Lesson Summary

Students are introduced to a basic insect-plant relationship—herbivory. They learn about three different sources of food that a tree might provide (leaves, sap, and wood); six different insects’ specific approaches to eating those three parts of trees; and the defensive strategies employed by trees to prevent being eaten. The activity allows you to introduce the concept of specificity in an insect-plant relationship—a tree host may only be susceptible to damage by a particular insect predator in a particular region under the right environmental conditions. This is illustrated visually by an impact triangle, an important forest health concept.

For this activity students work in groups to read about insect interactions on one of three tree food sources and then create personal advertisements to help match trees to insects that can feed on them. The ads highlight the needs of insects and trees without identifying them by name. The entire class attempts to pair anonymous insects with trees based on the requirements specified by each organism in its ad. In the discussion that follows, you may contextualize the organism match-ups in terms of the impact triangle—unmatched trees have evolved defenses to discourage herbivory, and unmatched insects have specialized feeding requirements that preclude eating some kinds of trees. Finally, students demonstrate understanding by individually completing an impact triangle describing an insect-tree relationship not covered by their group.

Background

The Shared History of Plants and Insects

Plants coevolved with insects over millions of years. As a result, there are some very close symbiotic interactions between them. Pollination is one of the most recognizable associations, one that benefits plants (insects fertilize flowers) and insects (plants provide nutrients and food). There are other types of interactions—mutualistic, commensal, and parasitic. These relationships have developed through a history of amazing evolutionary adaptations (see Resources and References for some examples of symbiosis in forests).
Any aspect of a plant or insect’s life cycle has unique properties, creating multiple niches for associations to occur. Feeding adaptations are one example of these specialized relationships. Since leaves are different in structure and function from roots, a ground-dwelling insect would not have the means to eat foliage. Similarly, a tiger swallowtail butterfly’s coiled sipping mouthpart, adapted to sucking nectar from flower bases, would be ineffective for munching tree leaves. However, the butterflies’ offspring, caterpillars, have chewing mouth parts and are efficient defoliators (see Resources and References for more on swallowtail feeding adaptations).

Trees have adapted to insect feeding pressures as well. For example, oak trees sequester tannins that make their leaves toxic and inedible to many insects. However, some insects are able to process these tannins, having adapted in turn to the selective pressures imposed upon them by trees. Interestingly, the ability to process plant toxins is to the insects’ advantage because it also makes them less palatable to birds. In this way, coevolution results in diverse and unique solutions to problems imposed by species upon each other.

Making a Case for an Organism

Traditionally, forest health focuses on insect pests and pathogens such as bacteria and fungi. These organisms are detrimental to trees because they directly influence the quality of trees that people value for beauty, food and fiber, or for the role they play in maintaining a diverse and robust ecosystem. However, while pests and pathogens may be problematic to humans, most perform essential roles in the forest as decomposers and components of the food web and by imposing adaptive pressures on their plant hosts.

In order to understand plant-insect relationships as more than just positive or negative associations, it helps to focus on the organism’s specific needs. One way to visualize the needs of an organism is to characterize it—give it a voice and advertise its preferences. This activity presents the life cycles of six different types of insects that are specific feeders on different types and parts of trees. To learn about their needs, students are asked to create advertisements for insects that are looking for homes or food, and advertisements for trees that are looking for protection against unwanted tenants. Figure 14 shows some examples of ads.

These advertisements are useful to specific organisms. The Student Page section contains details of these organisms—the first is written for the beech scale insect, a parthenogenetic species that feeds on sap from beech trees. The second is a general advertisement for trees, focusing on the fortifications that wood provides against insect damage.

Figure 14. Satisfaction guaranteed: These advertisements show some of the needs of a beech scale insect (top), and a hardwood tree (bottom).

The Impact Triangle through a Microscope

In forest health, the impact triangle is a useful concept used to understand the damages and diseases sustained by trees. Traditionally, this concept is referred to as “the disease triangle” and applies specifically to tree diseases, but the concept may be modified to understand other biotic impacts upon trees as well (see Resources and References for more on the disease triangle). In the case of insect herbivory upon trees, direct disease is not the result; however, insects do damage trees as they feed. The impact triangle helps delineate what conditions are necessary for significant damage to occur on trees, which initially is seen through the “microscopic” lens of one insect on one location on the tree. In later activities the impact triangle is revisited on a macroscopic scale.
Three factors are necessary precursors to biotic damage on a tree. First, the host, the tree itself, is typically vulnerable, stressed, or weakened so that it becomes susceptible to damage-causing agents. Second, damage-causing agents must be present and able to break through the tree’s defensive networks. Trees and insects are coevolved and share specific relationships; the right kind of host is only susceptible to the right kind of insect, otherwise there is typically no impact on the tree. Third, the environment in which host and causal agent exist is conducive to both to the spread of the agent and the susceptibility of its host.

This idea is diagrammatically represented by the following impact triangle (Figure 15), which includes these three components represented by the three sides of the triangle: a host tree, a damage-causing agent, and local conditions in the environment that allow the host-agent interaction to occur.

The text in italics, conditions that protect the host tree from attack and conditions that hinder the agent’s ability to attack, result in “no impact” upon the tree. The text in bold, inside the impact triangle, represents conditions that make the host susceptible to attack and conditions favoring the agent’s ability to attack. If the right host tree and the right insect are found in an environment that is amenable to the host being attacked and overwhelmed by the insect—then tree damage (impact) occurs.

The importance of the impact triangle is that it describes the unique set of factors necessary to cause a tree to weaken or die. However, on a microscopic level the impact triangle concept may also be applied to a part of a tree, which is a specific feeding ground, rather than the whole tree or the whole tree stand. For example, consider the impact triangle in a scenario involving eastern tent caterpillars on a cherry tree (Figure 16).

![Figure 15. A basic impact triangle: This diagram is similar in some ways to a Venn diagram—conditions that are jointly met by different elements result in specific consequences for a tree.](image)

![Figure 16. An impact triangle for eastern tent caterpillars on a cherry tree.](image)

To read this diagram, imagine the rectangular box represents all potential environmental conditions that the tree may be subjected to, or in the case of this particular activity, all specific environmental conditions that may be experienced at a specific tree location. On the left are conditions that affect the host tree. On the right are conditions that affect the causal agent (the insect pest). The dashed line in between shows that while there are specific conditions that may favor either host or agent, sometimes the same condition might affect both equally.

The impact, defoliation, occurs only on the leaves and only if environmental conditions on the host side and the agent side apply. For example, an absence of bird or wasp predators would be a disadvantage for the cherry tree if there were many caterpillars present; however, if there were few caterpillars present, then defoliation would not occur, regardless of the fact that the lack of predators would make it a safe environment for the caterpillars to feed and grow.
Thinking in systems: Transporting the triangle

This activity introduces the impact triangle, an important concept that is also part of activities 4 and 5. The impact triangle is a powerful model that can be applied in multiple contexts. Here, we look at a simple, three part system through a very tiny lens—one tree species, one insect, and one part of the tree where conditions must be ripe for an observable impact to occur.

However, the real power in using the impact triangle is the ability to scale it upward. The impact triangle, more traditionally known as the disease triangle, may be applied to fungi, bacteria, and other tree pathogens (Activity 4). It may also be applied to large-scale populations of trees and insects—the impact of an epidemic number of insect agents causes damage on the scale of a forest (Activity 5) rather than just the tips of the leaves of a single tree. In teaching this concept, keep in mind that the analogy may be transported to other scenarios as well. For instance, the impact triangle may also be used to describe the specific epidemiology of diseases in human populations.

For forest health management, as for human health management, understanding the mechanisms of disease perpetuation in populations is the first step to combating and controlling their spread. The impact triangle is one tool that facilitates comprehension.

Getting Ready

- Read the Background, Doing the Activity, and Student Page sections to familiarize yourself with the material.
- Prepare the supplies outlined in the Materials section.
  - For every five students to share:
    - 1 copy of Student Page A, B, or C (2 pages).
    - 2 sheets of 3 by 4 foot newsprint or poster paper.
    - 2 or 3 markers.
  - Plan to divide your class into at least three groups, so you can distribute at least one copy Student Page A, B, and C to each group.
  - For each student:
    - 1 copy of Student Page D.
  - For the teacher:
    - 1 roll of tape.

Doing the Activity

Part A: Introduction to insect-tree feeding relationships
10 minutes

1. Introduce students to an impact triangle using Figure 15 as a visual guide (see Resources and References for more visuals). Explain that insects have specific food preferences for different trees and even different parts of a tree. Trees in turn have various defensive mechanisms that work against different insects and at different locations. The impact triangle helps contextualize insect adaptations against those of trees.

2. Inform students that they will be exploring different feeding grounds for insects. Split the class into at least three groups. Hand out one copy of Student Page A, B, or C to each group. Tell students that each group will work in secret, and they cannot share handouts with other groups.

3. Ask each group to read the handout, using a note-taker to underline or circle the following:
   - What are the trees’ defensive strategies?
   - What are the insects’ offensive strategies?
   - What environmental conditions might favor the insects but not the trees?
   - What environmental conditions might favor the trees but not the insects?

Part B: Advertising premium locations
25 minutes

4. Instruct groups to work on creating advertisements for trees and insects. The goal is to attract the right insects to host trees that will support them, or the right strategies to defend trees against an insect invasion. Read the two ads from Figure 14 out loud and explain that they are examples of ads for specific organisms.

Each group should do the following:
   - Pick an insect from the Student Page and create an ad promoting housing, food, or roommates that would be attractive to that insect.
   - Pick a tree from the Student Page and create an ad selling defenses against unwanted tenants that the tree would find interesting.
   - Make sure not to give away the insect or tree’s name on the ads.
   - Write in pencil on the backs of each ad the names of the tree and insect for which it was written.
5. Distribute two sheets of newsprint and some markers to each group. Remind students again that they are working in secret, and encourage them to be creative (Figure 17).

Figure 17. Poster play: When conducting this activity, youth have shown appreciation and eagerness for having a chance to get creative while learning new things.

Photos: Amanda Burnett

Part C: Discussion and reflection
45 minutes

6. Collect all groups’ ads and reorder them so matched trees and insects (those made by the same group) are not near each other. Use the roll of tape to post the ads on the walls of the classroom. Allow students to walk around and read the ads.

7. Ask students to see if any of the advertisements by insects might be matched with a suitable tree. Have them focus on matching pairs from other ads than those made by their own group. Collect pairs of matched ads and re-position them. You can leave unmatched pairs hanging as well. Anticipate a portion of unmatched ads, since some insects are species-specific herbivores (they feed only on beech trees, for example), while others are generalists (they feed on many hardwood species, for example).

8. Lead students in a discussion of why they picked the pairs that they did and why they left some advertisements alone. Then ask groups to reveal the identities and some details of the organisms. For example: If an ad for an Ips engraver beetle was correctly matched with an ad for a pine tree, ask those who made the ads to describe to the other groups what conditions the Ips engraver beetle would be happy with, and what conditions would keep the pine tree healthy.

Keep in mind that some advertisements may seem to be more generic than they actually are, depending on how much detail students provide. This is especially so in the case of trees—while most insects in the Student Pages have been identified to genus or species level, some of the trees may be broadly referred to as “conifers” or “hardwoods” even though there are many species within these groups. As a result, you may find some unintentional match-ups in the ads. Use these opportunities to discuss species-specific interactions, or to have students provide more details about their organisms.

Some matches may have been made between insects and trees covered by different Student Pages. For instance, the examples used in Figure 14 take an insect from Student Page B and a tree defense from Student Page C. There are specific conditions under which this match would work. Only beech trees are susceptible to the beach scale insect, a fact that is not provided in Figure 14. The ad for tree bark reinforcements likewise does not specify which species it applies to. Clarify these ambiguities with students when they offer more details about their ads.

For ads which remain unmatched, ask students what made that tree so impenetrable, and what made the insect unable to find its preferred food.

9. Next give students copies of Student Page D. Remind them about the impact triangle discussed in the beginning of class. Ask them to focus on a particular location or environment on a particular tree of their choice, and find an insect that specializes in eating that part of that tree. Ask them to pick a host tree, insect agent, and environment (or tree location) from the information on the handout or from what they learned in class, and to fill in Student Page D accordingly. Have them specify on the triangles what the impact would be for the tree if all three components of the triangle were satisfied. The page can be completed in class or turned in as homework.

Assessment

The following are group assessments. Using the students’ advertisements, check that they can do the following:

• Identify relevant information about defensive and offensive strategies employed by insects and trees from a text. Seen in ads made during Part B of the Doing the Activity section.

• Present relevant information about insect and tree needs for survival. Seen in ads made during Part B.

• Apply the impact triangle concept by connecting specific insects with the correct host trees. Seen in students’ match-ups during in Part C.

For individual assessment, use the answers to Student Page D to check that students can do the following:

• Complete an impact triangle for a particular insect-tree interaction. Seen in students’ answers to Student Page D.
Extension Ideas

• Some of the insects introduced in the activity are social, while others feed alone. Sometimes, the effect of the insects’ herbivory is devastating to the plant, while other times, it may have little effect on its overall health. For each pair of insects introduced—leaf eating, sap sucking, or stem boring, ask students to define what type of relationship exists between: a) individual insects (such as between one eastern tent caterpillar and another), b) individual insects and the tree, c) a group of insects and a tree, and d) a group of insects and the forest. What is the level of impact upon the individual tree if just one insect were feeding on it versus a group of insects? What is the level of impact upon the forest if just one tree were being fed upon, versus all the trees of that species? Ask students to turn in a report with their conclusions.

Resources and References

• The University of Florida’s SFRC Extension website for educators includes several related resources.
  ▪ Images and figures used in this activity, including those of the impact triangle, are found in a visual presentation online.
  ▪ Flash cards from the Pocket ID Guide provide more information about insect pests. You may use the flash cards to assess students’ understanding of the impact triangle. The flash cards mentioned below correspond either to the species on the Student Pages or to related species with similar life cycles and behaviors.
    o Student Page A: Eastern Tent Caterpillar, Pine Sawflies.
    o Student Page B: Scale Insects, Sycamore Lace Bugs.
    o Student Page C: Twig Girdler, Ips Engraver Beetles.

• The impact triangle for pathogens such as fungi is known as the disease triangle. This concept is taught by means of a game in New Activity 3: The Disease Triangle, in What Is a Healthy Forest?

• There are many symbiotic relationships that contribute to the health, good or bad, of a forest. Some of these relationships are covered in Extension to PLT Activity 26: Dynamic Duos, in What Is a Healthy Forest?

• Feeding relationships can determine survival and extinction in a forest. Two species of swallowtail butterflies are used to teach about generalist and specialist diets and their affects on populations in Extension to PLT Activity 45: Web of Life.

Visit http://sfrc.ufl.edu/extension/ee/foresthealth.html

• More information about pine sawflies, leafhoppers, and Ips engraver beetles may be found at the University of Florida’s Department of Entomology and Nematology Extension website, Featured Creatures.

Visit http://entnemdept.ifas.ufl.edu/creatures/

• More information about the beech scale insect may be found in the USDA Forest Service Forest Insect and Disease Leaflet 75, “Beech Bark Disease,” Houston, D. R. and J. T. O’Brien, 1983.


• More information about eastern tent caterpillars and twig girdlers may be found at Auburn University’s Department of Entomology and Nematology’s Web Publications.

Visit http://www.ag.auburn.edu/enpl/webpub.htm

• Extensive picture resources may be found at the University of Georgia’s Center for Invasive Species and Ecosystem Health’s website, Insect Images.

Visit http://www.insectimages.org/
How to Eat a Tree – An Insect’s Guide to Finding Food in the Forest

Instructions

Shhh! Your group is working in secret. Read the following text and work as a team to identify the answers to the following questions. Circle or underline the answers in the text.

• What are the trees’ defensive strategies?
• What are the insects’ offensive strategies?
• What conditions might favor the insects but not the trees?
• What conditions might favor the trees but not the insects?

When you are finished, wait for your teacher to provide you with materials and instructions to complete the second part of this activity.

Leaf-Eating Insects

The most visible and easily accessible part of a tree is the leaf. Many animals focus on leaf feeding, either stripping down the soft tissues in between veins, or chewing the whole leaf down to the base of the stem. Since leaves are a tree’s primary food production organs, defoliation, depending on the age and health of a tree, can cause weakening, slower growth, and even death. Leaves may be protected from herbivores by bristles, spines, tough coats of wax, or toxins in the leaf cells, but even so, some insects have evolved strategies around these defenses.

Eastern tent caterpillars

Eastern tent caterpillars are the larval form of a moth, *Malacosoma americanum*. As caterpillars they are known for being highly social tent builders. They hatch in the hundreds in early spring and build their tents in the crooks of tree branches. These tents are used for shelter from predators and for temperature regulation, since they cannot feed unless they are warm. As the caterpillars grow and molt, they expand the size of their tent, layer by layer, and search farther along the branches for leaves to eat. When a caterpillar locates fresh foliage, it marks its trail back to the tent for its tent-mates to follow. This makes the tent caterpillars a very efficient defoliating colony, and large groups of them can strip an entire tree of its leaves.

Eastern tent caterpillars are eaten by numerous predators and parasites, including wasps and birds, and their populations are usually kept in check by these animals. However, if predator populations are low, the eastern tent caterpillars can attack trees unhindered. Caterpillars feed on numerous broadleaf species, but prefer species from the Rosaceae family, such as cherry, apple, and hawthorn trees.
Pine sawflies

Pine sawflies, *Neodiprion* species, are not “true flies” despite their name. They are related to wasps, bees, and ants. There are several species of sawflies whose larvae feed on conifers, particularly pines (*Pinus* species). The adult females use their saw-shaped ovipositors to cut slits into pine needles and lay their eggs. The newly hatched larvae feed only on the outer needle tissues, but older larvae chew up entire needles, leaving only little stubs behind.

Pine sawflies can attack pine trees of all ages and may move from one tree to the next as they defoliate them. When outbreaks occur, this can severely affect the growth of pines. Some species, such as the redheaded pine sawfly, *Neodiprion lecontei*, have multiple generations of young per year, and feed on both old needles and new growth. Others, such as the European pine sawfly (*Neodiprion sertifer*), have only one generation of larvae that feed only on needles from the previous year. All southern pine species are hosts for pine sawflies. Natural sawfly predators include several species of birds and insects, such as ground beetles and parasitic wasps, which feed on sawfly larvae and pupae.
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Sap-Sucking Insects

The internal transportation structures of trees are xylem and phloem tubes, which run like veins from roots to leaves, carrying water, minerals, nutrients, sugars, and starches. Sap contains nutrients that nourish the cells of the tree, and insects that feed on sap extract the same minerals and nutrients for their own growth and development. Sap-sucking insects may be found in the root system of trees, as well as the stems, branches, and tree trunk, but they can be stopped by thick bark. Once a sap sucker has gained entry to the xylem or phloem, it must also have the ability to process toxins produced by the tree for protection.

Beech scale

Beech scale (Cryptococcus fagisuga) is a tiny scale insect, related to aphids, leaf hoppers, cicadas, and other “true bugs.” It is an entirely female species, producing young by parthenogenesis. In the early summer, adults lay a few eggs and die. Their young nymphs have feelers and legs, and are able to crawl in search of beech trees (Fagus grandifolia), their preferred food source. Since they are so small, they may also be transported by wind, water, or other animals.

The scale insect, like all sap-sucking true bugs, has a specialized needle-like mouthpart which it injects into the tree. Once attached, it sucks on tree sap while morphing into a legless, immobile adult, producing a waxy scale covering for protection in the process. In large numbers, the insects can deplete beech trees of much needed water and nutrients, but the more serious consequence of their work is the number of wounds they leave behind as they feed. These wounds become entry points for woody tissue-digesting fungi, the most famous being the Nectria species, which can kill beech trees.
Leafhoppers

Leafhoppers (Cicadellidae) are tiny, winged “true bugs,” related to scale insects and cicadas. Like scale insects, leafhoppers also have a needle-like feeding apparatus that they use to suck out sap from xylem tubes. One of the most diverse of all insect families, leafhopper bugs have specialized associations with many plants and trees. The young nymphs are expert jumpers and the adults can fly, allowing them to move great distances in search of food.

Many species of leafhoppers are considered pests of some commercially important crops, such as grape, peach, and plum, as well as ecologically significant trees such as palms. This is because their feeding methods create wounds on plants and trees and deplete them of resources. Most importantly, leafhoppers may also transmit viral and bacterial diseases from one tree to the next, much as mosquitoes carry malaria to people. They are preyed upon by fast-moving animals such as dragonflies and damselflies, mantids, spiders, lizards, and birds.
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When you are finished, wait for your teacher to provide you with materials and instructions to complete the second part of this activity.

Stem-Boring Insects

Woody trunks, branches, and twigs combined are the most abundant tissue structures found on a tree. That’s a lot of food! However, woody tissue is not a free meal. The xylem, which provides structural support to trees, is hard-to-digest cellulose and lignin. The inner bark, phloem, is nutritious but protected by the outer bark. Coniferous trees additionally produce resin, which they maintain under pressure inside the trunk. A successful stem borer must be able to resist being flushed out by this resin as the insect drills through the wood, as well as resist the aromatic compounds that the tree releases, which act as a further deterrent. For this reason, stem-boring insects often focus on finding dead or dying trees rather than live ones, and often partner with other organisms, such as fungi, to aid in the work of weakening the trees for their mutual benefit.

Twig girdler

In the early fall, female twig girdler beetles, Onicideres singulata, are ready to lay eggs. They do so by selecting small branches of trees and chewing a groove around the circumference. This “girdling” process kills the branch tip past the groove by cutting off nutrient flow. The female makes a notch in the branch above the girdling point to lay single eggs. Hatched larvae burrow into the twigs to feed on the dead inner bark (phloem) and wood beneath. They pupate inside the branch as well, and emerge as adults the next fall.

Girdled branches often break off due to mechanical stresses such as the wind, and this may give trees an uneven look. The twig girdlers are otherwise harmless, since the health of the whole tree is not compromised. Twig girdler beetles attack numerous broadleaf nut-bearing and fruit-bearing trees, including pecans, walnut, elm, and citrus. In orchards, twig girdler damage may reduce nut and fruit yield and cause stem deformities on the trees.
**Ips engraver beetle**

There are three species of *Ips* engraver beetles that feed on southern pines. Males seek out weakened, stressed, or dying pines (*Pinus* species) preferentially, since these trees are easier to colonize. Once a male locates a suitable host tree it tunnels in and releases pheromones to attract females and other males. A mass attack on a pine can completely overwhelm its defenses, if the pine is unable to flush out the beetles with sticky resin. Adults tunnel and feed in the inner bark (phloem) and lay their eggs. Hatched larvae make feeding tunnels through the phloem tissue and pupate.

Emerging adults can fly as far as four miles in search of new trees to colonize. Apart from the damage the beetles cause through their feeding activities, they also introduce a blue stain fungus into the trees. This fungus colonizes and blocks the xylem tissues, further weakening the pines and hastening their death. *Ips* engraver beetles in large numbers can kill healthy trees, but these outbreaks tend to be relatively small and short-lived.
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Instructions

The following diagram represents a system with three components, represented by the three sides of the triangle. The components are a host tree, an insect agent, and environmental conditions at a particular location on the tree. Under specific conditions, represented by the area inside the triangle, these components interact to cause an impact on the tree. Conditions found in the area outside the triangle will not result in any impact.

You have seen many examples of insect-tree interactions. Pick an insect-tree pair and complete the following gaps in the diagram:

- What is the host tree, insect agent, and tree location (environment)?
- What environmental conditions go inside the triangle, resulting in damage to the tree?
- What environmental conditions go outside the triangle, resulting in no effect to the tree?
- What is the impact on the tree if conditions within the grey triangle are right?

The Impact Triangle

What is the impact on the tree if conditions within the grey triangle are right?

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