Notes: Basic entomology for arborists

Insect pests play a critical role in the development, health, decline and regeneration of trees in natural forest ecosystems. In urban trees, insect injury is usually negligible, barely noticeable or more typically a nuisance problem, but at times it can become very conspicuous and destructive, sometimes resulting in tree mortality. Insect populations vary from year to year, place to place and from tree to tree. There are many biotic and abiotic factors that influence both insect abundance and host susceptibility to insect attack. Diagnosing insect damage and managing insect pests requires a basic understanding of insect development, phenology (timing of natural events), types of insects and their feeding damage, signs and symptoms of insect pests, and the environmental influences on development, reproduction and population dynamics. The following text provides some important basic information about insect pests and their management.

INTRODUCTION

Insects:

- comprise the largest phylum within animal kingdom – Arthropoda
- the name Arthropoda is derived from the Greek terms: arthron (joint) and poda (foot), referring to the jointed legs or 'feet'.
- are in the class Insecta or Hexapoda
- are the most abundant organisms on Earth. They occupy most habitats
- exert a strong influence on their ecosystem, and have huge impact on, forests, human and animal health and agriculture
- are, for the most part, beneficial (predators, parasites, pollinators, scavengers and decomposers—nutrient recyclers
- some eliminate the weak and old, reducing competition and creating space for regeneration and increasing age diversity of the stand
- influence the growth, destruction and regeneration of forests
- can at times become very destructive especially during droughts, in over-crowed stands and when introduced into a new ecosystem where natural checks and balances are lacking.

Insects are successful because of their:

- diversity (more than one million described species)
- small size
- high reproductive potential
- short life cycle (rapid evolution)
- flight
- protective exoskeleton
- adaptability

CLASSIFICATION:

- Members of the Animal kingdom are divided into approximately smaller groups called *phyla* (singular *phylum*).
- Insects and their relatives are included in the Phylum Arthropoda, which includes: sowbugs, millipedes, centipedes, scorpions, spiders, mites, ticks, crabs, shrimp (Crustaceans) and insects.
- The phylum Arthropoda is further divided into *classes*, e.g., Insecta, Crustacea, Arachnida, etc.
- Classes are then divided, based on shared similarities, into *orders*,
- Orders are further divided into *families* sharing similar characteristics, and then into *genera* (genus, singular). Each genus is, in turn, divided into separate *species*. A species is a group of organisms with similar physical characteristics that can and do interbreed, and share the same gene pool. For example: California oak worm (*Phryganidia californica*).

- Kingdom – Animalia
- Phylum – Arthropoda
- Class – Insecta
- Order – Lepidoptera
- Family – Dioptidae
- Genus – *Phryganidia*
- Species – *californica* (This is the specific name or specific epithet. The genus is capitalized but not the species; both should be italicized.)

Arthropods sharing the following characteristics are placed in the Class Insecta:

- segmented bodies
- bilateral symmetry (one side mirrors the other)
- chitinous exoskeleton (tough, pliable protective covering)
- 3 distinct body regions - head, thorax, abdomen
  - **abdomen:** The posterior body division of an insect that is visibly segmented, contains the respiratory, reproductive, excretory systems and much of the digestive system.
  - **head:** A rigid capsule formed from several fused segments and sclerotized (hardened) plates that house the eyes, mouth parts and antennae.
  - **thorax:** The second of three major divisions in the body of an insect is composed of three segments, each bearing a pair of legs. Wings are attached to the 2^{nd} and 3^{rd} thoracic segments.
- 3 pairs of jointed legs attached to the thorax
- Wings (usually 2 pair) Hind wings may be greatly reduces as in flies or missing in other insect with only one pair of wings. In beetles, the forewings are modified into hard wing covers (elytra). Some insects lack wings.
- compound eyes and/or ocelli (simple eyes)

Class Insecta is divided into orders:

- Orthoptera – grasshoppers, crickets, cockroaches, matids, walking sticks, katydids
- Diptera - flies
- Coleoptera – beetles
- Lepidoptera – moths and butterflies
- Homoptera – aphids, cicadas, treehoppers, spittle bugs, leafhoppers, bark aphids (Adelgids), psyllids, whiteflies, scales, mealybugs, etc.
- Hemiptera – lygus bugs, box elder box, squash bugs, stink bugs, ash plant bug
- and others

Most important orders:

- beetles (Coleoptera)
- moths and butterflies (Lepidoptera)
- wasps, ants, and bees (Hemiptera)
- flies (Diptera)
- homoptera (aphids, scale insects, psyllids, lacebugs, adelgids,

FEEDING—Insect mouth-parts are adapted to particular modes of feeding

- Chewing – beetles, moth and butterfly larvae, sawfly larvae, grasshoppers, etc. Some insects that do not have chewing mouthparts as adults do as larvae, such as moths and butterflies.
- Piercing and sucking – aphids, scale, leaf hoppers, whiteflies, mealybugs, true bugs, mosquitoes, black flies, etc.

- Chewing and lapping (liquid-nectar) – flies, bees and wasps
- Sponging (liquid food) – certain flies
- Siphoning (plant nectar) – Lepidoptera (adults)

INSECT DEVELOPMENT: The change in form that takes place as insects grow from immature stage to adults is called **metamorphosis.** The two basic types are:

Complete development

- Involves four life stages – egg (embryo) larva, pupa and adult. For example, in the life cycle of a beetle, the embryo growing within an egg, 'hatches' into the larval (grub) stage. The grub, after completing its development, enters a quiescent pupal stage where adult characteristics are acquired. Soon after, the adult beetle emerges.
- The immature forms of insects with complete development do not resemble adult, hence there is a 'complete' change of form during development.
- Examples: beetles, moths and butterflies, bees, wasps, ants, etc.

Incomplete development

- involves only three life stages - egg, *nymph* and adult. Insects with this type of development undergo gradual changes in form as they develop from the immature to the adult stage.
- The immature forms of insects with incomplete development are called nymphs. As the insect grows, it molts (sheds its skin or exoskeleton). After each molt, the nymph is slightly larger and more adult-like in appearance. After a final molt, the adult emerges.
- The immature stage (nymph) resembles the adult. The principal changes during growth are in size, body proportions, development of the eyes, wings and other body parts.
- Examples: aphids, scales, whiteflies, true bugs, cicadas, grasshoppers and crickets, earwigs and dragonflies, etc.

Stages of development:

- The egg is the embryonic stage.
- The larva or nymph is the active, feeding, post-embryonic form, typically with limited movement. Jointed legs are generally present on insect larvae. In appearance, the larva usually looks completely different than the adult form. For example, a caterpillar differs from a butterfly. Larvae also behave differently than the adults; they are found in different places, and eat different food.
- The larvae (plural) of some insects, e.g., caterpillars, sawflies, may also have rudimentary (fleshy, and unjointed) legs (prolegs) on some of their abdominal segments. Some larvae, e.g., fly maggots, some beetle grubs, etc., entirely lack legs.
- Larvae or nymphs are highly adaptive to exploiting food sources that may be limited in time
- The pupa is the non-feeding, inactive stage between larva and adult in insects with complete metamorphosis where structural reorganization takes place.
- Pupae (plural) often have a hard (scleritized) protective exoskeleton may be enclosed in other structures such as cocoons, nests or hard cases. The pupal stage may also allow the insect to pass through adverse conditions in protected areas such as leaf litter and soil.
- The adult stage is the winged form with a capacity for reproduction and long distance dispersal.
- Adult insects emerge (**eclose**) from pupae by splitting the pupal case, and the whole process of pupation is controlled by hormones.
- Some insects produce only one generation a year, while other produce two or perhaps a third generation a year, depending on climate. Other insects may produce multiple generations, e.g., bark beetles, aphids, etc. A few wood boring insects may take several years or longer to complete a single generation, e.g., carpenterworm, cicadas, golden buprestid, etc.

- Insects overwinter in the egg, larval or pupal stage, usually in protected locations.
- Pupae may enter dormancy or *diapause* until the appropriate season for the adult insect.

Terms used to describe components of metamorphosis:
- **Molting**—the shedding of the hard exoskeleton to allow for growth. The cast-off 'skin' is referred to as the exuvia or exuvium (exuviae-plural)
- Stadium—time interval between molts.
- **Instar**—the form assumed within a specific stadium. Upon emerging from the egg, the insect is in its first larval or nymphal instar. At the end of this stadium the insect molts and enters the second larval or nymphal instar, and so on. The final instar is the adult (imago).

Growth:
- Egg hatch is generally timed to the availability of food.
- Growth by immature stages (both larvae and nymphs) is accomplished by molting, which involves the shedding of the tough outer body covering (exoskeleton), allowing growth to take place.
- Insects may have several to many molts.
- Once formed, adult insects don't grow.

MAJOR GROUPS OF TREE PESTS:

Leaf feeders (defoliators)
- Symptoms: leaves partially or totally consumed, skeletonized, mined, scalloped (edges) or riddles with holes.
- Examples: moth and butterfly and sawfly larvae, leaf beetles, grasshoppers, etc.,
- Impact: defoliation may reduce tree growth and impair health. Repeated defoliation may initiate decline making them more susceptible to secondary (stress-triggered) pests, often leading to mortality.

Phloem feeders
- *Symptoms*: leaf wilt, dieback of leaves, shoots, branches, and entire trees or dead patches of bark.
- *Signs*: Look for wilting (fading) foliage, frass (boring dust and fecal pellets), bleeding, pitching, sap flow, tunnelling in the phloem and/or wood, and holes in the bark.
- Examples: bark beetles, pitch moths, clear winged borers
- Impact: tree mortality, branch, tip or shoot dieback. Tree death or dieback is caused by destruction of the phloem and cambium.

Wood borers
- *Symptoms*: dieback of branches, entire tree or areas of bark, cracked or sunken bark, bleeding, etc.
- *Signs*: Look for boring dust/fecal pellets (frass) exit holes in the bark and burrowing in wood. This group of insects that often burrow in both the phloem (inner bark) and xylem (wood).
- Examples: flatheaded borers, roundheaded borers, ambrosia beetles, horntails, carpenterworm, etc.
- Impact: tree and branch mortality

Sap feeders (piercing and sucking)
- *Symptoms*: stippled, yellow spotted, bleached, silvered, bronzed or distorted foliage. No loss of tissue.
- *Signs*: look for honeydew; sooty mold; cast skins; white, cottony/waxy material, etc..
- Examples: aphids, scale, adelgids, psyllids, leafhoppers, plant bugs, mealybugs, lacebugs, thrips, etc.
- Impact: feeding weakens, stunts, deforms or causes dieback.

Gall formers

- These insects, typically gall wasps, produce abnormal swellings or growths - brightly colored or oddly shaped (galls) in response to egg laying or feeding damage
- *Symptoms*: occasional branch dieback, deformities on leaves, buds, flowers, shoots, and branches, growth reduction
- Impact: disfigures tree, heavy infestations can weaken tree.

Bud and shoot insects

- *Symptoms*: tip dieback, 'crooks', bushy growth, multiple stems, deformities.
- *Signs*: Look for burrowing in cambial region an/or center of the stem
- Examples: twig girdlers, twig beetles, twig weevils, tip moths, cicadas
- Impact: loss of vigor, deformities.

Insects affecting roots

- Examples: root weevils, root bark beetles, cicadas, scarab beetles, (white grubs - June beetles, rain beetles).
- Impact: growth loss, kill seedlings and small trees.

Insects affecting seeds

- Examples: acorn weevil, filbertworm, cone beetles
- Impact: reduced reproduction

INSECTS AND HOST SPECIFICITY

- Most insects are relatively host-specific, i.e., they feed on a single species (monophagus), several species or the members of a genus, several closely genera within a family, or occasionally many families (polyphagus), e.g., gypsy moth. Native insects, having co-evolved with their host(s), have developed some resistance to their host's feeding inhibitors.

INTRODUCED VS. NATIVE INSECTS

- **Introduced pests** are potentially destructive because their new hosts typically lack effective resistance. More importantly, they arrive without their natural enemies, so there are few natural checks and balances. Notable examples of introduced pests include Eucalyptus borer, redgum lerp psyllid, gypsy moth, Asian longhorned beetle, oak pit scale, etc
- **Indigenous** (native) pests, having coevolved with their hosts, have developed tolerance to their host's physical and chemicals defenses.

INSECTS AND TREE MORTALITY

- Most insects capable of killing trees can only do so when their host is sufficiently stressed due to drought, soil aeration deficits, root loss, fire damage, severe mineral imbalances, etc. Examples: bark beetles and borers.
- Repeated defoliation may cause dieback or sufficiently weaken plant resistance to stress-triggered pests and diseases.
- Insects are seldom the direct cause of tree death. They usually play a secondary role in the death of a tree, and are often only one component of a complex involving multiple biotic and abiotic factors.

IMPACTS OF INSECT FEEDING:

- growth reduction, impaired health
- defoliation (partial or complete and multiple-year defoliations)
- energy depletion (sap-feeding)

- deformities (galls)
- twig and branch dieback (girdling of branches and trunks)
- loss of wood strength (wood borers)
- nuisance: honeydew, sooty mold, migrating insects, reduced appearance
- disease transmission
- mortality

INSECT ABUNDANCE is greatly influenced by abiotic and biotic factors**:**

- For pest damage (or disease) to occur, a destructive pest or an aggressive or virulent pathogen must be present, environmental conditions must favor the agent's development, and the host plant must be susceptible, in a susceptible condition (sufficiently stressed), or in a susceptible stage of development, e.g., succulent new foliage, etc.
- Insects are cold-blooded, so the rate at which they develop is largely dependent on the temperature of their environment.
- The developmental rate of insects is controlled primarily by temperature. Insects and the plants they feed on, require a certain amount of heat to develop from one stage of their life cycles to the next. There is a lower threshold where development begins, and an upper threshold beyond which development ceases or mortality occurs. In general, insects develop rapidly when the weather is warm and more slowly when it is cold. Extreme temperatures, however, can be lethal.
- Host resistance and nutritional suitability, as well as the activity and development of insects are influenced by environmental conditions. For instance, plants receiving ample irrigation and nitrogen fertilization are usually more susceptible to leaf- and sap-feeding insects, as well as foliar diseases, than plants that have not been irrigated and fertilized. These practices generally promote succulent growth and improved plant nutrition.
- Most damage from leaf-feeding insects is done early in the season when the leaves are young and succulent. Young leaves are more palatable and nutritious than mature leaves because they contain higher concentrations of water, nitrogen (amino acids and proteins), and other essential elements. In addition, leaf tissue becomes less palatable and digestible to chewing insects as concentrations of cellulose, lignin, and tannins increase with age. The leaf cuticle that thickens with maturity is another important deterrent to insect feeding.
- Adverse environmental conditions may suppress populations of natural enemies more than they suppress that of the pest. When favorable conditions return, pest populations often rebound quickly because their natural enemies usually take longer to recover, giving the pest a short-term advantage
- Pest outbreaks typically occur when environmental conditions are favorable and natural enemies (insect predators, parasitoids are scarce, and pathogenic microorganisms are inactive or at low levels. Every insect has natural enemies that reduce their populations under certain conditions. Populations of many pests are held in check most of the time by their natural enemies. It is common for natural enemies to reduce pest populations substantially, but sometimes not enough to prevent damage.
- Insect populations fluctuate from year to year and throughout their distribution range. Some pest problems are perennial, others are sporadic and relatively short-lived, and a few like the California oakworm are more cyclic.

ENVIRONMENTAL FACTORS INFLUENCING TREE HEALTH AND PEST SUSCEPTIBILITY:

- soil moisture availability (drought)
- soil aeration deficits (flooding, restricted drainage, excess irrigation, soil compaction, compacted fills, pavement, etc.
- temperature extremes
- constant wind
- humidity

- available sunlight, exposure,
- air quality
- soil characteristics: texture, structure, pH, depth, salt content, toxicity, nutrient content, etc.
- competition with other vegetation
- defoliation
- topography – affects water runoff, soil moisture, drainage, soil depth, exposure to sunlight, etc.

DIAGOSIS

Symptoms - changes in normal growth and appearance of a tree:

- missing, tattered foliage, holes, scalloped edges, skeletonized, mined
- yellowed, bronzing, bleached or stippled foliage
- leaf spotting and blotching
- twig and branch dieback, tree death
- leaf wilting, leaf tip and marginal dieback of leaves
- distortion, galling
- bleeding

Signs are the evidence of insect activity, e.g., the pests themselves, the materials they leave behind, or the characteristic damage they cause:

- **honey dew:** sticky droplets of sugar liquid – ex. aphids, soft scale, leafhoppers, mealy bugs, psyllids, whiteflies
- **lerps,** crystallized sugar shelters; red gum lerp psyllids, spotted gum lerp psyllid
- **sooty mold:** black, sooty fungal growth on leaves and other surfaces – ex. aphids, soft scale, leafhoppers, mealybugs, psyllids, whiteflies.
- **tar-like fecal specks:** lace bugs, thrips, plant bugs.
- **frass:** fecal pellets, sawdustlike material
- **tents, webs, silken mats:** tent caterpillars, webworms, leaf rollers, leaf miners, etc.
- **frothy, spittle-like material:** spittle bugs.
- **eggs, egg masses**
- **cast skins:** aphids, leaf hoppers, lace bugs, cicadas, clearwinged moths, etc.
- **pitch (sap or kino) masses/flows:** sequoia pitch moth, cypress bark moth, eucalyptus longhorned beetle, etc.
- **pitch tubes:** western pine beetle, red turpentine beetle
- **bleeding:** borers, ex. Pacific flatheaded borer, bronze birch borer, alder borer, etc.
- **cottony, waxy material:** aphids, scale, whiteflies, mealybugs, adelgids and psyllids.
- **frass**: fecal pellets and/or sawdustlike boring dust – bark beetles, borers, carpentermoth, clearwing moths
- **boring**: exit holes, tunneling under the bark, tunneling in the wood
- **galls:** gall wasps, psyllids

THE DIAGNOSTIC PROCESS:

- identify the host
- assess symptoms, patterns of symptoms or occurrence, e.g., one tree or many, symptoms scattered or spread uniformly throughout the crown. Determine when symptoms began. Are they increasing, decreasing or remaining the same? More than one species affected?
- determine plant parts affected: leaves, twigs, branches, trunk, root crown, roots, or the entire tree.
- determine type of feeding damage
- look for obvious causes: signs of the pest(s)
- determine the common pest species associated with the plant in your area
- consider:
    - abiotic factors and site conditions,

    - recent climatic events such as floods, droughts, hail storms, extremes temperatures, etc.
    - tree age and health
    - recent or past site disturbances
- when secondary pests are involved identify the proximate cause (predisposing factors): drought, wet soil, soil compaction, plant adaptability, soil characteristics, topography, etc;
- determine if the pest is likely to cause significant damage? And should something be done, and if so, what?
- With the above information, it should be possible to make a preliminary diagnosis.

Management strategies should be based on the key life history features:

- preferred egg-laying site (exposed or protected).
- timing of developmental stages
- period of time between egg laying and hatch
- minimal developmental temperature, developmental time
- emergence periods and number of generations per year
- #'s of instars, length of each instar
- crawler stage
- pupation period, location
- overwintering stage and site
- most susceptible stage if pesticides are used
- signs of natural enemies
- pest status - primary (able to feed on healthy trees) or secondary (attacks only stress-weakened trees).
- part(s) of plant attacked.
- feeding behavior
- most damaging stage
- most susceptible stage to management

IPM (Integrated Pest Management) basics:

- monitor for pests or changes in the plant's appearance
- identify the pest or disorder
- consider the environmental tolerances of the plant and determine if environmental stress or site disturbance is involved, and if so remediate unfavorable conditions to enhance plant health.
- monitor the pest population or damage.
- review pest's life history
- set an economic injury threshold.
- act when the pest is likely to cause unacceptable damage. Time application of pesticides to coincide with peak activity of the most susceptible life stage.
- consider all pest management options and evaluate the benefits, and risks of each method. Factor in cost, efficacy, time for treatment to work, permanence of treatment and environmental and worker safety.
- If pesticides are required on a regular basis to manage a pest, consider replacement with another species or resistant cultivar.

Basic Entomology

Bruce W. Hagen

Insects comprise the largest phylum within animal kingdom – Arthropoda. The name is derived from the Greek terms arthron (joint) and poda (foot), referring to the jointed legs or ‘feet.’ Insects include the largest numbers, both in species and individuals, in the animal kingdom.

Within the phylum Arthropoda is the class Insecta or Hexapoda. The term Hexapoda, literally meaning six feet, is now the preferred name used to describe insects. Insects have a distinct head, thorax and abdomen, one pair of antennae, three pairs of legs and usually one or two pairs of wings in the adult stage.

CLASSIFICATION:

Kingdom – Animalia
- **Phylum** – Arthropoda
  - **Class** – Insecta
    - **Order** – Lepidoptera (example)
      - **Family** – Dioptidae
        - **Genus** – *Phryganidia*
          - **Species** – *californica*
          - **Scientific name –** *Phryganidia californica*
            - **Common name – California oak worm**

The phylum **Arthropoda** contains: millipedes, centipedes, spiders, mites, crustaceans, **insects** and others. They all share the following characteristics:

- bilateral symmetry (one side mirrors the other)
- chitinous exoskeleton (hard covering)
- segmented body
- paired and jointed appendages

Arthropods sharing the following characteristics are placed in the Class **Insecta**:

- 3 body regions - head, thorax, abdomen
- 3 pairs of jointed legs
- wings- usually 2 pair
- compound eyes and/or ocelli

The Class Insecta is further divided into **orders** based on similarity of characteristics.

IMPORTANT ORDERS OF INSECTS:

Orthoptera – grasshoppers, crickets, cockroaches, matids, walking sticks, katydids
Isoptera – termites
Hemiptera – plant bugs, assassin bugs, stink bugs, lace bugs, psyllids, etc.
Homoptera – cicadas, treehoppers, spittle bugs, leafhoppers, aphids, bark aphids, psyllids, whiteflies, scales, mealybugs, etc.
Coleoptera – beetles and weevils.
Lepidoptera – moths and butterflies.
Hymenopters – ants, bees, wasps and sawflies.
Diptera – flies

Insect mouth-parts are of considerable use in classification. They determine the type of damage or mode of feeding. Types of mouth-parts:

- **Chewing** – beetles, moth and butterfly larvae (Lepidopters) sawfly larvae (Hymenoptea), grasshoppers (Orthoptera), termites
- **Piercing and sucking** –Hemiptera, some Diptera (mosquitos, black flies)
- **Chewing and lapping** – bees and wasps
- **Sponging** – certain flies
- **Siphoning** – Lepidoptera

Insects, in contrast to many other forms of life, go through several different developmental stages throughout their lives. Most insects completely change their form as they develop. They go through four stages **- egg, larva, pupa**, and **adult**. This is known complete metamorphosis and is the most advanced form of insect development, allowing for division of labor and reduction of competition. Beetles, moths and butterflies are examples of this group. Aphids, scales and true bugs have simple or incomplete metamorphosis. Such insects go through only three stages **- egg**, **nymph** and **adult**. Those insects with this type of development do not completely change form, as the immature stage (nymph) closely resembles the adult. The principal changes during growth are in size, body proportions, development of the eyes, wings and other body parts.

The egg is the embryonic stage. The larva or nymph is the active feeding, post-embryonic form, typically with limited movement. The pupa is the inactive, non-feeding stage between the larva and adult stage where structural reorganization takes place. The adult stage is the winged form with a capacity for reproduction and long distance dispersal.

Growth by immature stages (both larvae and nymphs) is accomplished by molting, which allows the hard, outer body covering (exoskeleton) to be shed so growth can take place. Insects may have several to many molts. The period of time between molts is called the stadium. The insect during this period is called the instar. Once formed, adults don't grow. Larvae are unique in that they are a specialized feeding stage, typically utilizing a food source different than that of the adult. Pupae are often found in protective cocoons, nests or cells.

DEVELOP PEST MANAGEMENT STRATEGIES ON KEY LIFE HISTORY FEATURES:
- preferred host(s), alternate hosts
- plant parts attacked
- pest status **-** primary (can kill or injure healthy trees) or secondary pest (attacks only stress-weakened trees)
- type of feeding damage, parts attacked
- # of eggs laid, location
- pupation site
- period of time between egg laying and hatch
- minimal developmental temperature, developmental time
- #'s of instars, length of each instar
- pupation period, location
- overwintering stage and site
- emergence periods
- # of generations per year
- natural enemies, unfavorable environmental conditions
- environmental factors that favor development

Common insect pests of urban trees
There are five basic types of insect pests that feed on trees and shrubs:

TYPE	PARTS AFFECTED

- **leaf feeders** (defoliators) leaves.
- **inner-bark feeders** twigs, branches, trunks, roots.
- **borers** – wood branches, trunks, roots and shoots
- **sap feeders -** leaves, buds, shoots, twigs, branches, trunks, bark.
- **gall formers** leaves, flowers, buds, twigs, branches, roots.

LEAF FEEDERS:
Symptoms: leaves partially or totally consumed, skeletonized, mined, scalloped (edges) or riddles with holes. Trees often defoliated.

Includes: caterpillars, (tent makers, leaf rollers, bud worms), weevils, leaf beetles, leaf miners, sawflys.

Examples: California oakworm, western tent caterpillar, western tussock moth pine sawfly, fruit tree leaf roller, elm leaf beetle

Impact: partial or total defoliation reduces photosynthetic capacity, impacting growth and health and making them more susceptible to secondary pests, bark beetles, borers, scale insects, mites, root and canker diseases.

INNER BARK FEEDERS:
Symptoms: wilt, dieback of leaves, shoots, branches, and entire trees. Look for wilting (fading) foliage, granular boring dust, bleeding, pitch tubes, sap flow and 'shot' holes in the bark.

Includes: bark beetles, flatheaded borers, roundheaded borers, weevils, pitch moths, clearwinged moths and bark moths.

Examples: western pine beetle, pine engravers, red turpentine beetle, cypress/cedar bark beetles, oak bark beetle, shothole borer, elm bark beetle, Douglas fir engraver, sequoia pitch moth, eucalyptus longhorned borer, alder borer, bronzed birch borer, ash/lilac borer, Pacific flatheaded borer, oak twig girdler, etc.

Impact: tree mortality, branch or shoot dieback, tree stress, introduction of decay causing fungi. Girdling of the cambium and damage to the inner bark and outer wood layer causes dieback or wounding of affected portions.

BORERS (WOOD):
Symptoms: dieback of branches, entire tree or areas of bark, cracked or sunken bark, bleeding, exit holes, boring dust (frass). This group of insects burrows in both the sap and heartwood.

Includes: ambrosia beetles**,** wood boring caterpillar, clear-winged moths, flatheaded and roundheaded borers, termites and carpenter ants.

Examples: carpenterworm, birch/locust borer, oak cordwood borer, cedartree borer, banded alder borer, western ash borer, ash/lilac borer, ponderous borer, subterranean and drywood termites and giant root borer, oak ambrosia beetle, etc.

Impact: tree mortality, stress, internal decay, hazard potential

BORERS (BUDS AND SHOOTS):
Symptoms: tip dieback, "crooks", bushy growth, multiple stems, deformities.

Includes: tip and shoot moths, terminal and shoot weevils, and twig borers.

Examples: Monterey tip moth, lead cable borer, pine shoot borer, orchard pruner, oak twig girdler, cypress bark beetles.

Impact: loss of vigor, deformities.

SAP FEEDERS:
Symptoms: Stippled, yellow spotted, bleached, silvered or bronzed foliage. No loss of tissue. Look for honeydew, sooty mold, cast skins, white, cottony/waxy material.

Includes: aphids, scale insects, mealybugs, psyllids, wooly bark aphids (adeldigs), whiteflies, plant bugs, spider mites.

Examples: black scale, pit scale, sycamore scale, ash bug, irregular pine scale, black pine leaf scale, white pine needle scale, oyster shell scale, tulip tree scale redgum lerp psyllid, pepper tree psyllid, wooly apple aphid, tulip tree aphid, green birch aphid, linden aphid, beech aphid, wooly oak aphid, giant conifer aphid, ash whitefly

Impact: weakens, stunts, deforms or kills, honeydew and sooty mold create a nuisance.

GALL FORMERS:
Symptoms: unusual growths or deformities of varying size, shape and color on leaves, buds, flowers, shoots, and branches resulting from insect feeding or egg laying. Galls (abnormal swellings) form in response to egg laying (chemical response) or feeding damage (mechanical response). Look for swellings or abnormal growths - brightly colored or oddly shaped structures (galls).

Includes: cynipid wasps, midges, aphids, adelgids, psyllids, thrips, and mites (bud, gall, blister, and rust).

Examples: Monterey pine needle gall midge, honey locust pod gall midge, wooly apple aphid, oak apples, live oak gall, etc.

Impact: growth reduction disfigures tree, heavy infestations can weaken tree, weaker trees tend to more gall pests.

scarab beetles, (white grubs - June beetles, rain beetles). – *Impact:* growth loss, kill seedlings and small trees.

Insects affecting seeds - *Examples*: acorn weevil, filbertworm, cone beetles (spreads pine pitch canker).

Plant Health Care – a More Proactive Approach to Pest Management

Bruce W. Hagen

Many serious pests are associated with rapid growth, succulent foliage, increasing age, stress resulting from unfavorable environmental conditions and inappropriate tree care. Although conventional pest management certainly plays an important role in managing plant health, it has its limitations. Pesticides provide only a short-term solution to stress-induced pest problems. They do little or nothing to alleviate unfavorable environmental conditions or alter tree care practices that may be contributing to the problem. This is perhaps the most serious limitation of conventional pest management—a focus on the pest rather than on the plant and its physical environment. Reliance on pesticides can lead to pesticide resistance and environmental contamination. It can also have a devastating impact on non-target insects including beneficial species, resulting in pest resurgence or secondary pest problems. There are, of course, a number of new biochemicals and microbial pesticides that have few environmental side effects.

To contend with these problems, a more balanced approach was developed. The resulting strategy, dubbed integrated pest management (IPM), is based on using a combination of management options such as chemical, biological, cultural, physical, and mechanical means to maintain pest populations/damage below an unacceptable 'injury' level. IPM relies on regular monitoring and acting when pest populations/damage threatens to cause aesthetic and or economic loss. The goal of IPM, which has its roots in agriculture, is to avoid the unnecessary use of pesticides and to minimize the adverse environmental impacts of pesticide use. Although IPM encourages mitigating environmental stress to improve plant health, it does not necessarily emphasize it.

Plant health care (PHC), with a broader approach than IPM, focuses on managing health, appearance, structural stability of landscape plants. Pest management is just one aspect of PHC. Initially, it involves carefully assessing site conditions and horticultural practices, and then monitoring for changes in health. Health, in a general sense, refers to reasonable growth, appearance, pest resistance, resilience to stress and ability to adapt to changing conditions. Inherent characteristics, environmental factors, climatic events, insects and disease, mechanical injury, site disturbances, age and horticultural practices all interact to influence tree health. Early detection of changes, and mitigation of problems or conditions that may be contributing to stress or favoring pest development is critical. The goal of PHC is to develop a long-term management strategy to improve and maintain plant health through appropriate tree care practices. This strategy relies heavily on establishing, restoring and/or maintaining favorable and stable growing conditions throughout the life of the plant. In this manner, plant health and natural pest resistance can be enhanced or maintained, minimizing serious pest problems and greatly reducing the need for pesticides. Although PHC recognizes the need to use pesticides to avoid serious plant injury, pesticides alone will not solve the underlying problems.

Concepts of Plant Health Care

The health and management of a plant must be considered in the context of the entire landscape, the existing maintenance program, as well as past practices and disturbances. Managed landscapes are an interrelated system of plants, soil, environmental factors, pests, animals, and people. For the most part, they are not sustainable without specialized tree care. It is important to understand that landscapes are dynamic and change over time. Plants grow in size, competing for space, sunlight, water, and minerals. Environmental conditions change—there are occasional droughts, floods, frosts, storms, etc. Tree-care practices change with ownership, and there are site disturbances. Wounding by poor pruning technique, lawnmowers, or string trimmers can lead to decay and impaired health. Irrigation systems may fail, leading to droughty or saturated soil conditions. Frequent and excessive irrigation, particularly where drainage is restricted, creates conditions favoring root pathogens. Sprinkler design is also important because it can encourage root diseases by frequently wetting the lower trunk and root collar. Irrigation systems designed to establish young trees quickly become obsolete, leading to poor rooting or premature decline as water demand exceeds supply. Moreover, there is often competition from turf and other dense ground covers. Plant health and vigor usually decline with age and increasing competition.

Trees and pests

Plants are subject to insect or disease pests if they are inherently susceptible, in a vulnerable condition (sufficiently stressed) or favorable stage of development (succulent foliage), and if pest development is favored by the ambient environmental conditions. The level of damage, of course, is dependent on host-plant resistance and nutritional content, abundance of natural enemies and/or pest virulence or aggressiveness. Most pests are fairly host-specific usually one or several species within a single genus. Only a few pests have a broad host range.

Native pests, by and large, cause relatively minor damage because their hosts, having evolved with the pest, have adapted and developed reasonable resistance. Consequently, pests have developed some tolerance to their host's physical and chemicals defenses as well. Native pests can, at times, become numerous and destructive in response to favorable environmental conditions or if their natural enemies are scarce. Pest problems are typically short-lived and sporadic. Serious and widespread damage can occur if environmental stress becomes severe. For example, bark beetle outbreaks are common during prolonged droughts. Borers and canker diseases are also more prevalent on drought-stressed plants. Leaf diseases such as anthracnose, leaf spot, needle casts, rusts, fireblight, etc., are prevalent on developing tissue during rainy or humid periods.

Introduced pests are potentially destructive because their new hosts often lack effective resistance. More importantly, they arrive without their natural enemies. Notable examples of introduced pests include gypsy moth, Asian longhorned beetle, sudden oak death, Dutch elm disease, chestnut blight, and pine pitch canker. Such pests, due to their aggressiveness or pathogenicity can attack and kill healthy trees. Furthermore, foreign insect pests usually arrive without their natural enemies, allowing for rapid pest buildup and spread. The red gum lerp psyllid, recently introduced to California from Australia, is a good example of this phenomenon. Lacking natural enemies, it has spread rapidly throughout the state, causing severe defoliation of susceptible species. Repeated defoliation has caused widespread mortality throughout California wherever red gums are planted.

Most introduced pests are not easily managed even with pesticides. At best, pesticides offer only a temporary solution. The successful introduction of effective parasitoids and predators is the best, long-term solution for managing introduced pests. The most practical means to deal with certain pests like Dutch elm disease and sudden oak death is through prevention–exclusion, regulatory control, and proper sanitation. The selection of resistant cultivars is another long-term solution.

Pest Resistance:

There is a misconception that 'healthy' trees are more pest resistant than stressed trees. While it is true that severely stressed trees are more susceptible to secondary pests, healthy trees are in general no more resistant to pests than moderately stressed trees. In reality, healthy trees can be both more or less resistant to different pests. The notion that stressed trees are more susceptible to pests is based on the assumption that stressed plants have less energy to allocate for defense. Numerous studies have shown that moderate stress typically enhances pest resistance by increasing energy reserves and the production of defensive chemicals (allelochemicals).

Growth rate, a common measure of tree health, can be misleading. It is a mistake to assume that rapid tree growth is a sign of good health. Contrary to what most people believe, rapidly growing trees are often less tolerant of environmental stress and more susceptible to pest problems than slower growing trees. The reason being is that in rapidly growing trees, much of the available energy is used for leaf and shoot growth rather than root growth, accumulation of energy reserves and production of defensive chemicals.

Health is dependent on photosynthetic output and adequate energy reserves. This allows for replacement of lost or damaged tissue, effective response to invading pathogens (compartmentalization), and the production of allelochemicals that increase pest resistance.

Trees allocate energy for respiration (all living cells need energy to survive), growth, reproduction, storage and defense. Energy allocation is dynamic, changing with time of day/season, cultural practices and environment. Flexibility is necessary because carbohydrate availability is typically insufficient to support all life processes simultaneously. Trees are opportunistic–when conditions are favorable they allocate more energy to growth and less to storage and defense. Plants adjust their energy use priorities in different environments to best meet their need.

Trees, having evolved in harsh environments, where resources, e.g., light, water and minerals are limiting, have developed strategies to acquire adequate resources. Under unfavorable conditions, they're able to maintain high photosynthetic output, a favorable root to shoot ratio, adequate energy reserves and chemical defenses by restricting top (foliar) growth. By slowing growth and maintaining a smaller leaf surface area, trees are able to direct more energy to their roots. This conserves energy, maintains adequate photosynthesis, increases availability of water and nutrients, and allows for energy storage and production of allelochemicals. In this manner, environmental tolerance and pest resistance are improved.

Environmental conditions unfavorable to trees cause **stress** by altering or impairing normal physiological function, e.g., photosynthesis, water and mineral absorption, transpiration, transport, hormonal growth regulation, carbohydrate storage and metabolism, etc. This can impair health, leading to increased susceptibility to secondary pests. Stress can also be caused by biotic factors that adversely affect physiological function. The intensity and duration of stress, and the stage of plant development determine the impact on tree health. Abiotic factors causing tree stress include: drought, poor soil aeration (flooding, poor drainage, excess irrigation, irrigation temperature extremes, mineral imbalances, air pollution, wind, shade, etc. Biotic factors causing stress include defoliation (insect or disease), excessive pruning, root severence, competition, age, girdling roots, etc. Stress has a major impact on growth, but photosynthetic capacity remains largely unchanged until stress become severe. At this point, both growth and photosynthesis are impacted. Severe stress leads to energy depletion and suppressed levels of natural defensive compound and increased susceptibility to secondary pests. Severely stressed trees are generally poor hosts for sap- and leaf-feeding insects, due to low tissue water content, poor nutrition and higher levels of defensive chemicals.

Host nutritional suitability:

The attractiveness or 'palatability' of a plant to a pest is determined not only by the concentration of toxic or inhibitory compounds, but by the amount of available nitrogen (amino acids) in their growing tissues. A pest's survival and abundance depends on the relative availability of these compounds. Nitrogen, an essential component of protein, is a limiting nutrient for most plants, animals, insects, and pathogens. Growth and reproduction of plant-feeding insects is usually limited by the nutritional suitability of its host(s). Plant suitability generally increases with nitrogen content. Much insect-feeding and leaf-disease damage is done early in the season when the foliage is young, succulent, non-lignified and loaded with amino acids–the building blocks for proteins. Expanding foliage initially contains high levels of amino acids, and certain defensive compounds, e.g., alkaloids and cyanogenic glycosides, and proportionately more water. Availability of amino acids begins to decline with maturity. Phloem-feeding insects, e.g., aphids, psyllids, whiteflies, scale, etc., feed on amino acid-rich sap in the phloem moving to new growth.

Young leaves are more suitable or nutritious to the insects and pathogens that are adapted to their host's defensive chemicals because they contain higher water and protein concentrations and because their protective cuticles are not fully developed. As leaves age their nutritional quality declines, their toughness increases, as do concentrations of other allelochemicals, e.g., tannins and lignins. Leaf tissue gradually becomes less digestible to many chewing insects due to increasing levels of lignin. Lignin, a natural component of wood and leaves, serves to stiffen wood and toughen leaves. Feeding typically lessens and insect populations diminish as leaf-tannins and other defensive compounds increase. There are though, many pests that prefer mature or over-mature foliage because some defensive compounds may decrease with age. Pest development and survival is also greatly influenced by environmental conditions and abundance of natural enemies. In addition, ants can contribute to pest problems because they aggressively protect sap-feeding insects from predation and parasitism.

Leaf diseases are most prevalent on new, succulent foliage as well. They typically develop early in the season when rain and mild temperatures favor spore production, dispersal, germination, and tissue damage. Cool, wet springs favor disease development by slowing shoot elongation and leaf development, thus extending the period of time that the leaves are succulent and susceptible to infection. Powdery mildews, though, can develop on mature leaves when environmental conditions are favorable.

Stress and age-related effects

For the most part, stress has not been shown to increase susceptibility to most pests as commonly thought. Stressed plants may be more resistant to certain pests, e.g. defoliators and sap-feeders, or just poor quality hosts. Severe stress, resulting from drought, defoliation, root loss, etc., increases susceptibility to secondary pests. Secondary pests, those that attack and kill or seriously injure stress-weakened plants are relatively common and extremely destructive in forests and managed landscapes. Such pests include bark beetles, borers (flatheaded, roundheaded, clearwinged and carpenterworms), root diseases, canker-causing pathogen, canker-rots, and sap-rots. Drought stressed plants, though, are not more susceptible to sap-feeding and leaf-feeding insects and spider mites as generally reported.

Many serious pest problems are more prevalent in older trees. As trees age, their mass (respiratory demand) increases while their photosynthetic capacity (foliar surface area) changes little or decreases. Ultimately, energy demand for life-sustaining processes exceeds energy production. When this occurs, energy for defense is largely diverted to meet metabolic demand and maintain growth. Thus, tree health and resistance to pests decrease with age. Management practices must reflect these changes.

Factors increasing susceptibility to pests

The most common environmental factors predisposing trees to pest attack include: drought, poor soil aeration, shade, temperature extremes, competition, root loss, and defoliation. Water availability–too much or too little, is perhaps the single most important stress-causing agent in managed landscapes. Drought reduces photosynthesis, growth, and water-content of tissue, while improving host nutritional quality. It favors the development of secondary pests such as bark beetles, borers, canker diseases, root-diseases, spider mites, etc. Drought in conifers reduces resin flow – the first line of defense against bark beetles and borers. Trees become susceptible to attack when they are unable to continue producing resin. Severely stressed trees are targeted and successfully colonized. Bark beetles, which attack en masse, are able to overwhelm drought-weakened defenses. Less stressed neighboring trees may also be attacked and killed when beetle populations are high and attacks persist. In eucalyptus, a well-hydrated phloem is critical to resistance to the eucalyptus longhorned borer. Adequate moisture levels ensure an abundant flow of kino, a gummy, resinous-like material. Judicious irrigation is an effective means to prevent and mitigate many secondary pest problems. Overcrowding and the ensuing competition for limited water, minerals and sunlight are associated with forest pest outbreaks, and is a common problem in managed landscapes. Grasses, brush, and turf are strong competitors, which can restrict tree growth and affect health.

Most tree roots cannot function in soils where gaseous diffusion is restricted. Oxygen normally diffuses from the atmosphere into the soil through the pore spaces between the larger soil particles and soil aggregates within the upper meter or so of the soil, while carbon dioxide produced by the roots and soil organisms during respiration, diffuses upward into the atmosphere. Oxygen deficits can result and harmful concentrations of carbon dioxide can accumulate when gaseous diffusion is restricted.

Oxygen is essential for root respiration–the release of energy from sugars manufactured by the leaves during photosynthesis. Water and minerals dissolved in it are absorbed by the roots and/or mycorrhizae and transported into the vascular system. Energy for normal root growth and function is only available if soil oxygen levels are adequate. All living cells require oxygen for respiration, but it is more critical for roots since oxygen in the soil is often limited. Soil compaction, flooding, excess irrigation, poor drainage, etc., restrict gaseous diffusion, leading to reduced soil aeration.

Soil aeration is determined by both soil texture and structure. In general, compacted and finer soils, due to a higher proportion of small pore spaces, tend to drain poorly and hold less oxygen than coarser, sandy soils or well-structured soils. Water retained in the small pores displaces oxygen and inhibits gaseous diffusion. Soil structure, however, can greatly increase the proportion of large pore spaces.

Too much water due to excessive irrigation and/or impeded drainage is a major problem contributing to poor growth and pest problems in landscape plants. Oxygen contained within the soil's pore space is displaced by excess soil water. Aeration deficits inhibit root respiration, restricting water and mineral uptake and ultimately photosynthesis. Symptoms include defoliation, chlorosis, small leaves, sparse foliage, reduced shoot growth, dieback, and decline.

Soil compaction destroys the soil's natural porosity by eliminating much of the soil's larger air space. Compacted soil contains little oxygen, holds little available water, and is more resistant to water and root penetration. Consequently, root growth and tree health suffer. Soil compaction is best managed by preventing it. The soil's natural porosity, which allows for water movement gaseous exchange and root penetration, is greatly reduced. Furthermore, inadequate soil oxygen due to soil compaction, excess irrigation or poor drainage favors the development of root pathogens, e.g., crown rot. It also inhibits mycorrhizal fungi (beneficial fungi) that enhance water and nutrient uptake and resist root pathogens.

Assessing Tree Health

Tree health can usually be assessed by overall appearance, e.g., color, density, and retention of the foliage, shoot length, annual increment, live-crown ratio, rate of wound closure, and relative freedom from serious pests. Rate of growth, however, is not always a reliable predictor of pest resistance. Low to moderate stress, which slows growth without significantly impacting photosynthesis, may result in increased carbohydrate storage and improved pest resistance. Symptoms of severe stress, though, include chronic pests, secondary, thinning crowns, off-color foliage, distress crops, epicormic sprouts, dieback, and decline.

Developing a PHC Management Plan

The goal of PHC is to develop a long-term management strategy to improve and maintain plant health and pest resistance by providing a favorable and stable growing environment. Watering according to plant's needs, fertilizing where appropriate, pruning for stability, avoiding site disturbances, and minimizing injury are critical elements of a management plan.

The goal is to create or restore and maintain stable growing conditions throughout the plant's life. Identify stress-causing factors and mitigate. Monitor for signs and symptoms pests or poor performance. To create more favorable growing conditions reduce competition and water according to species need. Irrigate deeply and infrequently. Alter or adjust existing irrigation systems to increase or decrease irrigation, or improve drainage as needed. Keep water from wetting the trunk and root-flare. Irrigate to reduce stress from drought or root loss.

To develop favorable soil-conditions minimize or mitigate soil compaction and maintain acceptable soil-nutrient levels. Use a soil analysis to determine the need for fertilization. Mulching the root zone with a 2- to 4-inch layer of wood-chips will help to conserve soil moisture, reduce soil surface temperatures, supplement nutrient levels, discourage weed growth and ultimately reduce soil compaction. This encourages mycorrhizal fungi, which improve water and nutrient uptake.

At least in California, serious soil nutrient deficiencies are fairly rare. Poor plant growth, often mistaken for nutrient deficiencies, is usually the result of poor soil aeration, drought, or excess irrigation. If a tree has a normal appearance and is growing reasonably well, it doesn't need to be fertilized. When plants lack a normal or desired appearance, the cause is seldom attributable to insufficient soil nutrients, even if the symptoms indicate nutrient deficiency. We can't expect fertilization to solve problems associated with improper planting and irrigation practices, restricted drainage, poor aeration, etc.

Although nutrient deficiencies can slow growth, photosynthesis remains largely unaffected until nutrient deficiencies become severe. Trees are adapted to relatively low levels of nitrogen. They're able to adjust to moderate nutrient deficiencies by shifting resources from foliar (shoot) growth to root growth. By slowing foliar growth, the root system is able to expand to exploit a larger volume of soil. This serves to balance nutrient supply and demand. Trees growing in nutrient-poor sites typically have small crowns and expansive root systems. Under nutrient limitations and moderate drought stress, plant growth declines while carbohydrate storage and defense increase, usually making plants less susceptible to many pests

With the exception of fruit and nut trees, young trees where faster growth is desirable, and plants growing in very sandy soils, there is no evidence that routine fertilization benefits most established plants. There is however, good reason to believe that that routine fertilization is generally undesirable once plants are established. Fertilization has long been promoted as a mean to enhance insect or disease resistance in landscape trees, but there is little evidence to support this claim. Most studies show that increased nitrogen availability in plant tissue in response to fertilization increases susceptibility to sap-feeding insects (aphids, adelgids, scale, psyllids, lace bugs, plant bugs, spider mites, etc.). Fertilization has also been shown to increase susceptibility to leaf-feeding insects, root and canker diseases, certain leaf diseases, and browsing mammals. By improving nutritional quality of the plant, and by suppressing concentrations of defensive compounds, fertilization increases susceptibility to many pests. In favorable environments where water and minerals are not limiting, growth generally takes priority while carbohydrate storage and defense typically decline. Therefore, rapidly growing plants may actually be more susceptible to many pests.

Except during active growth, developing shoots and leaves normally contain low levels of available nitrogen and high levels of defensive compounds (allelochemicals), so they are relatively pest resistant. Fertilization increases the availability of nitrogen in plants, favoring pest development. Furthermore, moderate to high levels of nitrogen fertilizer stimulates growth, reducing the levels of allelochemicals. When conditions are favorable, priority is shifted from carbohydrate storage and defense to growth. Thus, less carbohydrate is allocated for defense.

Nitrogen fertilization can indeed increase growth and improve appearance, but unless there is a soil nutrient deficiency it does little to improve tree health. The effect that added nitrogen will have on plant health, rate of growth, and susceptibility to pests depends on a number of factors such as species, age, timing, rate of application, type of material used – solubility and rate of release, soil fertility, rainfall or irrigation, etc.

The root to shoot ratio is an important consideration in managing plants because it can affects drought tolerance. It generally decreases with improved growing conditions. Regular, frequent, and ample watering and regular fertilization can result in a tree with a large top and comparatively small root system. Such trees are particularly sensitive to changes in soil moisture resulting from drought or reduced irrigation. Trees on moderately dry and/or infertile sites usually have a well-developed root system and a comparatively small crown. Such trees are typically more drought-tolerant, but may be less desirable to many homeowners. People generally prefer large, trees with dense foliage and desire fast growth when trees are small, but this can result in increased pest problems and maintenance costs.

A PHC manage plan must also address maintaining structural stability. This begins by planting trees appropriate to site conditions. In young trees it is important to develop strong structure, e.g., maintaining a central leader for as long as practical, maintaining lateral branches to less than 1/2 the diameter of the trunk or parent branch, and eliminating crowded, weakly attached branches. In young trees, it is critical to develop strong, safe structure. In mature trees it is critical to mitigate defective structure, maintain optimal foliage distribution (1/2 of the foliage in the lower 2/3's of the tree and remove no more than 25 percent foliage. All pruning contracts should specify adherence to the ANSI A-300 pruning standards.

Management objectives should change with age. When planting a new tree, the goals should be to establish the tree quickly, provide a favorable growing environment, minimize stress and promote moderate growth. Following establishment, management objectives should emphasize managing for structural stability, providing favorable, stable growing conditions and maintaining health rather than promoting growth.

The previous discussion is based on the work, research and publications of a number of individuals. Many of the more important points regarding fertilization and pest resistance can be attributable to Daniel Herms, Assistant Professor of Entomology, Ohio Agricultural Research and Development center, Ohio State University. William Mattson (USDA Forest Service, North central Experiment Station, East Lansing, Michigan), and Steven Dreistadt (University of California, Statewide Integrated Pest Management project, UC Davis, CA).

BioRational Insecticides

Bruce W. Hagen

Biorational pesticides have a different mode of action than conventional pesticides, they are relatively non-toxic to humans, animals and wildlife, more selective, and have shorter residuals. Some are inorganic minerals, e.g., sulfur, clay, etc. some are derived from biological sources, e.g., botanicals, citrus oil, B.t, nematodes, etc. and some are chemical analogues (synthesized) to naturally occurring biochemicals, e.g., insect growth regulators/chitin inhibitors, e.g., Neem oil derivatives, pheromones,etc.

Bacillus thuringiensis (Bt)	microbial	larvae of moths, beetle, mosquitoes
Bacillus popillae	microbial	larvae of white grub
Spinodad	Microbial	sucking insects many pests
Streptomyces fungi	microbial	root pathogens
Trichoderma	microbial	fungicidal
Parasitic nematodes	biological	many pests
Borates	inorganic	ants/termites, woodborers, wood preservative,
boric acid	inorganic	**dessicant -** roaches, ants, used in baits
citrus oils	organic	soft bodied insects, repellant, fungicidal
cinnamite	organic	aphids, mites
cryolite	inorganic	mites, beetle, caterpillars, thrips, moth larvae
diatomaceous earth	inorganic	**dessicant/abrasive -** ants, roaches, thrips, aphids, leafhoppers
clay (Kaolin) 'Surround'	inorganic	insects and foliar diseases
garlic	organic	repellant
horticultural oils	petroleum based	mites, sucking insects, eggs, some larvae
lime	inorganic	mites, sucking insects
lime sulphur	inorganic	mites, psyllids, scale
Merit	systemic	sucking insects, borers
neem oil, Azitin, Bioneem	plant derivitive	wide variety - feeding deterrent,
nicotine sulfate	plant derivitive	sucking insects
pyrethrin	plant derivitive	many insect pests
rotenone	plant derivitive	beetles, weevils, moth larvae, mites, safe for bees.
ryania	plant derivitive	thrips, moth larvae, others
sulfur	inorganic	mites
sabadilla	plant derivitive	thrips, true bugs,
silica aerogel	mineral	**dessicant -** ants, caterpillars, mites
soap, Insecticidal	soap	sucking pests, thrips, eggs, mites
Hexagon	very selective	spider mites, nor predatory mites
Scythe	soap	weeds, grass
sulfur	inorganic	mites, fungicidal

Inorganic compounds: fungicidal

Basic cupper sulfate, Bordeaux mix, copper hydroxide, copper oxychloride, sulfate, cupper sulfate, lime sulfur oil and lime sulfur