, Bugwood.org
Fig. 3 Scott Bauer, USDA Agricultural Research Service, Bugwood.org
Fig. 4 Herbert A. "Joe" Pase III, Texas Forest Service, Bugwood.org
Fig. 5 Whitney Cranshaw, Colorado State University, Bugwood.org
Fig. 6 James Solomon, USDA Forest Service, Bugwood.org
Fig. 7 H.J. Larsen, Bugwood.org
Fig. 8 David Cappaert, Michigan State University, Bugwood.org
Fig. 9 Bob Lepak, Bugwood.org

Gall-forming Insects

Fig. 1 William M. Ciesla, Forest Health Management International, Bugwood.org
Fig. 2 James Solomon, USDA Forest Service, Bugwood.org
Fig. 3 Steven Munson, USDA Forest Service, Bugwood.org
Fig. 4 William M. Ciesla, Forest Health Management International, Bugwood.org
Fig. 5 Milan Zubrik, Forest Research Institute - Slovakia, Bugwood.org
Fig. 6 E. Bradford Walker, Vermont Department of Forests, Parks and Recreation, Bugwood.org
Fig. 7 Steven Katovich, USDA Forest Service, Bugwood.org
Fig. 8 Whitney Cranshaw, Colorado State University, Bugwood.org
Fig. 9 Albert (Bud) Mayfield, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 10 Gyorgy Csoka, Hungary Forest Research Institute, Bugwood.org
Fig. 11 Milan Zubrik, Forest Research Institute - Slovakia, Bugwood.org

Hemlock Woolly Adelgid

Fig. 1 CT Agricultural Experiment Station Archive, Connecticut Agricultural Experiment Station, Bugwood.org
Fig. 2 James Johnson, Georgia Forestry Commission, Bugwood.org
Fig. 3 William M. Ciesla, Forest Health Management International, Bugwood.org
Fig. 4 Jason Moan, North Carolina Forest Service
Fig. 5 Chris Evans, River to River CWMA, Bugwood.org
Fig. 6 Shimat Joseph, University of Georgia, Bugwood.org
Fig. 7 William M. Ciesla, Forest Health Management International, Bugwood.org
Fig. 8 Harvard Forest, harvardforest.fas.harvard.edu/research/hwa.htm

Balsam Woolly Adelgid

Fig. 1 Jerald E. Dewey, USDA Forest Service, Bugwood.org
Fig. 2 Scott Tunnock, USDA Forest Service, Bugwood.org
Fig. 3 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 4 William M. Ciesla, Forest Health Management International, Bugwood.org
Fig. 5 William M. Ciesla, Forest Health Management International, Bugwood.org
Fig. 6 Ronald F. Billings, Texas Forest Service, Bugwood.org
Fig. 7 Jason Moan, North Carolina Forest Service

Pine Webworm

Fig. 1 Steven Katovich, USDA Forest Service, Bugwood.org
Fig. 2 Ronald F. Billings, Texas Forest Service, Bugwood.org
Fig. 3 Connecticut Agricultural Experiment Station Archive, Connecticut Agricultural Experiment Station, Bugwood.org
Fig. 4 Natasha Wright, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 5 Robert L. Anderson, USDA Forest Service, Bugwood.org

Redheaded Pine Sawfly

Fig. 1 Gerald J. Lenhard, Louiana State Univ, Bugwood.org
Fig. 2 USDA Forest Service - Region 8 Archive, USDA Forest Service
Fig. 3 James McGraw, North Carolina State University, Bugwood.org
Fig. 4 Andrew J. Boone, South Carolina Forestry Commission, Bugwood.org
Fig. 5 Albert (Bud) Mayfield, Florida Department of Agriculture and Consumer Services, Bugwood.org

Eastern Tent Caterpillar

Fig. 1 David Cappaert, Michigan State University, Bugwood.org
Fig. 2 Clemson University - USDA Cooperative Extension Slide Series, , Bugwood.org
Fig. 3 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 4 A. Steven Munson, USDA Forest Service, Bugwood.org
Fig. 5 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 6 Robert L. Anderson, USDA Forest Service, Bugwood.org

Forest Tent Caterpillar

Fig. 1 Ronald S. Kelley, Vermont Department of Forests, Parks and Recreation, Bugwood.org
Fig. 2 Kenneth E. Gibson, USDA Forest Service, Bugwood.org
Fig. 3 Steven Katovich, USDA Forest Service, Bugwood.org
Fig. 4 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 5 Ronald S. Kelley, Vermont Department of Forests, Parks and Recreation, Bugwood.org
Fig. 6 USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org
Fig. 7 Ronald S. Kelley, Vermont Department of Forests, Parks and Recreation, Bugwood.org
Fig. 8 James B. Hanson, USDA Forest Service, Bugwood.org

Fall Webworm

Fig. 1 Milan Zubrik, Forest Research Institute - Slovakia, Bugwood.org
Fig. 2 G. Keith Douce, University of Georgia, Bugwood.org
Fig. 3 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 4 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 5 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 6 Ministry of Ag and Regional Development Archive, Ministry of Agriculture and Regional Development, Bugwood.org
Fig. 7 Lacy L. Hyche, Auburn University, Bugwood.org
Fig. 8 Ronald F. Billings, Texas Forest Service, Bugwood.org

Orangestriped Oak Worm

Fig. 1 USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org
Fig. 2 Lacy L. Hyche, Auburn University, Bugwood.org
Fig. 3 Steven Katovich, USDA Forest Service, Bugwood.org
Fig. 4 James Solomon, USDA Forest Service, Bugwood.org
Fig. 5 Lacy L. Hyche, Auburn University, Bugwood.org
Fig. 6 Lacy L. Hyche, Auburn University, Bugwood.org
Fig. 7 Lacy L. Hyche, Auburn University, Bugwood.org
Fig. 8 Erich G. Vallery, USDA Forest Service - SRS-4552, Bugwood.org
Fig. 9 James Solomon, USDA Forest Service, Bugwood.org

Pine Colaspis Beetle

Fig. 1 Gerald J. Lenhard, Louiana State Univ, Bugwood.org
Fig. 2 Florida Department of Forestry
Fig. 3 Gerald J. Lenhard, Louiana State Univ, Bugwood.org
Fig. 4 Laura Lazarus, North Carolina Forest Service, Bugwood.org
Fig. 5 John Moser, USDA Forest Service, Bugwood.org

Bagworm

Fig. 1 Eric R. Day, Virginia Polytechnic Institute and State University, Bugwood.org
Fig. 2 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 3 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 4 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org

Fall Cankerworm

Fig. 1 John H. Ghent, USDA Forest Service, Bugwood.org
Fig. 2 Ronald S. Kelley, Vermont Department of Forests, Parks and Recreation, Bugwood.org
Fig. 3 E. Bradford Walker, Vermont Department of Forests, Parks and Recreation, Bugwood.org
Fig. 4 Jerald E. Dewey, USDA Forest Service, Bugwood.org
Fig. 5 William A. Carothers, USDA Forest Service, Bugwood.org
Fig. 6 USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org
Fig. 7 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 8 USDA Forest Service - Ogden Archive, USDA Forest Service, Bugwood.org

Locust Leafminer

Fig. 1 David Cappaert, Michigan State University, Bugwood.org
Fig. 2 Bruce W. Kauffman, Tennessee Department of Agriculture, Bugwood.org
Fig. 3 Whitney Cranshaw, Colorado State University, Bugwood.org
Fig. 4 Herbert A. "Joe" Pase III, Texas Forest Service, Bugwood.org
Fig. 5 USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org
Fig. 6 Bruce W. Kauffman, Tennessee Department of Agriculture, Bugwood.org

Gypsy Moth

Fig. 1 Ferenc Lakatos, University of West-Hungary, Bugwood.org
Fig. 2 Milan Zubrik, Forest Research Institute - Slovakia, Bugwood.org
Fig. 3 USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org
Fig. 4 USDA APHIS PPQ Archive, USDA APHIS PPQ, Bugwood.org
Fig. 5 Rusty Haskell, University of Florida, Bugwood.org
Fig. 6 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 7 USDA APHIS PPQ Archive, USDA APHIS PPQ, Bugwood.org
Fig. 8 William M. Ciesla, Forest Health Management International, Bugwood.org
Fig. 9 John H. Ghent, USDA Forest Service, Bugwood.org
Fig. 10 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 11 John H. Ghent, USDA Forest Service, Bugwood.org

Japanese Beetle

Fig. 1 David Cappaert, Michigan State University, Bugwood.org
Fig. 2 Daniel Herms, The Ohio State University, Bugwood.org
Fig. 3 David Cappaert, Michigan State University, Bugwood.org
Fig. 4 Ryan Blaedow, North Carolina Forest Service
Fig. 5 naturesperspective.com

Southern Pine Beetle

Fig. 1 Erich G. Vallery, USDA Forest Service - SRS-4552, Bugwood.org
Fig. 2 Erich G. Vallery, USDA Forest Service - SRS-4552, Bugwood.org
Fig. 3 Ronald F. Billings, Texas Forest Service, Bugwood.org
Fig. 4 Erich G. Vallery, USDA Forest Service - SRS-4552, Bugwood.org
Fig. 5 J.R. Baker & S.B. Bambara, North Carolina State University, Bugwood.org
Fig. 6 Erich G. Vallery, USDA Forest Service - SRS-4552, Bugwood.org
Fig. 7 Ronald F. Billings, Texas Forest Service, Bugwood.org
Fig. 8 Andrew J. Boone, South Carolina Forestry Commission, Bugwood.org
Fig. 9 Andrew J. Boone, South Carolina Forestry Commission, Bugwood.org

Ips Engraver Beetles

Fig. 1 John L. Foltz, University of Florida, Bugwood.org
Fig. 2 Jerald E. Dewey, USDA Forest Service, Bugwood.org
Fig. 3 Pest and Diseases Image Library, Bugwood.org
Fig. 4 Ronald F. Billings, Texas Forest Service, Bugwood.org
Fig. 5 Jeffrey Eickwort, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 6 Tim Tigner, Virginia Department of Forestry, Bugwood.org

Black Turpentine Beetle

Fig. 1 John L. Foltz, University of Florida, Bugwood.org
Fig. 2 Pest and Diseases Image Library, Bugwood.org
Fig. 3 J.R. Baker & S.B. Bambara, North Carolina State University, Bugwood.org
Fig. 4 Gerald J. Lenhard, Louiana State Univ, Bugwood.org
Fig. 5 USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org
Fig. 6 Ronald F. Billings, Texas Forest Service, Bugwood.org
Fig. 7 Ronald F. Billings, Texas Forest Service, Bugwood.org
Fig. 8 G. Keith Douce, University of Georgia, Bugwood.org

Elm Bark Beetles

Fig. 1 Natasha Wright, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 2 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 3 USDA Forest Service
Fig. 4 J.R. Baker & S.B. Bambara, North Carolina State University, Bugwood.org
Fig. 5 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 6 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 7 Linda Haugen, USDA Forest Service, Bugwood.org

Hickory Bark Beetle

Fig. 1 Natasha Wright, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 2 James Solomon, USDA Forest Service, Bugwood.org
Fig. 3 J.R. Baker & S.B. Bambara, North Carolina State University, Bugwood.org
Fig. 4 Ontario Ministry of Natural Resources
Fig. 5 Ontario Ministry of Natural Resources

Pine Sawyer Beetles

Fig. 1 Natasha Wright, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 2 Lacy L. Hyche, Auburn University, Bugwood.org
Fig. 3 Fabio Stergulc, Università di Udine, Bugwood.org
Fig. 4 Laura Lazarus, North Carolina Forest Service, Bugwood.org
Fig. 5 Natasha Wright, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 6 Kenneth R. Law, USDA APHIS PPQ, Bugwood.org
Fig. 7 Randy Cyr, Greentree, Bugwood.org

Ambrosia Beetles

Fig. 1 Natasha Wright, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 2 W.H. Bennett, USDA Forest Service, Bugwood.org
Fig. 3 Andrew J. Boone, South Carolina Forestry Commission, Bugwood.org
Fig. 4 J.R. Baker & S.B. Bambara, North Carolina State University, Bugwood.org
Fig. 5 Will Hudson, University of Georgia, Bugwood.org
Fig. 6 Albert (Bud) Mayfield, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 7 James Johnson, Georgia Forestry Commission, Bugwood.org
Fig. 8 Petr Kapitola, State Phytosanitary Administration, Bugwood.org

Asian Longhorned Beetle

Fig. 1 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 2 Steven Katovich, USDA Forest Service, Bugwood.org
Fig. 3 E. Richard Hoebeke, Cornell University, Bugwood.org
Fig. 4 E. Richard Hoebeke, Cornell University, Bugwood.org
Fig. 5 Kenneth R. Law, USDA APHIS PPQ, Bugwood.org
Fig. 6 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 7 Dennis Haugen, USDA Forest Service, Bugwood.org
Fig. 8 Dennis Haugen, USDA Forest Service, Bugwood.org

Emerald Ash Borer

Fig. 1 David Cappaert, Michigan State University, Bugwood.org
Fig. 2 Marianne Prue, Ohio Department of Natural Resources - Division of Forestry, Bugwood.org
Fig. 3 David Cappaert, Michigan State University, Bugwood.org
Fig. 4 Art Wagner, USDA APHIS PPQ, Bugwood.org
Fig. 5 Eric R. Day, Virginia Polytechnic Institute and State University, Bugwood.org
Fig. 6 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 7 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 8 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 9 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 10 Michigan Department of Agriculture, Bugwood.org

Sirex Woodwasp

Fig. 1 Whitney Cranshaw, Colorado State University, Bugwood.org
Fig. 2 David R. Lance, USDA APHIS PPQ, Bugwood.org
Fig. 3 Dennis Haugen, Bugwood.org
Fig. 4 Dennis Haugen, Bugwood.org
Fig. 5 Dennis Haugen, Bugwood.org
Fig. 6 Paula Klasmer, Instituto Nacional de Tecnologia Agropecuaria, Bugwood.org
Fig. 7 Dennis Haugen, Bugwood.org
Fig. 8 Jason Moan, North Carolina Forest Service

Pales Weevil

Fig. 1 USDA Forest Service - Region 8 - Southern Archive, USDA Forest Service, Bugwood.org
Fig. 2 USDA Forest Service - Northeastern Area Archive, USDA Forest Service, Bugwood.org
Fig. 3 Southern Forest Insect Work Conference Archive, Southern Forest Insect Work Conference, Bugwood.org
Fig. 4 Mary Ann Hansen, Virginia Polytechnic Institute and State University, Bugwood.org

Nantucket Pine Tip Moth

Fig. 1 USDA Forest Service Archive, USDA Forest Service, Bugwood.org
Fig. 2 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 3 David J. Moorhead, University of Georgia, Bugwood.org
Fig. 4 A. Steven Munson, USDA Forest Service, Bugwood.org
Fig. 5 Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org
Fig. 6 Terry S. Price, Georgia Forestry Commission, Bugwood.org

Twig Pruners and Girdlers

Fig. 1 Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org
Fig. 2 Natasha Wright, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 3 James Solomon, USDA Forest Service, Bugwood.org
Fig. 4 Gerald J. Lenhard, Louisiana State University, Bugwood.org
Fig. 5 Phil Pellitteri, University of Wisconsin Insect Diagnostic Lab
Fig. 6 Gale and Jeanell Strickland, BugGuide.net

Forest Pathology Introduction

Chestnut Blight: The American Chestnut Foundation Image Archive
Disease Triangle: Ryan Blaedow, North Carolina Forest Service
Oyster Mushrooms: USDA Forest Service - North Central Research Station Archive, USDA Forest Service, Bugwood.org
Fusiform Rust: Paul A. Mistretta, USDA Forest Service, Bugwood.org
Dutch Elm Disease: Linda Haugen, USDA Forest Service, Bugwood.org
Oak Anthracnose: Robert L. Anderson, USDA Forest Service, Bugwood.org
Pruning Wound: Joseph O'Brien, USDA Forest Service, Bugwood.org
Brown Spot Needle Blight: Edward L. Barnard, Florida Department of Agriculture and Consumer Services, Bugwood.org
Hyphae: University of Wisconsin, Turfgrass Diagnostic Lab
Spore Tendrils: Ministry of Agriculture and Regional Development, Bugwood.org
Spores: H.C. Evans, CAB International, Bugwood.org
Bacterial Leaf Scorch: Theodor D. Leininger, USDA Forest Service, Bugwood.org
Bacteria: Division of Plant Industry Archive, Florida Department of Agriculture and Consumer Services, Bugwood.org
Virus: Sebastian Kaulitzki, Dreamstime.com
Nematodes: David Cappaert, Michigan State University, Bugwood.org

Anthracnose

Fig. 1 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 2 Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org
Fig. 3 USDA Forest Service
Fig. 4 David Davison, Florida Department of Agriculture and Consumer Services
Fig. 5 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 6 Joseph O'Brien, USDA Forest Service, Bugwood.org

Brown Spot Needle Blight

Fig. 1 Edward L. Barnard, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 2 Darroll D. Skilling, USDA Forest Service, Bugwood.org
Fig. 3 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 4 H.C. Evans, CAB Interational, Bugwood.org
Fig. 5 Edward L. Barnard, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 6 USDA Forest Service Archive, USDA Forest Service, Bugwood.org
Fig. 7 USDA Forest Service Archive, USDA Forest Service, Bugwood.org

Pine Needle Cast

Fig. 1 Erich G. Vallery, USDA Forest Service - SRS-4552, Bugwood.org
Fig. 2 Erich G. Vallery, USDA Forest Service - SRS-4552, Bugwood.org
Fig. 3 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 4 Edward L. Barnard, Florida Department of Agriculture and Consumer Services, Bugwood.org

Dogwood Anthracnose

Fig. 1 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 2 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 3 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 4 Clemson University - USDA Cooperative Extension Slide Series, , Bugwood.org
Fig. 5 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 6 Joseph O'Brien, USDA Forest Service, Bugwood.org

Fusiform Rust

Fig. 1 USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org
Fig. 2 Forest Insect and Disease Leaflet #26
Fig. 3 USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org
Fig. 4 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 5 Forest Insect and Disease Leaflet #26
Fig. 6 Robert L. Anderson, USDA Forest Service, Bugwood.org

Hypoxylon Canker

Fig. 1 Ronald F. Billings, Texas Forest Service, Bugwood.org
Fig. 2 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 3 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 4 USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org

Pitch Canker

Fig. 1 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 2 L.D. Dwinell, USDA Forest Service, Bugwood.org
Fig. 3 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 4 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 5 Terry Price, Georgia Forestry Commission, Bugwood.org
Fig. 6 Robert L. Anderson, USDA Forest Service, Bugwood.org

Wetwood / Slime Flux

Fig. 1 William Jacobi, Colorado State University, Bugwood.org
Fig. 2 Whitney Cranshaw, Colorado State University, Bugwood.org
Fig. 3 Randy Cyr, Greentree, Bugwood.org
Fig. 4 Joseph O'Brien, USDA Forest Service, Bugwood.org

White Pine Blister Rust

Fig. 1 Petr Kapitola, State Phytosanitary Administration, Bugwood.org
Fig. 2 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 3 USDA Forest Service - Ogden Archive, USDA Forest Service, Bugwood.org
Fig. 4 USDA Forest Service - Region 8 Archive, USDA Forest Service, Bugwood.org
Fig. 5 Vickie Brewster, apsnet.org
Fig. 6 Petr Kapitola, State Phytosanitary Administration, Bugwood.org
Fig. 7 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 8 Minnesota Dept of Natural Resources Archive, MN Dept of Natural Resources, Bugwood.org

Beech Bark Disease

Fig. 1 Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org
Fig. 2 Petr Srutka, Czech University of Agriculture - Prague, Bugwood.org
Fig. 3 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 4 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 5 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 6 Linda Haugen, USDA Forest Service, Bugwood.org
Fig. 7 Andrej Kunca, National Forest Centre - Slovakia, Bugwood.org
Fig. 8 Jason Moan, North Carolina Forest Service

Sudden Oak Death

Fig. 1 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 2 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 3 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 4 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 5 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 6 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 7 Joseph O'Brien, USDA Forest Service, Bugwood.org

Thousand Cankers Disease

Fig. 1 Whitney Cranshaw, Colorado State University, Bugwood.org
Fig. 2 Ned Tisserat, Colorado State University, Bugwood.org
Fig. 3 Ned Tisserat, Colorado State University, Bugwood.org
Fig. 4 Jim LaBonte, Oregon Department of Agriculture
Fig. 5 Whitney Cranshaw, Colorado State University
Fig. 6 Whitney Cranshaw, Colorado State University, Bugwood.org
Fig. 7 Jennifer Juzwik, USDA Forest Service Northern Research Station
Fig. 8 Whitney Cranshaw, Colorado State University, Bugwood.org
Fig. 9 Whitney Cranshaw, Colorado State University, Bugwood.org
Fig. 10 Ned Tisserat, Colorado State University, Bugwood.org

Fireblight

Fig. 1 Mary Ann Hansen, Virginia Polytechnic Institute and State University, Bugwood.org
Fig. 2 University of Georgia Plant Pathology Archive, University of Georgia, Bugwood.org
Fig. 3 Division of Plant Industry Archive, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 4 Rebekah D. Wallace, University of Georgia, Bugwood.org
Fig. 5 University of Georgia Plant Pathology Archive, University of Georgia, Bugwood.org
Fig. 6 Jody Fetzer, New York Botanical Garden, Bugwood.org
Fig. 7 Division of Plant Industry Archive, Florida Dept. of Agriculture and Consumer Services, Bugwood.org

Bacterial Leaf Scorch

Fig. 1 Theodor D. Leininger, USDA Forest Service, Bugwood.org
Fig. 2 Rebecca A. Melanson, Louisiana State University AgCenter, Bugwood.org
Fig. 3 Edward L. Barnard, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 4 Theodor D. Leininger, USDA Forest Service, Bugwood.org
Fig. 5 Edward L. Barnard, Florida Department of Agriculture and Consumer Services, Bugwood.org

Oak Decline

Fig. 1 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 2 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 3 Robert A. Haack, USDA Forest Service, Bugwood.org
Fig. 4 David Cappaert, Michigan State University, Bugwood.org
Fig. 5 Joseph O'Brien, USDA Forest Service, Bugwood.org

Oak Wilt

Fig. 1 John N. Gibbs, Forestry Commission, Bugwood.org
Fig. 2 D. W. French, University of Minnesota, Bugwood.org
Fig. 3 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 4 Fred Baker, Utah State University, Bugwood.org
Fig. 5 James Solomon, USDA Forest Service, Bugwood.org
Fig. 6 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 7 USDA Forest Service - Forest Health Protection - St. Paul Archive, USDA Forest Service, Bugwood.org
Fig. 8 T.W. Bretz, USDA Forest Service, Bugwood.org

Dutch Elm Disease

Fig. 1 Linda Haugen, USDA Forest Service, Bugwood.org
Fig. 2 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 3 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 4 Paul H. Peacher, USDA Forest Service, Bugwood.org
Fig. 5 Fabio Stergulc, Università di Udine, Bugwood.org
Fig. 6 William Jacobi, Colorado State University, Bugwood.org

Laurel Wilt

Fig. 1 Albert (Bud) Mayfield, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 2 James Johnson, Georgia Forestry Commission, Bugwood.org
Fig. 3 Albert (Bud) Mayfield, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 4 Division of Plant Industry Archive, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 5 Michael C. Thomas, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 6 Albert (Bud) Mayfield, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 7 R. Scott Cameron, Advanced Forest Protection, Inc., Bugwood.org
Fig. 8 Albert (Bud) Mayfield, Florida Department of Agriculture and Consumer Services, Bugwood.org

Annosus Root Rot

Fig. 1 Andrew J. Boone, South Carolina Forestry Commission, Bugwood.org
Fig. 2 USDA Forest Service Archive, USDA Forest Service, Bugwood.org
Fig. 3 Robert L. James, USDA Forest Service, Bugwood.org
Fig. 4 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 5 USDA Forest Service Archive, USDA Forest Service, Bugwood.org
Fig. 6 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 7 Edward L. Barnard, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 8 Jason Moan, North Carolina Forest Service

Armillaria Root Rot

Fig. 1 Rocky Mountain Research Station/Forest Pathology Archive, USDA Forest Service, Bugwood.org
Fig. 2 Edward L. Barnard, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 3 Andrej Kunca, National Forest Centre - Slovakia, Bugwood.org
Fig. 4 Mike Schomaker, Colorado State Forest Service, Bugwood.org
Fig. 5 Joseph O'Brien, USDA Forest Service, Bugwood.org
Fig. 6 Robert L. Anderson, USDA Forest Service, Bugwood.org

Littleleaf Disease

Fig. 1 Daniel H. Brown, USDA Forest Service, Bugwood.org
Fig. 2 Clemson University - USDA Cooperative Extension Slide Series, , Bugwood.org
Fig. 3 Clemson University - USDA Cooperative Extension Slide Series, , Bugwood.org
Fig. 4 Clemson University - USDA Cooperative Extension Slide Series, , Bugwood.org
Fig. 5 Jason Moan, North Carolina Forest Service

Phytophthora Root Rot

Fig. 1 Linda Haugen, USDA Forest Service, Bugwood.org
Fig. 2 André Bolay, St. Fédér. de Recherches Agronomiques de Changins, Bugwood.org
Fig. 3 Edward L. Barnard, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 4 H.J. Larsen, Bugwood.org
Fig. 5 Edward L. Barnard, Florida Department of Agriculture and Consumer Services, Bugwood.org
Fig. 6 Andrej Kunca, National Forest Centre - Slovakia, Bugwood.org
Fig. 7 Andrej Kunca, National Forest Centre - Slovakia, Bugwood.org

Procera Root Disease

Fig. 1 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 2 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 3 Manfred Mielke, USDA Forest Service, Bugwood.org
Fig. 4 Manfred Mielke, USDA Forest Service, Bugwood.org
Fig. 5 Robert L. Anderson, USDA Forest Service, Bugwood.org
Fig. 6 Mary Ann Hansen, Virginia Polytechnic Institute and State University, Bugwood.org

Disorders and Abiotic Stress Agents

Wind: Steven Katovich, USDA Forest Service, Bugwood.org
Snow/Ice: Minnesota Department of Natural Resources Archive, Minnesota Department of Natural Resources, Bugwood.org
Rain: R.L. Croissant, Bugwood.org
Lightning: Ryan Blaedow, North Carolina Forest Service
Hail: Joseph O'Brien, USDA Forest Service, Bugwood.org
Storms: Joseph O'Brien, USDA Forest Service, Bugwood.org
Flooding: Karan A. Rawlins, University of Georgia, Bugwood.org
Drought: Robert L. Anderson, USDA Forest Service, Bugwood.org
Salt Damage: Paul A. Mistretta, USDA Forest Service, Bugwood.org
Frost/Freezing: Joseph O'Brien, USDA Forest Service, Bugwood.org
Heat: Ryan Blaedow, North Carolina Forest Service
Air Pollution: Tim Tigner, Virginia Department of Forestry, Bugwood.org
Fire: Dale Wade, Rx Fire Doctor, Bugwood.org
Mechanical Damage: Joseph O'Brien, USDA Forest Service, Bugwood.org
Root Injury: Joseph O'Brien, USDA Forest Service, Bugwood.org
Herbicide Damage: Purdue University, Botany and Plant Pathology Extension Service
Nutrient Imbalances: Joseph O'Brien, USDA Forest Service, Bugwood.org
Frost Cracks: James Solomon, USDA Forest Service, Bugwood.org; Joseph O'Brien, USDA Forest Service, Bugwood.org
Sun Scald: Ryan Blaedow, North Carolina Forest Service; William Jacobi, Colorado State Univ, Bugwood.org
Soil Compaction: Peter Bedker, Bugwood.org
Soil Grade Changes: USDA Forest Service - Forest Health Protection - St. Paul Archive, USDA Forest Service, Bugwood.org
Improper Pruning: Joseph O'Brien, USDA Forest Service, Bugwood.org
Deep Planting: Joseph LaForest, University of Georgia, Bugwood.org
Improper Mulching: Gary Watson, Morton Arboretum, Bugwood.org
Included Bark: Joseph O'Brien, USDA Forest Service, Bugwood.org
Girdling Roots: Joseph O'Brien, USDA Forest Service, Bugwood.org
Genetic Disorders: Iowa State University, University Extension

Glossary

abdomen	last body segment of an insect containing most of the internal organs
abiotic	not living
aeciospore	a type of spore produced by rust fungi
anaerobic	not requiring oxygen for respiration
annual	occurring for one year only
antenna	a type of sensory organ on the head of an insect (pl. antennae)
asymptomatic	not having symptoms
bacteria	microscopic, single celled prokaryotic organisms (sn. bacterium)
basidiospore	a type of spore produced by basidomycetous fungi such as rust fungi
biocontrol	the use of one organism to manage or control another (alt. biological control)
biotic	living
blight	a general term used for a disease that causes blighting
blighting	a rapid and complete chlorosis, browning, then death of plant tissues such as leaves or shoots
bud break	initiation of growth from a bud, usually in reference to the beginning of leaf expansion or shoot growth in the spring
canker	localized region of tissue death in the inner and/or outer bark on stems, branches or twigs
chlorotic	yellowing or whitening of normally green plant tissue
coalesce	to grow or expand into each other to eventually become one
compartmentalize	the sectioning off of damaged or diseased plant tissues using physical and/or chemical barriers
compound eye	insect eye composed of up to several thousand individual light sensing units
conk	a type of fruiting body produced by some wood-decaying fungi
contact pesticide	a hard, shelf-like, spore-bearing structure of certain wood-decaying fungi found on stumps, logs, or trees
cultivar	a cultivated variety of a plant species that has been deliberately selected for specific desirable characteristics
defoliation	loss of plant foliage
disease center	a localized area of disease in the landscape characterized by infected, dying, and dead individuals
drip line	the edge of the area located directly under the tree canopy

elytra a hardened pair of wings modified to act as protective covers for underwings

emergence the act of insects coming out of dormancy or metamorphosis

entomology the study of insects

epicormic sprout a type of shoot that emerges from a dormant bud along the trunk or branch of a tree

exoskeleton an external skeleton that covers and protects an insect's body

exotic not native

forest protection the scientific branch of forestry concerned with the study and control of stress agents

frass insect excrement

fruiting body any complex or multi-celled structure that contains or bears spores

hypha a tubular filament making up the structure of most fungi (pl. hyphae)

flagging term for a pattern of symptom development; a single branch that dies and is easily visible in an otherwise healthy crown

fungi eukaryotic, spore-producing, non-chlorophyll-containing organisms with absorptive nutrition

fungicide a pesticide that is used to kill fungi

gall tumor-like tissue on a plant resulting from rapid, uncontrolled cell division and enlargement caused by fungi, insects, or bacteria

gallery a tunnel created under the bark of a tree made by insects for the purpose of feeding or reproduction (pl. galleries)

girdle to sever the nutrient and water conducting tissues around the circumference of a tree stem or branch

heartwood formed in some tree species, a physiologically inactive portion of the xylem rich in antimicrobial chemicals and tyloses

host in a parasitic relationship, the organism that has stored energy utilized by the parasite

hypopharynx tongue-like organ of an insect

infection the entry of a pathogenic organism into a susceptible host

infection court the site at which infection occurs

infestation assault or occupation of a host by (usually numerous) parasites

inner bark general term referring to the cambium and phloem tissues that lie below the outer bark surface

inoculum pathogen propagules such as spores that are used for the process of infection

insect vector an insect that can transmit a pathogenic organism from one plant to another

insecticide a pesticide that kills insects

instar a developmental stage of an insect larva between each molt

labium	lower lip of an insect
labrum	upper lip of an insect
larva	the juvenile life stage of insects which undergo complete metamorphosis (pl. larvae)
lateral shoot	a side shoot or branch, usually suppressed by the apical dominance exterted by the terminal shoot
lenticel	a pore most commonly found on the surface of plant stems and roots used for gas exchange (not found on all plant species)
lesion	localized region of tissue death
mandible	appendage near an insect's mouth similar to a jaw; the most anterior of the three pairs of oral appendages
meristem	plant tissue capable of cell division that is responsible for growth
mesothorax	second segment of the thorax
metamorphosis	the process of an immature insect developing into the adult form
metathorax	third segment of the thorax
molt	the process of shedding the exoskeleton or skin to make way for new growth
monocyclic disease	a disease caused by pathogens that reproduce only once per year
motile spore	a spore capable of self-propulsion
mycelium	mass of tubular filaments (hyphae) of fungi (pl. mycelia)
nematode	worm-like microorganism that is free living in the soil or water and feeds on plant cells with a spear-like mouthpart called a stylet
niche	a small cut or hollow area in plant tissue where eggs are laid
nymph	the juvenile life stage of insects which undergo incomplete metamorphosis
ocellus	a simple type of insect eye composed of only one light sensing unit (pl. ocelli)
outbreak	a surge in the population of a forest pest (usually insects)
outer bark	a protective layer of dead cells that covers the stem and branches of a tree
ovipositor	an egg laying appendage on some female adult insects that may be stout, blade-like, saw-like, or needle-like; may be modified for stinging
parasite	a biotic stress agent living in or on a host organism as a recipient of energy transfer and causing injury or disease in the process
parthenogenesis	a form of asexual reproduction through the development of unfertilized eggs
pathogen	a biotic stress agent that causes disease
pathology	the study of diseases

perennial	occurring for two or more years
petiole	the stem-like portion of a leaf that attaches the leaf blade to the branch
pheromone	a chemical that is released by an organism that triggers a social response in the same species
phloem	a layer of living cells in the inner bark that conducts photosynthetic products from leaves to the rest of the plant
photosynthesis	the process through which plants convert carbon dioxide and water into sugar (glucose) using the energy from sunlight
pitch tubes	a hardened mass of dried resin on the bark surface at the site of insect entry
polycyclic disease	a disease caused by a pathogen that reproduces more than once per year
predator	free-living organisms that kill their host, usually consuming more than one individual to reach maturity
predisposing factor	a stress agent that stresses a plant causing it to become susceptible to secondary or opportunistic stress agents
primary stress agent	any agent capable of stressing, injuring, or killing an otherwise healthy tree
proboscis	elongated mouthparts used for piercing-sucking activities
prolegs	fleshy legs located on the abdomen of some insect larvae
prothorax	first segment of the thorax
pupa	the life stage of an insect during which complete metamorphosis occurs (pl. pupae)
pupation	the act of undergoing complete metamorphosis
pycniospore	a type of spore produced by rust fungi
refoliate	to produce leaves again after defoliation occurs
resistant	subject to, but tolerant of attack by a parasite
rhizomorph	a thick string-like strand of clustered hyphae in which the hyphae have lost their individuality
root graft	the fusing of two roots resulting in the connection of vascular tissue between the individual roots involved
sapwood	outermost layer of xylem tissue responsible for transporting water and mineral nutrients from the roots to the crown
secondary stress agent	a stress agent that can only attack a tree that has been sufficiently weakened by a predisposing factor
sign	direct visual observation of a stress agent itself or its activity
silviculture	the science of forest establishment, growth, and composition
spermogonium	a small fruiting body that produces the cells used for sexual reproduction in some fungi (pl. spermogonia)

spore	a small propagative unit of some microorganisms (e.g. fungi) that acts as a seed
stag heading	crown dieback resulting in dead branches extending outward from a section of crown containing foliage
stomate	microscopic opening or pore in plant foliage or young shoots used for gas exchange and the primary source of water loss driving transpiration (pl. stomata)
stramenopile	a group of microorganisms once classified as fungi, but differing significnatly, leading to their classification as a unique phylum (e.g. oomycetes including phytophthora known as water molds)
stress agent	any agent that causes a sustained disruption of the normal physiological processes or structural functioning of a tree
stroma	a compact fungal structure on which fruiting bodies generally form (pl. stromata)
substrate	surface upon which an organism grows and derives nutrients from
susceptible	capable of being parasitized
symbiotic	a relationship between two organisms (usually different species) that benefits both individuals
symptom	a visible plant reaction a stress agent
symptomatic	showing symptoms
systemic pesticide	a pesticide that is absorbed by the plant and can be translocated in portions of the vascular system
teliospore	a type of spore produced by rust fungi
terminal shoot	shoot originating from the tip of a branch, usually exerts apical dominance on lateral shoots
thorax	middle body segment containing appendages used for locomotion
transpiration	the process during which water is lost from the plant surface to the atmosphere causing the movement of water through the xylem
urediospore	a type of spore produced by rust fungi
vascular system	general term referring to those tissues (xylem and phloem) that conduct water, nutrients, photosynthetic products, and a variety of plant compounds throughout the plant
virus	a microscopic infectious stress agent that can only replicate inside of living cells
wind throw	the act of a tree being blown over by the wind
xylem	central core of wood in stems and branches below the inner bark that contains the sapwood, growth rings, and heartwood

North Carolina Forest Service – Forest Health Branch

All North Carolina Forest Service personnel are tasked with maintaining healthy forests. Our Mission is to protect, manage and promote forest resources for the citizens of North Carolina. Foresters and technicians work in the areas of water quality, urban forestry, tree nurseries, forest management, education and outreach, and forest protection to achieve this mission. The Forest Protection Section of the NCFS is primarily concerned with tree health and those agents which directly affect forest health including fire, biotic stress agents, and abiotic stress agents.

The Forest Health Branch of the Forest Protection Section specializes in the biotic and abiotic stress agents including insects, diseases, and invasive plants. They maintain statewide pest surveillance and take action when significant forest resources are threatened. The Forest Health Branch provides professional expertise and advice on the management of harmful forest and shade tree pests, and is responsible for training NCFS personnel how to identify and understand the roles of and threats posed by insects and disease-causing organisms in natural and managed forest systems.

The Forest Health Branch provides diagnostic assistance when forest health problems are encountered. Homeowners, landowners, and consulting foresters are encouraged to first contact their county forestry staff for assistance with tree health issues. When necessary, cases may then be passed along to Forest Health staff who are specially trained in forest health issues. Forest Health personnel provide assistance throughout the state; offices are located in Raleigh, Clayton, Goldsboro, and Morganton. On-site visits, inspections, and consultations can usually be conducted within one week. Pictures can also be emailed to the Forest Health Branch, and assistance can often be provided over the phone/email for minor problems. If a non-native invasive insect, disease, or weed of concern is suspected, the Forest Health Branch should be contacted immediately.

Forest Health Branch Head

Robert Trickel

1616 Mail Service Center
Raleigh, NC 27699-1616
(919) 857-4858
rob.trickel@ncagr.gov

Forest Health Specialist - West

Brian Heath

220 Old Colony Rd.
Morganton, NC 28655
(828) 438-3793 x 201
brian.heath@ncagr.gov

Forest Health Specialist - East

Kelly Oten

762 Claridge Nursery Rd.
Goldsboro, NC 27530-7965
(919) 731-7988 x 209
kelly.oten@ncagr.gov

Forest Health Monitoring Coordinator

____
____
____
____

Forest Health Technician - West

Craig Lawing

220 Old Colony Rd.
Morganton, NC 28655
(828) 438-3793 x 209
craig.lawing.@ncagr.gov

Forest Health Technician - East

Wayne Langston

762 Claridge Nursery Rd.
Goldsboro, NC 27530-7965
(919) 731-7988 x 214
wayne.langston@ncagr.gov