FSTY 307 - Disturbance Ecology & Forest Health

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LECTURE MATERIALS

Forests - An Overview

What is a Forest?

Forests are usually described as an ecosystem dominated by trees, but is it really that simple? To understand forests from a perspective of disturbance ecology, it is important to remember the many species processes and interactions that take place in a forest ecosystem.

Consider a managed timber farm and a mostly untouched stand. A timber farm will likely have low diversity as compared to the untouched stand, but does that make it any less of a forest? The answer, obviously, is no. A major key to defining forests and their health is to first understand that forests come in all shapes and sizes. For our purposes in this course, consider a forest to be any plant community where major disturbance is relatively infrequent, allowing for long-living plants to develop.

Forest Ecology Basics

It can become a bit of a headache to think about forests from an ecological point of view. Stand composition/structure, natural abiotic/biotic factors, and human interactions combine to create a hard to predict future. Time can further complicate predictions, as disturbance events in the short term may seem random, but can display patterns over long periods of time. This long term pattern of disturbance events is referred to as its natural disturbance regime.

One of the chief concepts in forest disturbance ecology is stand diversity and how it relates to a forest's stability. Throughout this course we will learn more about how disturbance affects diversity (and vice versa) and how that in turn can make or break stand stability and therefore health.

Health & Management

There are many definitions of forest health:

EXAMPLES:

1. O'Laughlin, 1994: Forest health is a condition of forest ecosystems that sustains their complexity while providing for human needs.
2. USDA Forest Service, 1993: Forest Health is a condition where biotic and abiotic influences on the forest do not threaten resource management objectives now or in the future
3. Wilson, 1991: In the broadest sense, a healthy forest is a description of a productive, resilient, and diverse ecosystem; a forest with a future.
4. Joseph et al., 1991: A healthy forest is one that is resilient to changes and characterized by tree species and landscape diversity that provides sustained habitat for fish, wildlife and humans.

As you can see, these definitions are not all alike; the definition of forest health tends to change based on the objectives of the person defining it. True assessment of forest health involves multiples aspects such as:

- review of species composition and structure
- identification of signs and symptoms
- understanding of the ecosystem (natural disturbance regime, scale, recovery)

Introduction to Entomology

Introduction

Entomology is the scientific study of insects. The word "entomon" (Greek) and the word "insectum"(Latin) both mean "divided". The insect body is divided into recognizable parts; however, insects come ina startling diversity of forms. View thisslideshow [http://www.alexanderwild.com/] to experience a tiny portion of insect diversity.

Diversity

More than 1.7 million species of organisms have been described. About 1 million of those are insects
(Fig. 1). The largest order of insects is the beetles, with over 390,000 species known. New species of
organisms (including insects) are being found all the time, and it is likely that we have only described a
fraction of the extant diversity: estimates of the number of species on Earth range from 5 million to 30
million or more.

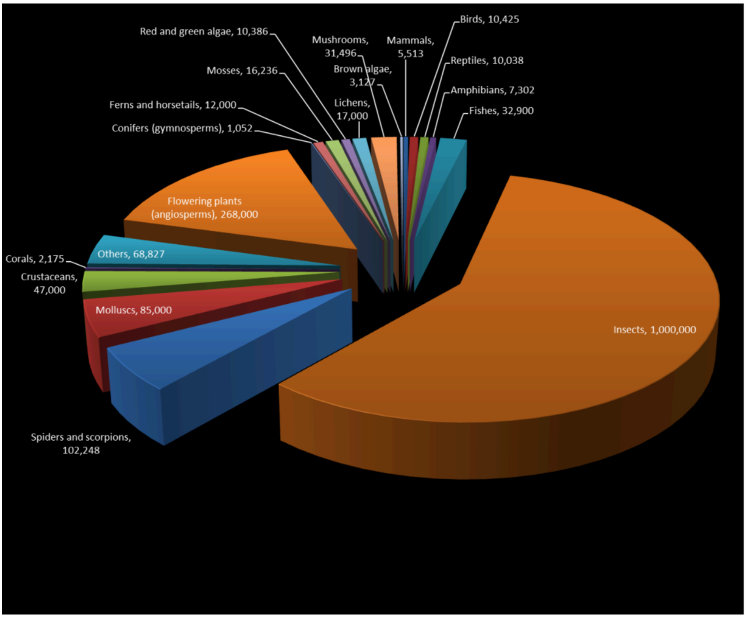


Fig. 1. Numbers of described eukaryotes. The species totals do not include bacteria or domestic animals. Based on data from https://www.currentresults.com/Environment-Facts/Plants-Animals/number-species.php

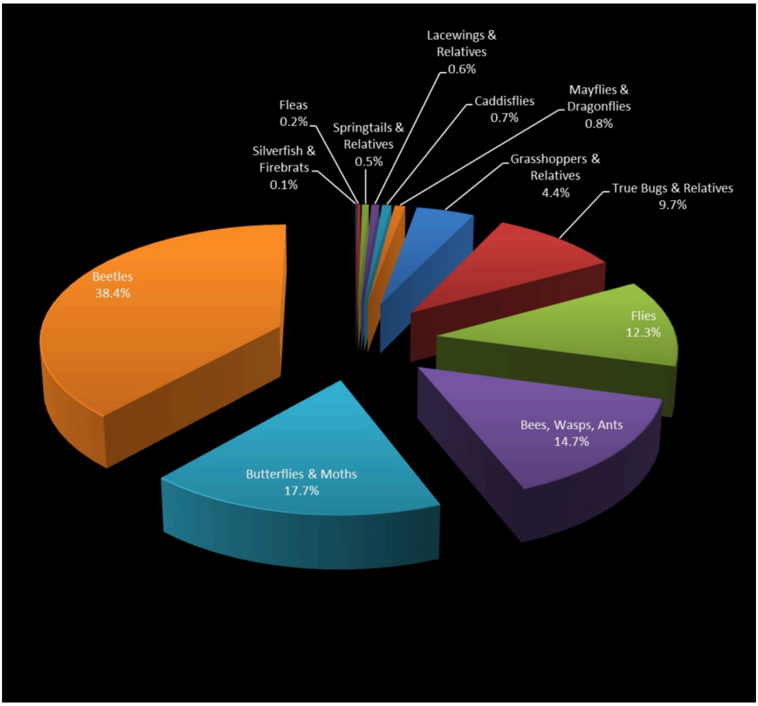


Fig. 2. Proportion of insect diversity made up by various groups.

Classification

With so many different species, we need a logical, systematic way to group similar organisms together. Better yet, we need a system that reflects evolutionary relationships, rather than simply physical similarities. The branch of biology that deals with taxonomy and nomenclature is called systematics. Taxonomy is the science of grouping organisms with a similar evolutionary history together, while nomenclature is the selection of names for those groups.

The system we use is based on a nested hierarchy devised by Carl von Linné in 1758. Smaller, more specific categories are nested within larger groupings. The highest modern level of this system is the Domain, and the most specific level is, of course, the species (Fig. 3).

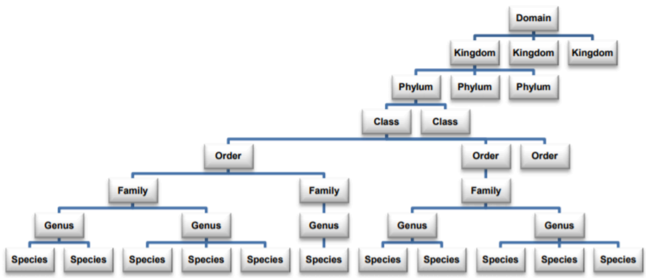


Fig. 3. Hierarchical classification system. The highest (most inclusive) level is the domain; the most specific level is the species. Note that this is a nested hierarchy: if two species are in the same genus, they must also be in the same family, the same order, and so on.

As an example, Table 1 shows the classification of one of the insects you will learn about in this course, the mountain pine beetle. Note that higher level group names, like Coleoptera, are always capitalized. A particular species is denoted by a binomial, made up of both the genus name and the species name. The genus name is always capitalized, while the species name is in lower case. Both the genus and species names are italicized, or underlined in handwriting.

Table 1. Classification of the mountain pine beetle, *Dendroctonus ponderosae*

Domain:	**Eukaryota**
Kingdom:	**Animalia**
Phylum	**Arthropoda**
Class	**Insecta (or Hexapoda)**
Order	**Coleoptera**
Family	**Curculionidae**
Genus	*Dendroctonus*
Species	*ponderosae*

Why do you have to learn the genus and species names instead of common names? For one thing, many organisms do not have common names. For another, common names can vary widely from place to place, and person to person, and they can be misleading. In a field like forest health, it is crucial to be sure you are dealing with a particular species and not a similar species (perhaps with a different host, biology, or life cycle) in order to choose the best management strategy and tactics.

Body Plan

Despite their enormous diversity, all insects share some common features. Like all arthropods, they have an **exoskeleton** and jointed legs. Insects are distinguished from other arthropods by having three distinct body regions called **tagmata**, each specialized for different functions (Fig. 4). The head is specialized for feeding, and for sensing the surrounding world. All the mouthparts are here, as well as one pair of antennae, and (often) a pair of large compound eyes. There may also be simple eyes, called ocelli, that detect light levels but are likely not image-forming. The thorax is specialized for locomotion, and bears three pairs of jointed legs and usually two pairs of wings (in adults). The abdomen is specialized for vital functions such as digestion and reproduction.

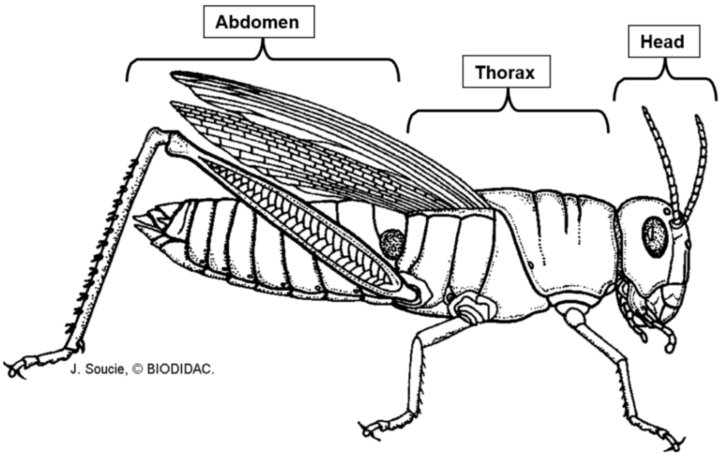


Fig. 4. The three tagmata of an insect's body.

Exoskeleton

One of the keys to insect success is their exoskeleton. The skeleton provides support, protection, and sites for muscle attachment; unlike our skeleton though, the insect skeleton is on the outside surface of the body. It can form a tremendous variety of external shapes, while leaving the internal organs virtually unchanged. This is one of the reasons behind the diversity of insects that you saw earlier.

The exoskeleton, or cuticle, sits on top of the cellular epidermis, and is secreted by the epidermal cells (Fig. 5). The inner, flexible layer of cuticle is called the endocuticle. The outer layer, which is often rigid, is called the exocuticle. On top of the exocuticle is a thin, waxy layer called the epicuticle, which helps to protect the insect from desiccation and physical damage.

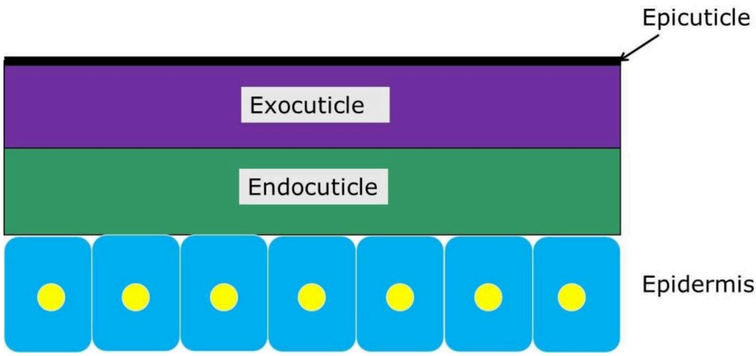


Fig. 5. The insect cuticle is located outside the epidermal cells. The inner endocuticle is flexible, while the outer exocuticle is often hardened. The waxy epicuticle helps to prevent desiccation and physical damage.

The insect exoskeleton is mostly made up of **chitin**, which is chemically similar to cellulose (Fig. 6). In areas where the exocuticle is rigid, the chitin has undergone **sclerotization**, or "tanning", a process in which the chitin chains are cross-linked with a protein called sclerotin.

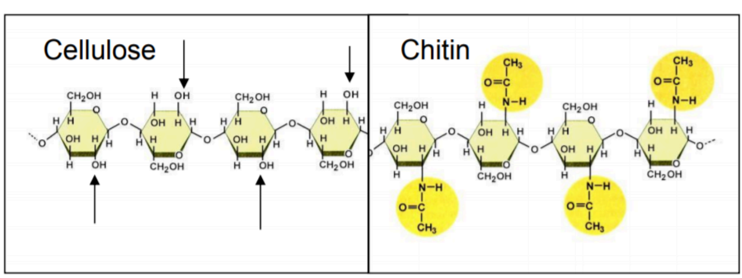


Fig. 6. The chemical structure of cellulose (left) and chitin (right).

Mouthparts

Insects rely on a tremendous variety of food sources, and utilize many feeding modes. Different insect groups have mouthparts that are adapted for different types of foods (Fig. 7). If you are in FSTY 317, you will have an opportunity to take a closer look at some of these adaptations in the lab.

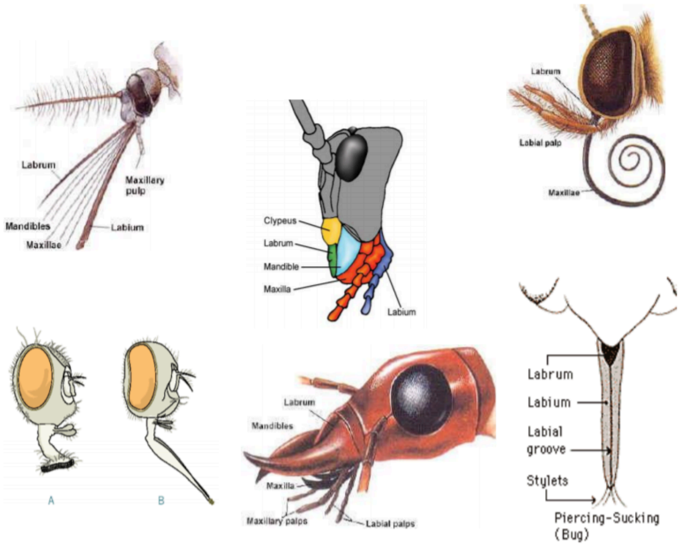


Fig. 7. A few of the mouthpart types seen in insects. While the different types are specialized for different functions, and look quite different, notice that all the same components are there (in different shapes).

Legs

Insect legs are also adapted for life in many different environments (Fig. 8). As with mouthparts, even in leg types that look very different, all of the same parts are there but in modified shapes. Once again, if you are in FSTY 317, you will have an opportunity to take a closer look at some of these adaptations in the lab.

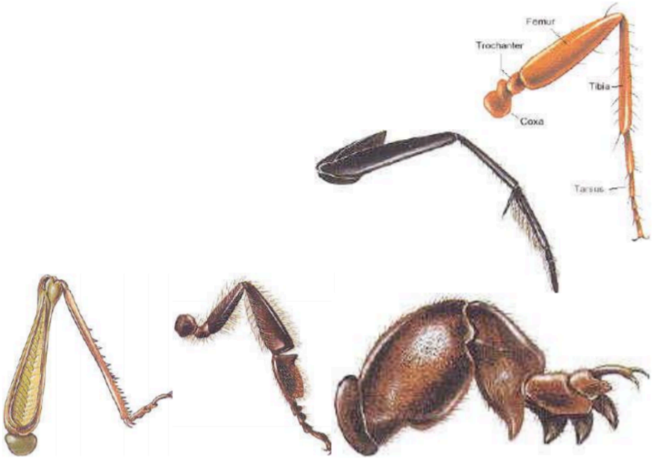


Fig. 8. Insect leg adaptations for different habitats.

Wings

Perhaps the most important factor in the success and diversity of insects is their ability to fly. In fact almost all orders of insects end in "-ptera", meaning "wing". The names in some way describe the shape or structure of the wings: for example, the name of the order Coleoptera, or beetles, means "sheath wing". Most insects, like this beetle https://upload.wikimedia.org/wikipedia/commons/7/7a/Lady_beetle_taking_flight_right_bright.jpg have two pairs of wings. Beetles have the front wings modified into hardened coverings for the membranous hind wings. These hardened front wings are called **elytra** (singular: elytron), the "sheath" referred to by the order name Coleoptera.

Some well-known insects, such as monarch butterflies and some dragonflies, are capable of undertaking long migrations. Other species can also disperse long distances when they are carried by air currents and storm systems. Such systems carried mountain pine beetles from British Columbia, across the Rocky Mountains, and into Alberta.

Reproduction

Most insects reproduce sexually, although sex determination is not always the same as in humans. In some groups, such as the Lepidoptera (butterflies and moths), females have X and Y chromosomes, while males have two X chromosomes. Honey bees and some other social insects are haplodiploid. The females are diploid, carrying two complete sets of chromosomes, but males are haploid, and carry only one set. This system leads to a very high degree of relatedness among the members of a colony, all of whom are offspring of a single mated pair.

Many insects also reproduce asexually. Some, like several species of stick insects (https://upload.wikimedia.org/wikipedia/commons/e/ea/2013-03-09_Indische_Stabschrecke_carausius_morosus_anagoria.JPG), are completely parthenogenic and may have been so for thousands or even millions of years. Others, like many aphids (Fig. 9), are parthenogenic for much of the summer, but produce males and reproduce sexually in the fall as environmental conditions start to deteriorate.

Fig. 9. Winged and wingless aphids on aspen. M. Poirier, ©2015

Development

Insects have a tough, protective exoskeleton. In order to grow, they must moult, or shed, that exoskeleton and produce a new one (https://www.youtube.com/watch?v=wpNehJ0V_aM). In almost all insects, moulting happens only in the immature stages. The period of time between moults is called an **instar**. From the time the insect hatches from the egg until its first moult, it is in its first instar. From the first moult to the second moult is the second instar, and so on. The final moult transforms the insect to the adult stage.

There are three basic types of development patterns, or metamorphosis, in insects. The most ancestral insects change little from one moult to the next, except in size. At the final moult, they become reproductively mature, but they are always wingless. This type of metamorphosis is called **ametabolous**.

Other insects change relatively gradually. With each successive moult the wings become more developed; at the final moult, the wings are fully functional and the insect is reproductively mature. This type of gradual metamorphosis is called **hemimetabolous** (in insects with aquatic immature stages and terrestrial adult stages, such as dragonflies), and **paurometabolous** in terrestrial insects.

About 80% of insects are **holometabolous**, and undergo "complete" metamorphosis. The egg hatches into a larva, which will grow through several moults. At the second to last moult, it will become a pupa. In this stage, almost all of its tissues and cells are broken down and rebuilt into the adult insect. Holometabolous insects have adults that look completely different from their larvae, and that often inhabit completely different environments. In these insects, the larvae are specialized for feeding and growth, while the adults are specialized for dispersal and reproduction.

Remember that insects are small, and mostly ectothermic. Their rate of development, as well as their mobility and metabolic efficiency, are strongly influenced by the temperature of their surroundings.

Life Cycles

Some insects have relatively straightforward life cycles, while others are very complex (Fig. 10). Managing populations of forest health agents requires you to understand the life cycle of the species you want to manage. What is its reproductive biology, how many life stages are there, when and where does each life stage occur, how does each stage make its living? The answers to questions such as these determine what management strategies and tactics are likely to be most effective.

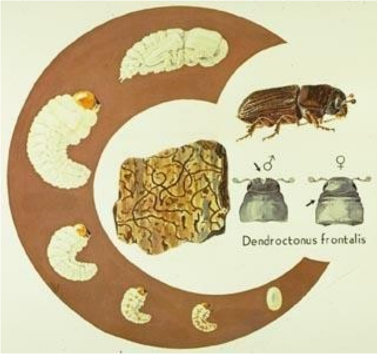
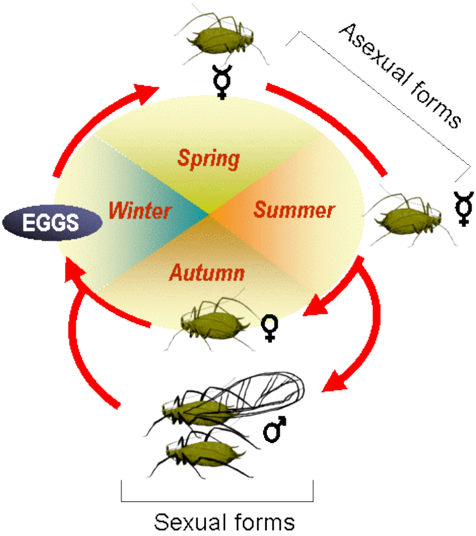


Fig. 10. Life cycles of the southern pine beetle, Dendroctonus frontalis, and an aphid.



Factors Affecting Insect Populations

Populations of some insects are strongly regulated by the availability of susceptible hosts. Many bark beetles require dead, dying or downed trees of a particular species. As the availability of such host material increases, so does the bark beetle population. For example, spruce beetle (*Dendroctonus rufipennis*, http://www.forestpests.org/vd/images/0805006-SMPT.jpg) populations tend to increase following blow-down events, which result in large amounts of downed spruce in a stand. This type of population regulation is known as **bottom-up** regulation, and is commonly seen among K-selected organisms.

Other insect populations are mostly regulated by factors other than food, such as parasites and predators. For example, Douglas-fir tussock moth (*Orgyia pseudtsugata*, https://tidcf.nrcan.gc.ca/images_web/imfc/insectes/moyen/orgia_pseudotsugata_21.jpg) larvae feed on the foliage of Douglas-fir. Food is rarely limiting, as Douglas-fir is common in the areas where this insect is found, and the trees produce copious amounts of foliage. However, as larval densities increase, so do the densities of parasites and predators that feed on the larvae, and various diseases are transmitted more easily in dense populations. Douglas-fir tussock moth populations usually decline sharply after one to three years because of the influence of parasites, predators and pathogens. This type of population regulation is known as **top-down** regulation, and is commonly seen among r-selected organisms.

Feeding Groups

Given their diversity, it shouldn't be surprising that insects can be found almost everywhere and can eat virtually anything. Many species, though, are restricted to certain types of food, certain species of food, or even certain parts of their food species. Most of the insects you will be concerned with in this course are **phytophagous**, or herbivorous, meaning that they eat plant material. Some of these are specialists on foliage (**foliophagous**), phloem (**phloeophagous**), or on wood (**xylophagous**).

Other insects feed primarily on fungi (**mycophagous**), or on dead material (**saprophagous**). Still others are **predaceous**, or predatory. Some are parasites of vertebrates or plants, keeping their hosts alive while they feed on them. Finally, there are some insects that adopt a strategy intermediate between parasitism and predation. These insects lay their eggs in or on other insects, and the larvae parasitize their hosts, keeping the host alive. At some point in development, however, the parasitic larvae switch to a predatory strategy, kill their host, and consume it.

Insect-Plant Interactions

On any plant (any tree, in this course), herbivores will be found feeding on it. Even pollinators of a flowering plant are included here, as they are feeding on nectar and pollen produced by the plant. There are also likely to be insects that are predators or parasitoids of the herbivores. A third category of insects is often referred to as "tourists". They use trees for shelter, basking, or perches, but do not derive nutrients from the trees (directly or indirectly).

All plants have a wide range of physical and chemical defenses against herbivores. Physical defenses may range from droopy leaves, to trichomes, to various thorns and spines. Chemical defenses may make the plant smell like it is not susceptible, or may even act as repellents, anti-feedants or digestion inhibitors. They may also be outright toxic to herbivorous insects.

Forests and Insects

As hosts for insects, trees are very long-lived. A tree's generation time far outlasts that of its insect herbivores. Furthermore, like other plants, trees can't run away! They are dependent on physical and chemical defenses to reduce the level of damage caused by herbivores to the point where it does not threaten their survival or reproductive ability.

Herbivores are a natural part of a tree's ecosystem. In general, trees have evolved to produce excess photosynthetic organs (leaves) to tolerate herbivore feeding, bark to prevent entry of organisms into the wood, and formidable chemical defenses throughout their systems. Some level of damage is likely to be of little or no consequence to the tree, unless it has other issues as well. For example, a tree that has been infected by a pathogen, or scarred by a fire, may be much more susceptible to bark beetles than trees that have not experienced these pre-disposing disturbances.

Ecological Effects

Within a forest, herbivorous insects play several important roles (Fig. 11). They are particularly important in nutrient cycling, breaking down plant tissues that can tie up nutrients for a long time. They may do this directly: for example, termites have symbiotic protozoans in their guts that allow them to digest the cellulose in wood: They may also release nutrients indirectly by feeding on foliage, then depositing scraps or feces on the forest floor.

As you have already seen elsewhere in the course, forest insects are important in successional processes. Even if they are acting on a small scale, the disturbances they cause lead to a mosaic of tree species and ages on the landscape.

Finally, forest insect activities help to provide food and habitat for many other organisms, including bears, woodpeckers, other insects (especially ants), and fungi. Dead trees are important components of forest systems.

Fig. 11. Wood dust under a tree indicating activity of boring insects, which help release nutrients back into the soil; red trees caused by bark beetle infestations, which alter successional processes on a landscape scale; insects affecting trees provide food and habitat for other species, such as bears and woodpeckers, as well as other insects.

Detection and Diagnosis

Forest insects are always present, in any ecosystem. Detecting their presence does NOT mean that they constitute a forest health problem. It is important that forest managers make objective responses based on sound diagnostic and ecological information. They must also always consider the management objectives and values for each particular stand. Insects, including those that feed on trees, are a natural part of the ecosystem, so you must learn to take a holistic view.

When diagnosing a potential forest insect pest problem, you will often observe **symptoms**. Theserepresent the tree's response to a herbivorous insect or other disturbance agent. Generally, you will not be able to determine the exact cause of the symptoms, although they may help you to narrow down the potential causative agents. To diagnose the problem definitively, you will need to observe **signs**, which show direct evidence of the causative agent. Often, the best signs are the agents themselves. For example, a symptom might be a dying lodgepole pine in a young plantation in central BC. That symptom suggests that the root system or the stem has been damaged in some way, but it does not tell you exactly what caused the damage. If you dig around in the area of the root collar and find masses of resin-soaked soil with white grubs inside them, you can diagnose the damage as being caused by Warren root collar weevil, *Hylobius warreni*. Notice that factors such as location and tree species can also be important in diagnosis.

Hazard and Risk

When deciding whether or not to take action to manage a forest health agent, the two concepts of hazard and risk are important to consider. Unfortunately, the two terms are easy to confuse, and are frequently used interchangeably by many people.

The stand **hazard** generally refers to the susceptibility of a stand to damage. In other words, if a particular insect was to start causing damage in that stand, how bad would the damage be? Factors such as the location of the stand, the species mix, the age profile, and overall tree health can be important in determining stand hazard. Many of the major forest insect pests in BC have well-developed hazard rating systems that allow inputs of various data, and produce a hazard index for a given pest in a particular stand.

The stand **risk** generally refers to how likely an outbreak is to occur in that particular stand, often based on its proximity to the nearest large population of the pest of interest. Analyses of both hazard and risk are necessary to determine what management strategies and tactics might be most useful, or even whether management is indicated at all. Both hazard and risk, as I've described them, are often rolled into a single risk-rating system.

Hazard and risk are most useful as tools to evaluate future damage to a stand. In order to apply them successfully, managers must understand the ecology of the tree, the insect, the stand and the landscape. Both the tree's requirements and the insect's requirements will have an impact on future damage, and insect population dynamics can determine how likely an outbreak may be, and how it might behave in the future.

Forest Insect Management

In this course, you will have the opportunity to look at many different groups and types of forest health agents. The agent, the host, and the surrounding environment all interact, and each affects the other in various ways (Fig. 12). As you gain experience with the major forest insects of BC, keep this triangle in mind. Good forest management examines ways to manipulate the host, the environment, and/or the agent, rather than simply attempting to control the agent. Strategies (overall approaches), and tactics (specific methods within those approaches), must be considered within the context of objectives and values. It is also important to assess the efficacy of those strategies and tactics, and modify them as necessary.

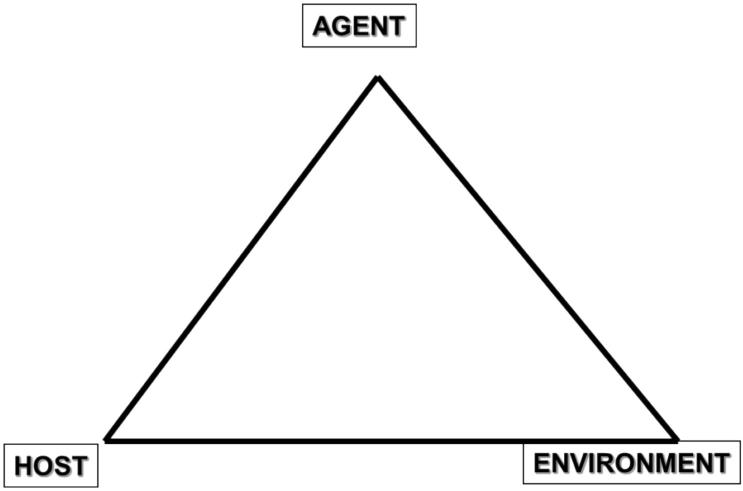


Fig. 12. The "forest health triangle", representing the interactions between a forest health agent, its host, and the surrounding environment.

Bark Beetles Overview

Bark Beetle Ecology and Management

Introduction

Bark beetles are among the most economically important insects in forests. https://www.nbclearn.com/portal/site/learn/freeresources/changing-planet/cuecard/54762. They are insects, so they are in the phylum Arthropoda, class Hexapoda (or Insecta), and the order Coleoptera, the beetles. Some years ago, bark beetles were in a separate family called the Scolytidae, but they are now in the subfamily Scolytinae of the family Curculionidae, or weevils. Most weevils have a long snout, which bark beetles lack but, genetically, bark beetles are simply specialized weevils. The ambrosia beetles are also in the Scolytinae; these are specialist wood-boring beetles that feed on symbiotic fungi.

Table 1: Classification of bark beetles

Taxon	Name
Phylum	Arthropoda
Class	Hexapoda (Insecta)
Order	Coleoptera
Family	Curculionidae
Subfamily	Scolytinae

General biology

Bark beetles feed within the subcortical tissues of trees at some point during their life cycles. They may be monophagous or oligophagous. Some specialize in feeding on softwoods, while others specialize on hardwoods. There are about 6000 species worldwide, mostly in tropical and subtropical areas. There are about 480 species in the United States, and about 180 species in Canada.

Bark beetles, like all beetles, are holometabolous, developing through egg, larva, pupa, and adult stages. Almost the entire life cycle is spent in/on a tree. Adults disperse to new host trees by flying, and may feed on the tree where they emerge, or on new trees. Following flight, they colonize new hosts and reproduce. A full life cycle, from emerging adult to the next generation of emerging adults, can take months to years. The emergence and dispersal part of that life cycle may only last for days to weeks.

Reproduction

Once a bark beetle finds an acceptable new host tree, it will initiate a gallery under the bark, excavating the subcortical tissues in a pattern that is characteristic of the beetle species on a particular host. The gallery is also inoculated with fungal spores.

Some bark beetles, e.g. *Ips* species, are polygamous: the male initiates the gallery, and attracts several females. After mating, the females begin excavating egg galleries, moving out from the central space (called the nuptial chamber) in different directions. This results in a characteristic pattern of egg galleries radiating out from the central nuptial chamber. https://www.flickr.com/photos/151887236@N05/41559658490. Other bark beetles, e.g. *Dendroctonus* species, are monogamous. In these beetles, the female initiates the gallery, and is later joined by a single male beetle. The pattern of galleries in these beetles consists of a long, central egg gallery, with larval galleries extending perpendicularly. Used in combination with identification of the host tree, a bark beetle gallery pattern can be used as a sign.

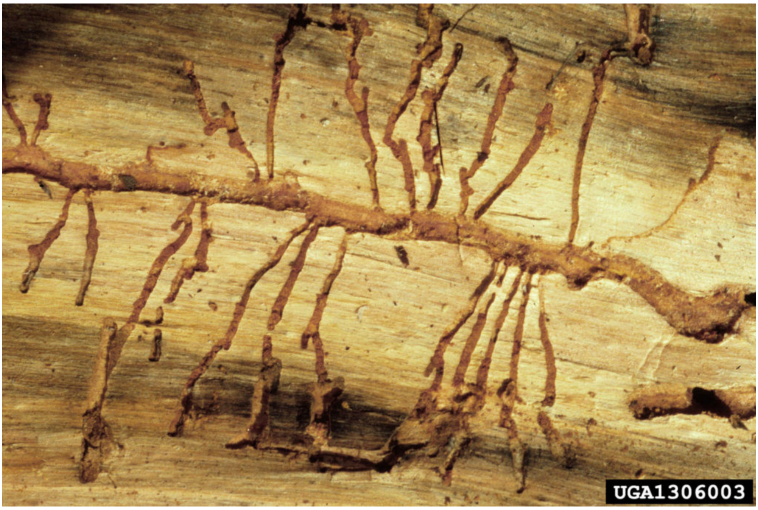


Fig. 1. Mountain pine beetle (Dendroctonus ponderosae) monogamous gallery. Photo by Leslie Chong – CC BY

Female bark beetles oviposit (lay) less than 300 eggs each, with the number depending on the beetle species and individual condition. These may be deposited singly in egg niches along the length of the main gallery, or in groups. Males assist females with the excavation of the galleries, and have several adaptations for clearing frass and boring dust out of the galleries. For example, the frons, or front of the head, is often flattened, as are the tibiae of the legs. Bark beetles in the genus *Ips* have an elytral declivity, or a flattened area on the tips of the elytra, which can be used to push frass and dust. Finally, viewed closely, bark beetles tend to have hairy bodies, which helps them to move sawdust around the galleries.

Fig 2. Mountain Pine Beetle, Dendroctonus ponderosae. Photo by Steve Clarkson -Public Domain

Fig 3. European Spruce Bark Beetle, Ips typographus, showing elytral declivity. Photo by Lindsey Seastone – CC BY-NC

Fig 4. Spruce beetle (Dendoctronus rufipennis) displaying hairs for moving sawdust. Photo by Staffan Lindgren – CC BY-NC-SA 2.0

Once the eggs hatch inside the galleries, the larvae feed on the phloem of the tree (in most bark beetles). They develop through 2-4 larval instars, and pupate in niches at the ends of the larval galleries. When they emerge as adults, they are often pale and relatively soft at first, and their reproductive organs are not fully developed. At this stage, they are referred to as teneral or callow adults. In order to become reproductive, most bark beetles must feed on a host tree, a process called maturation feeding. In some species, maturation feeding occurs under the bark of the tree as a teneral adult. Other species will fly to a new host and feed on live bark or foliage.

Bark beetles, like all insects, are profoundly affected by temperature. Prevailing temperatures govern the number of generations that can develop in a single year, or **voltinism**.

Semivoltine bark beetles take more than one year to complete their development. Univoltine bark beetles have one generation per year, while multivoltine beetles can complete multiple generations in a single year. It is important for the beetles that synchrony of emergence is maintained. They may not live very long as adults, so need to be able to find mates within a short window of opportunity. The insects may overwinter in the host tree, or in litter or soil on the forest floor. Overwintering beetles can be extremely cold-tolerant.

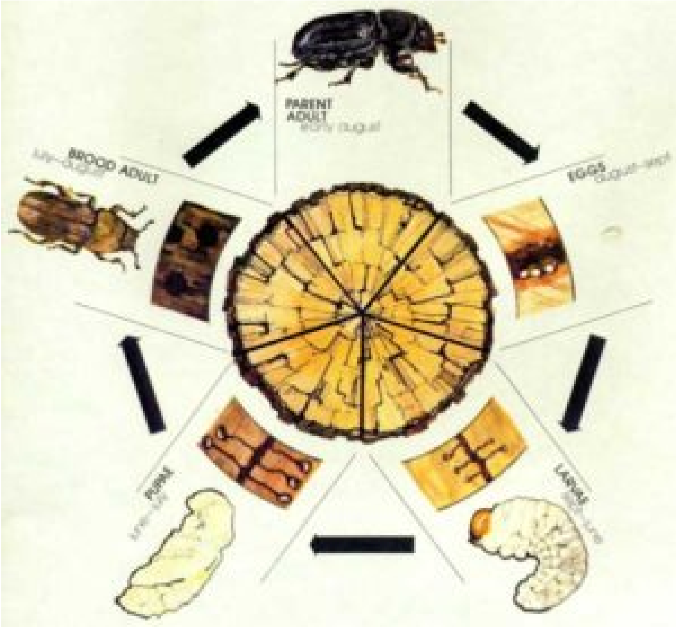


Fig 5. Typical pine beetle life cycle. Picture by Logan Jackson – CC BY-NC-SA 3.0

Emergence/dispersal

Emergence from the original tree may occur before or after overwintering, depending on the beetle and the climatic regime. Weather factors, such as temperature, humidity, and wind, influence bark beetle flight. There is usually a range of optimal conditions under which adults will fly, and this range is usually species-specific. For many species, temperatures need to be >16C, and even low levels of precipitation or wind can be problematic for an insect that is ~6-7 mm in size. The timing of flight is critical, if an individual is to encounter potential mates and susceptible hosts, while avoiding predation and competition. Dispersal can also be risky, especially in patchy, heterogeneous habitats.

Short range dispersal involves active flight, and uses energy. It is generally used for finding new, susceptible host trees, and potential mates, and the majority of any population likely only disperses for short distances. A relatively small percentage of a bark beetle population may also disperse long distances. They are initially photopositive, moving towards light, then later become host-positive, orienting to the scent of host trees. Long-distance dispersal is a poorly understood part of bark beetle biology, but it can be important. It was instrumental in the dispersal of mountain pine beetle from British Columbia, across the Rocky Mountains, and into Alberta.

Following its arrival among some potential hosts, a beetle must select a tree in which to initiate its gallery and reproduce. There is plenty of debate about the mechanisms that guide this choice. Landing on trees at random could play a role, but so could a variety of sensory cues. For example, like many insects, bark beetles have sophisticated sense of smell, and the primary attraction to a host is likely due to host odours. It is also probable that different cues play roles at different stages in the host selection process, and that the physiological state of the individual beetle influences the relative importance of these cues.

Fig. 6. A mountain pine beetle, Dendrotonus ponderosae, on a lodgepole pine tree, a potential host for the beetle. Photo by Lisa Poirier – CC BY-NC-SA 2.0

Colonization

Once it has landed on a tree, the beetle must accept it as a host and attempt to bore into the bark, or leave and try to find another host tree. The first beetles to arrive and attempt to colonize a host tree are known as "pioneer" beetles. As they bore into the bark and reach the subcortical tissues, they release secondary attractants to draw in other individual bark beetles of the same species. These secondary attractants are produced by the insects, and are often metabolized from compounds in the tree.

Trees are not defenseless. They produce copious amounts of resin, and multiple chemical compounds, in an effort to repel the beetles. Secondary bark beetles are those that tend to attack trees that have impaired defenses, usually because they are weakened by abiotic or biotic stresses, or are diseased or dying. Primary bark beetles are those that attack relatively healthy trees. Whether a beetle is behaving as a primary or secondary bark beetle has less to do with the species of beetle, however, and more to do with the size of its population. Mountain pine beetle, for example, is usually a secondary bark beetle, attacking dying, diseased, or stressed trees. It is only when populations reach high levels that the pioneer beetles are able to attract enough other beetles that they can overwhelm a healthy tree's attempts to defend itself.

Fig. 7. Pitch tubes, formed of resin, produced by a lodgepole pine tree in response to mountain pine beetles entering the bark. Photo by Lisa Poirier – CC BY-NC-SA 2.0

Interactions with other organisms

From the point of view of a bark beetle attempting to colonize a tree, any tree that is not well-defended will be easy to colonize but, chances are, many bark beetles will be attempting to use it as a host. On the other hand, a vigorous host will have fewer competitors under the bark, but will be much more difficult to colonize. There is a trade-off, then, between interspecific competition and host defenses exerting selection pressure on bark beetles (See Fig. 1 in Lindgren and Raffa 2013 http://www.entomology.wisc.edu/raffa/Research/AllPubs/Bark%20Beetles%20and%20Associates/Social%20Behavior/Lindgren%20and%20Raffa%20TCE%20Evolution%20of%20tree%20killing.pdf). A few bark beetles are able to survive and reproduce in live hosts, but most kill the host.

Aggregation pheromones, which attract other beetles of the same species, play an important role in overcoming the tree's defenses. If enough beetles attack an individual tree, it will eventually exhaust its resources and be unable to defend itself any longer. These mass attacks allow primary bark beetles to kill even healthy, vigorous hosts. There is a trade-off, however: more beetles attacking means more competition for their offspring. In addition to aggregation pheromones, each beetle also produces a small amount of an anti-aggregation pheromone, which acts to repel beetles of the same species. When the density of beetles rises to a certain point, the amount of anti-aggregation pheromone reaches a threshold level that r

epels any new beetles from attacking the tree. They frequently come close, but then start attacking neighbouring trees instead.

Fig. 8. Removal of bark by woodpeckers from a lodgepole pine killed by mountain pine beetle. Photo by Lisa Poirier – CC BY-NC-SA 2.0

Bark beetles are not alone when they invade a host tree. They may attack in large numbers, of course, but they also come with a range of symbionts including fungi, nematodes, bacteria, and various animals that use phoresy ("hitch-hiking" on the bark beetles) to disperse to new trees. Fungi are extremely important in bark beetle biology. The spores of symbiotic species are carried by the bark beetles in specialized structures called mycangia. Their growth inside the new host tree can help to block translocation of water and nutrients, weakening the tree and helping the beetle to invade successfully, or even killing the tree outright.

A wide range of organisms preys on or parasitize bark beetles. Vertebrates, such as woodpeckers, are able to extract the larvae from under the bark. Insect predators, such as checkered beetles, live under the bark, or walk around the surface of the bark hunting for beetles. A variety of parasitic wasps are able to locate bark beetle larvae from the outside of the tree, then lay eggs inside those larvae using long ovipositors. These natural enemies can cause substantial bark beetle mortality in some situations, but most estimates put mortality at 50% or less.

Epidemiology/population dynamics

Abiotic factors are generally the largest cause of mortality for bark beetles. In particular, temperature has both direct and indirect effects on survival and reproduction. Bark beetles are often well-adapted to cold temperatures during the overwintering phases of their life cycles. They enter a physiological state known as diapause, in which development is suspended. They may also develop tolerance to cold, building up cryoprotectants, compounds that lower the freezing point of their body fluids. Nevertheless, beetles can be killed by sudden or prolonged cold temperatures. Indirectly, temperature anomalies can disrupt the synchrony of emergence among the population, or affect the time of emergence so that more competition or tree defenses are encountered.

Bark beetles such as the *Dendroctonus* species undergo some relatively predictable population phases over time. These phases are characterized by factors such as the condition of the host trees attacked, attack densities, the role of secondary species (competition), the impact of mortality, and the mechanisms of population regulation. There are four distinct population phases: Endemic = normal state; incipient; epidemic; and post-epidemic (Safranyik and Carroll 2006; https://cfs.nrcan.gc.ca/publications/download-pdf/26039).

The endemic population phase is the usual state of most bark beetle populations. The population density is low, meaning that mass attack is not feasible. Emerging beetles attack small diameter trees with weakened defenses. There are many competitors in these relatively poor-quality hosts, and reproductive success is low.

Sometimes environmental factors provide an opportunity for populations to increase. There may be an increase in secondary beetle species, or anomalous weather patterns, either of which can weaken a greater number of trees. There is either reduced stand resistance to attack, or reduced environmental resistance, or both. The trees attacked by the bark beetle we are interested in still tend to be small and suppressed, but there are more of them, and the population of beetles starts to increase. Tree mortality during this endemic-incipient transition is scattered. The beetle population is very unstable, largely regulated by competition, and can often move back to endemic levels.

If the conditions favourable to this bark beetle persist, however, populations continue to increase, allowing the adults to access larger-diameter, better defended trees, while they also experience less competition from secondary bark beetle species. On average, beetles will have higher reproductive success in trees with greater phloem thickness. Populations can now move from the incipient phase to the epidemic phase.

Epidemic bark beetle populations attack healthy trees. The attack rate is high, and tree mortality is widespread. Reproductive success among the beetles is high, making their population resilient to very high rates of mortality. Population regulation is no longer dependent on competitors, but is regulated bottom-up by climatic factors and the availability of susceptible hosts.

The epidemic population phase is ended either by weather conditions that cause dramatically high bark beetle mortality, or by a lack of susceptible host trees. In the post-epidemic phase, most host trees are dead, and attack densities are still high but decreasing. There may be increasing competition from secondary bark beetle species, whose populations have built up by using the dead hosts left by the primary bark beetle. The impact of various mortality factors is population-dependent but, in general, the population is decreasing and unstable.

Major Species in BC

Dendroctonus ponderosae, mountain pine beetle
Dendroctonus rufipennis, spruce beetle
Dendroctonus pseudotsugae, Douglas-fir beetle
Dryocoetes confusus, western balsam bark beetle

Insect Defoliators

Defoliating Insects

Fig. 1. Douglas-fir partially defoliated by western spruce budworm, *Choristoneura occidentalis*.

Introduction

Like bark beetles, defoliating insects have substantial economic and ecological impacts on Canadian forests. The economically important bark beetles in Canada include insects in a single order, and only a few genera. Defoliating insects are much more diverse than bark beetles: many different types of insects feed on the leaves of trees. Some examples of major defoliator groups are shown in Table 1. In this section, we focus almost entirely on the Lepidoptera, although there are also some important Hymenoptera (sawflies) in Canada.

Table 1: Some important groups of defoliating insects, with examples.

Order	Common name
Lepidoptera	Moths and butterflies
Hymenoptera	Sawflies, leaf miners [leafcutting bees and ants]
Diptera	Leaf miners
Coleoptera	Flea beetles, leaf beetles, chafers, weevils
Orthoptera	Grasshoppers, crickets
Phasmida	Walking sticks
Homoptera	Aphids, adelgids, scale insects
Hemiptera	True bugs
Thysanoptera	Thrips
Acari	Mites (not insects)

Important Defoliators

In British Columbia, there are a number of Lepidoptera that defoliate conifers. Among the most economically and ecologically important are the budworms, in the family Tortricidae. There are several species of note, mostly distinguished by their hosts and geographic distributions. In the IDF (Interior Douglas-fir) zone, the western spruce budworm (*Choristoneura occidentalis*) feeds primarily on Douglas-fir, although it can also be found on *Abies* spp., *Picea* spp., and *Larix* spp. (https://tidcf.nrcan.gc.ca/en/insects/factsheet/1000040). The range of the spruce budworm, *Choristoneura fumiferana*, extends into the northeast corner of BC: the primary hosts are *Abies* spp. and *Picea* spp. (https://tidcf.nrcan.gc.ca/en/insects/factsheet/12018). The two-year-cycle budworm, *Choristoneura biennis*, also feeds on *Abies* spp. and *Picea* spp. in the northern interior of the province, west of the Rocky Mountains (https://tidcf.nrcan.gc.ca/en/insects/factsheet/12015). A "coastal" budworm species, *Choristoneura orae*, about which little is known, occurs in northwestern BC. Finally, the western blackheaded budworm, *Acleris gloverana*, occurs in coastal and interior wetbelts, preferring wetter habitats with hemlock. It feeds on a range of hosts, including Douglas-fir, *Tsuga* spp., *Picea* spp., and *Abies* spp. (https://tidcf.nrcan.gc.ca/en/insects/factsheet/1000039).

Fig. 2. A typical budworm larva, the western spruce budworm (*Choristoneura occidentalis*)

Besides the budworms, Lepidoptera in the family Geometridae (also known as "loopers" or "inchworms") are important defoliators in BC. The family name and common names arise from the characteristic arrangement of the legs and prolegs on the larvae. They have three pairs of jointed legs on the thorax, and only two pairs of prolegs on the abdomen, right at the very end. To move, the larvae stretch out the front part of their bodies and hang on by their front, jointed legs, then let go with the rear prolegs and pull the end of the abdomen forward to meet the thoracic legs. This movement pattern makes them "loop" the middle part of their bodies as they move. You should be aware of three species in particular: the western hemlock looper, *Lambdina fiscellaria lugubrosa* (https://tidcf.nrcan.gc.ca/en/insects/factsheet/1000002) https://www.flickr.com/photos/poirierl/46790085442; the western false hemlock looper, *Nepytia freemani* (https://tidcf.nrcan.gc.ca/en/insects/factsheet/1000001); and the phantom hemlock looper, *Nepytia phantasmaria* (https://tidcf.nrcan.gc.ca/en/insects/factsheet/1000004). All of these are generalist conifer feeders.

Another Lepidoptera family, the Erebidae, includes the tussock moths. There are several species in BC, but the most economically important is the Douglas-fir tussock moth, *Orgyia pseudotsugata* (https://tidcf.nrcan.gc.ca/en/insects/factsheet/1000009). Not only is this an important defoliator of Douglas-fir in the southern interior of the province, but the larvae are also covered in urticating hairs, which can cause serious reactions in some people.

One other generalist defoliator occasionally causes problems in conifer plantations in BC. The black army cutworm, *Actebia fennica*, feeds primarily on herbaceous vegetation following fires. Areas that have been replanted within the first year following a fire may have the conifers defoliated by these larvae.

There are many defoliating insects that affect hardwoods in BC. The species that most commonly experiences dramatic population increases in the interior is the forest tent caterpillar, *Malacosoma disstria* (https://tidcf.nrcan.gc.ca/en/insects/factsheet/9374). https://www.flickr.com/photos/poirierl/46842170411.

Fig. 3. An adult forest tent caterpillar, *Malacosoma disstria*.

Timing of Defoliation

Different species of defoliators may feed actively at different times in the growing season. The green spruce aphid, *Elatobium abietinum* (Hemiptera: Aphididae), is most active before new foliage flushes in the spring, so it feeds primarily on older, shaded needles using its piercing-sucking mouthparts. The spruce budworms, *Choristoneura* spp. (Lepidoptera: Tortricidae), need to chew their food, so they feed on tender, newly-flushed needles.

These preferences for new or old foliage influence the distribution of various defoliators in individual trees, and in stands. The tops of trees tend to have more new foliage than branches lower down. However, small trees tend to have proportionally more new foliage than larger trees. Western spruce budworm larvae often begin defoliating the tops of large Douglas-fir trees; as food becomes scarcer, they spin silk threads and lower themselves into smaller, often suppressed, trees (Fig. 2) to access much more young foliage.

A species' preference for old or new foliage can provide some indication of the impact of that defoliator on the host trees. For example, green spruce aphid tends to have less impact on its host than western spruce budworm has on its host. Why do you think that is? A few species show no particular preference for foliage age, or they begin feeding on young needles and then move to older needles. These defoliators, such as western hemlock looper and Douglas-fir tussock moth, tend to have the most pronounced effect on their hosts, sometimes causing tree mortality due to complete defoliation.

Environmental Influences

For new foliage-feeders, synchronization of egg hatch (or overwintering emergence) with the flushing of buds on the host tree is critical. If the eggs hatch too early, the larvae will have no food or shelter, and will likely freeze, desiccate, or starve. If they hatch too late, the needles will be too tough and well-defended, and will have lower nitrogen content, making them less nutritious. Egg hatch for many defoliators is closely synchronized with bud flush: for example, Douglas-fir tussock moth egg hatch usually occurs when 77-97% of the buds on the Douglas-fir hosts have flushed.

How do the insects achieve this synchrony? Bud flush is generally regulated by temperature, although some tree species also require an obligate cold period before their buds will flush. The insects are regulated by those same temperature cues, but other factors, such as photoperiod, can also affect development. Because other factors can influence egg hatch, it is sometimes possible for eggs to hatch "at the wrong time", leading to high mortality among the larvae. Climate change can affect these relationships, by reducing synchrony in some areas and increasing synchrony in others.

Synchronization is particularly important for some species. Sawflies tend to have a narrow window during which they can lay eggs in foliage. Early instar hemlock looper larvae have poor survival if they must feed on older needles, although the later instars do consume all ages of foliage. Young spruce budworm larvae (*Choristoneura* spp.) require newly-flushed foliage for survival. After emergence from their overwintering sites, the tiny larvae tunnel into the buds just as the scales loosen and the foliage begins to expand. The bud provides them with food, but also with protection from cold and desiccation. In eastern Canada and the US, black spruce buds tend to flush ~10-14 days after white spruce and balsam fir. The latter two species are highly susceptible to spruce budworm (*Choristoneura fumiferana*), while black spruce is usually less susceptible. Budworm larvae usually emerge from their overwintering sites in synchrony with bud flushing on white spruce and balsam fir, making these species most likely to be defoliated. This is thought to drive stand structure, to some extent, allowing black spruce to persist through budworm outbreaks, and promoting mixed-species stands.

Population Dynamics

Many defoliators tend to have cyclic populations, meaning that outbreaks do occur. The same species can be extremely common one year, and almost impossible to find a year or two later. Outbreaks often cause visible, noticeable defoliation, and can be short or long-lasting depending on the species and environmental conditions. Some spruce budworm epidemics have lasted more than 20 years, while Douglas-fir tussock moth outbreaks usually only last three to four years. Viewed on a landscape or regional scale, however, there are almost always some areas with at least some noticeable defoliation. As happens with fire, people tend to notice and be concerned about the defoliation and the insects during an outbreak.

Impacts

The term "defoliation" tells you exactly what the impact of these insects is on their host trees – their leaves are being removed. For an individual tree, that means that its overall photosynthetic area is reduced, so it can fix less carbon. It also means a reduction in transpirational area, so the tree is less able to move water and mineral nutrients from its roots to its crown. How much the defoliation affects the survival, growth, and reproduction of the individual tree depends on many factors, including

- tree and defoliator species
- stand structure
- site conditions
- weather
- defoliation intensity
- timing of defoliation

Trees are generally well-adapted to some defoliation. They carry excess foliage, they have elaborate physical and chemical defense mechanisms, and they usually have energy reserves. Angiosperms tend to be quite tolerant of defoliation, with extensive energy reserves and an ability to produce new leaves late in the growing season. Gymnosperms tend to be relatively sensitive to defoliation. Energy reserves can vary between conifer species; for example, pines tend to have greater reserves than do spruces. Hemlocks, spruces, and true firs often suffer mortality during defoliator outbreaks, while species such as larch are relatively tolerant. Species, and even individuals, can also vary in their ability to produce new foliage late in the growing season.

A reduction in the amount of foliage carried by a tree leads to decreased photosynthesis, decreased carbon sequestration and, consequently, decreased growth. These effects can also lead to death of fine roots and potential infections of the roots by pathogens. Younger and more vulnerable parts of the tree may die, resulting in top kill, crooks, forks, or stagheads. The tree may need to divert resources to new foliage or to defenses, leading to stress and general weakening. Occasionally, entire trees may die, but most defoliators do not cause much mortality.

Cone crops may be affected by defoliation. Some defoliators, such as western spruce budworm, will feed directly on developing cones and are pests in seed orchards. Relatively light defoliation may increase cone production, causing the trees to produce a stress cone crop. Heavier defoliation may cause a tree to divert resources away from cone production into the production of more leaves or defense compounds.

Stressed trees may become more susceptible to other agents, such as pathogens or bark beetles. Tree mortality may occur in defoliated stands for several years following an outbreak of a defoliating insect. Occasionally, defoliating insects also cause mortality directly. For example, both Douglas-fir tussock moth and western hemlock looper outbreaks can cause significant mortality. Other defoliators, such as western spruce budworm, are more likely to kill only parts of the tree. Mortality of the terminal shoot, also known as top kill, is common, and can cause deformities such as crooks, forks, or stagheads. Death of a terminal or a branch can provide an entry point for decay fungi, wood borers, or other agents.

At the stand and landscape levels, it usually takes several years of defoliation to cause severe mortality. Mortality is more likely when there is repeated defoliation, an unusually long or cold winter, poor growing conditions, or other stressors. Trees on poor sites tend to be less vigorous, and less able to recover from defoliation. Likewise, smaller trees in dense stands with shading already experience lower photosynthesis and greater competition, making them less likely to recover from a defoliator outbreak. Understory trees tend to have less foliage and a higher proportion of new foliage than larger trees, so it can take fewer larvae to defoliate them completely.

Are there any ecological benefits to defoliators? For one thing, they serve as a natural thinning agent in many stands. Thinning decreases competition and increases water availability for the remaining trees. There is also a brief nutrient flush, as the leaves are partially digested by the defoliating insects, then dropped to the ground to decompose. The remaining trees often experience faster growth in the years immediately following the defoliator outbreak. The net effect can be increased stand level productivity

Importance

Defoliators tend not to cause high losses in western Canada, but can be significant in the east (Fig. xx). When secondary losses are factored in, the impact of defoliating insects on forest health is substantial (Table x).

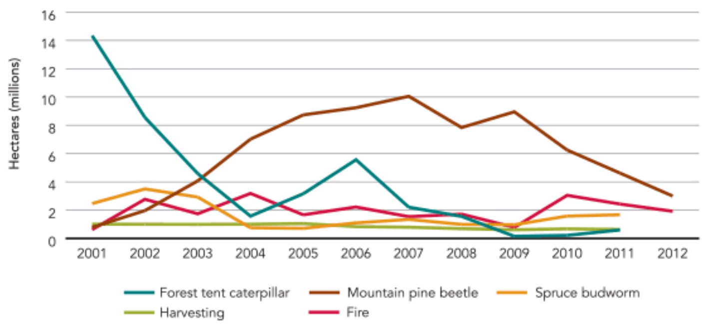


Fig. xx. I have no idea where I found this…

Table x. Hectares affected by defoliating insects in BC.

I take the data from https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health/aerial-overview-surveys/summary-reports, and update each fall

LAB MATERIALS

Bark Insects Lab

Bark insects are those that attack and consume the nutritional inner bark, or phloem of trees. The most important group in this category is the bark beetles (Order Coleoptera, Family Curculionidae, Subfamily Scolytinae), but other insects also utilize this resource. In this lab, you will look at those insects that complete their development in the inner bark.

As you work through this material and the lab exercises, review the life cycles of the different species in your field guide or through the links provided, and make note of the major characteristics.

Bark Beetles (Order Coleoptera, Family Curculionidae, Subfamily Scolytinae)

Bark beetles are extremely variable, and many innocuous species can easily be mistaken for economically important species (and *vice versa!*) unless you gain some general familiarity with different types. Bark beetle larvae cannot be differentiated easily from each other or from other weevil larvae (bark beetles are a subfamily of the weevils). For diagnosis, you normally have symptoms and signs from the host tree, which makes identification less difficult than it may seem. On occasion, someone will bring adult beetles to you, or you may be involved in trapping for monitoring purposes, and you should then be able to at least make an educated guess at an identification before sending specimens off to experts.

You should note the differences between **polygamous** and **monogamous** gallery patterns.

The most aggressive species are usually monogamous. Monogamous species (in the genera *Dendroctonus*, and *Scolytus*) have a **single, usually straight** (however, note the sinuous pattern of the western pine beetle) **egg gallery** that usually follows the grain of the wood, with **larval mines** radiating out perpendicularly to the egg gallery. These beetles frequently pack **frass** (a mix of feces and wood fragments) in the gallery. In **monogamous** species the attack is initiated by the female, with a single male joining. **Polygamous** species (e.g. *Ips*, *Dryocoetes* [*pronounced* **dry-o-seetes**]) have a central **nuptial chamber** constructed by the attack-initiating male, with a number of egg galleries, each excavated by one female, radiating out in a more or less species-specific pattern (Figure 1). The nuptial chamber is sometimes not visible, i.e., it may be within the bark. In *Ips perturbatus* and *Ips tridens*, both **spruce engraver beetles**, the egg galleries are parallel to each other and the grain, and may be mistaken for straight monogamous galleries. *Ips* galleries **do not** have frass in the galleries. Note also the **difference in width** between *Dendroctonus* galleries and those of secondary beetles.

Fig 1. Ips calligraphus (polygamous) gallery. Photo by Ronald Billings – CC BY

Fig 2. Mountain pine beetle (Dendroctonus ponderosae) monogamous gallery. Photo by Leslie Chong – CC BY

The spruce beetle, *Dendroctonus rufipennis*, generally lays eggs in batches on alternating sides of the gallery, and the larvae usually feed **communally** for the first while. Thus, you can see **areas** of feeding close to the egg gallery, followed by single larval mines radiating out from these communal feeding areas. In the mountain pine beetle, *Dendroctonus ponderosae*, the larvae tend to excavate **chambers** when they reach areas with blue stain. Thus, their larval mines tend to be short, with a chamber where they feed largely on fungus-infected phloem at the end. The Douglas-fir beetle, *Dendroctonus pseudotsugae*, has long larval mines. Douglas-fir beetle and western balsam bark beetle larvae turn into the bark at various stages, i.e., the gallery ends as if there is no successful brood. However, brood development is completed inside the bark. In the western pine beetle, *Dendroctonus brevicomis*, larval mines may not visible on the inside of the bark at all, because the larvae mine into the bark, possibly as a predation avoidance strategy.

You should note characteristics (size, colour, shape) of the insects covered in this lab, including larval forms, and the damage they cause. You will have an opportunity to see them more closely in the laboratory. Note that it is only important to be able to differentiate among species **within a host species**, not between different hosts, because the diagnosis uses the host as well as gallery pattern. For example, focus on the **gallery patterns** of *Dendroctonus ponderosae* in pine, and compare this to secondary bark beetles in pine. ****Note that this means it is important for you to be able to identify the tree species from a bark sample.**

Hylastes spp. and Hylurgops spp.

Beetles in these genera generally attack dead or dying conifers in contact with, or near the ground, e.g., down trees and root collars. After thinning, they can appear on stumps and down trees in large numbers. Some species in these genera are primary vectors of **black stain root disease, *Leptographium wageneri***. They are generally black, brown or reddish brown, and some species superficially resemble the mountain pine beetle. These insects breed in bark of dead conifers near the ground, or in direct contact with the ground. They do their maturation feeding on bark of live conifers, and may vector spores of black stain root disease while doing so. For a reference picture check https://www.fs.fed.us/r3/resources/health/field-guide/rd/blackstain.shtml.

Dendroctonus spp.

The genus name means "tree killer", and this genus includes some of the most economically and ecologically important bark beetle species. Most are North American, but one species occurs in Eurasia. Several species are displayed in the Petri dish. The mountain pine beetle is always black when mature, but adults may be brown or pale yellow before sclerotization of the cuticle is complete (**callow** or **teneral** adults). Note that there can be great variation in size, so you cannot reliably use size to differentiate bark beetle species. The spruce beetle, which tends to be a bit larger than mountain pine beetles, is all black, but can also have reddish-brown elytra (the colour of elytra is genetically determined). The Douglas-fir beetle always has reddish brown elytra, and a black pronotum and head, and is superficially very similar to the spruce beetle, but their host association differentiates them. Several other species resemble the spruce beetle and Douglas-fir beetle, but are found in different hosts, and are of minor importance. Host identification is critical to diagnosis.

Fig. 3. Douglas-Fir beetle, Dendroctonus pseuodotsugae – Joseph Benzel CC BY-NC

Ips spp.

These bark beetles are generally referred to as **engraver beetles**, because their egg galleries tend to score the sapwood very distinctly. Several species are important and, in Eurasia, the European spruce beetle, *I. typographus*, is the most important bark beetle species. *Ips* species can be recognized by their concave **elytral declivity** (the sloping part at the posterior end of the elytra), the edges of which have species-specific numbers of spines or teeth. Most *Ips* beetles avoid live trees. Thus, you almost never see pitch tubes associated with *Ips* attack. On down trees they often occupy the upper, exposed part of the tree.

Fig 4. European Spruce Bark Beetle, Ips typographus, showing elytral declivity. Photo by Lindsey Seastone, CC BY-NC

Scolytus spp.

These bark beetles are easily recognized by the straight shallow elytra, and the abdomen sloping up to the elytra, rather than the elytra sloping down. Several species are important, notably the non-native European elm bark beetle, ***S. multistriatus***, a vector of Dutch elm disease.

Fig. 5. European elm bark beetle, Scolytus multistratus, side view. Photo by Joseph Benzel, CC BY-NC

Predatory beetles

Adult predatory beetles are often found on trees or logs attacked by bark beetles. The majority of these are in the Family Cleridae, the checkered beetles. The adult beetles are typically dark grey, with a wavy light grey band across the elytra, and the thorax and underside is often red, e.g., the red-bellied clerid. Adults feed on adult bark beetles, and oviposit on attacked trees. Larvae of the checkered beetles live in the galleries of bark beetles, where they feed on the bark beetle larvae. They are easily recognized by their purple to pinkish colour and sclerotized double “horn” at the end.

Important Bark Beetles by Hosts

Bark beetles in pine

There are two important species in western North America. One is the **mountain pine beetle, *Dendroctonus ponderosae***, which occurs throughout western North America, and attacks almost all pine species. The other is the **western pine beetle, *Dendroctonus brevicomis***, which is restricted to ponderosa pine in British Columbia. It is an extremely important species in California, and has been locally important in BC.

Fig 6. Mountain Pine Beetle, Dendroctonus ponderosae. Photo by Steve Clarkson – Public Domain

In the southeastern United States, the **southern pine beetle, *Dendroctonusfrontalis***, is of major concern, particularly in loblolly pine, which is the major commercial species there.

Secondary species of occasional concern are the **lodgepole pine beetle, *Dendroctonus murrayanae***, a close relative of the spruce beetle, and the **red turpentine beetle, *Dendroctonus valens***. These species attack stressed or damaged trees low to the ground, and generally create large, brownish-red pitch tubes. The red turpentine beetle is the largest of the *Dendroctonus* species, reaching 9 mm or more in length. It is found low on the trunk, or in the roots, of stressed or dead pines, and it is red, rather than black. Small turpentine beetles can potentially be confused with **callow (teneral)** adults of other species (What is a callow or teneral adult?).

Common engraver species in pine are ***Ips pini*****, *****Orthotomicus(Ips) latidens*****, and *****Pseudips(Ips) mexicanus.* *Pityogenes*** spp. are very small beetles often associated with other bark beetles. ***P. knechteli*** is commonly found with *Ips* on pine. On occasion they kill immature pine, especially following thinning. They have spines on the elytral declivity, but the declivity is not concave with well-defined edges as in *Ips*.

Bark beetles on spruce

The spruce beetle, *Dendroctonus rufipennis* is second only to the mountain pine beetle in economic importance in temperate forests. It is distributed throughout the range of spruce in North America. Outbreaks have occurred in the east, but are particularly devastating in the west from Alaska to Colorado. The spruce beetle normally requires 2 years to successfully complete development, but warm summers will promote a 1-year cycle. The **boreal spruce beetle** (also called the Allegheny spruce beetle), ***Dendroctonuspunctatus***, is a minor species that attacks weakened spruce trees, but attacks do not kill the tree. Generally, single attacks are found at ground level, particularly in stands affected by ***Inonotus tomentosus***. ***Ips perturbatus*** has caused mortality of spruce in Alaska, but is secondary in northern BC. ***Ips tridens*** and ***Ipsborealis*** are also found on spruce. **The four-eyed spruce beetle, *Polygraphus rufipennis***, is a small secondary beetle usually found in the thin-barked portions of down spruce. Beetles in this genus have their eyes completely separated into two parts, giving this beetle its common name. In Newfoundland, it has caused significant mortality.

Fig. 7. Spruce beetle, Dendroctonus rufipennis. Photo by M. O'Donnell and A. Cline – CC BY-NC

Bark beetles in Douglas-fir

The Douglas-fir beetle (Fig. 3)**,** ***Dendroctonus pseudotsugae***, kills older, stressed Douglas-fir, particularly in dry environments. It is a significant problem east of the Cascade Mountains in the United States. In British Columbia, mortality tends to be associated with other problems, e.g., root disease, defoliation or other stress. This insect is not well adapted to breeding in living hosts, and outbreaks tend to subside within 2-3 years. The **Douglas-fir engraver,** ***Scolytus unispinosus***, is common on thin-bark portions of dead trees, and occasionally kills severely stressed younger trees.

Bark beetles on true firs (Abies spp.)

The most important species is the **western balsam bark beetle,** ***Dryocoetes confusus***. This insect has been largely ignored until recently. As commercial interest in high elevation forests increases, the need for management options for the western balsam bark beetle increases. Mortality is generally scattered over large areas, and weakened or declining trees (sometimes associated with defoliation) are preferred. The **fir engraver, *Scolytus ventralis***, kills *Abies* spp. on occasion. Grand fir has been susceptible in Idaho and south central BC, as well as on the south coast of BC (Sechelt and the east coast of Vancouver Island), usually associated with stress events. Many other secondary species attack true firs.

Fig. 8. Western balsam bark beetle, Dryocoetes confusus. Photo by Javier E. Mercado – CC BY-NC

Bark beetles on other trees

Most trees have some bark beetles associated with them. In general, these are secondary and of little importance. Exceptions are those species that vector diseases, e.g., the **European elm bark beetle, *Scolytus multistriatus*** (Fig. 5), and the **native elm bark beetle, *Hylurgopinus rufipes***, both of which vector Dutch elm disease, caused by the pathogen *Ophiostoma ulmi*. The former occurs in BC and Washington State, but the disease is not yet present in these populations.

Pitch moths (order Lepidoptera)

In addition to the bark beetles, there are also some moth species associated with large pitch masses on suppressed, diseased (stem rusts) or damaged conifers. **The Douglas-fir pitch moth**, ***Synanthedon novaroensis***, is the main conifer-infesting **clearwing moth (Family Sesiidae)** species found in northern BC, while in southern BC the **sequoia pitch moth**, ***Synanthedon sequoiae***, is more common. Both primarily attack lodgepole pine, contrary to what their common names might suggest. The latter is slightly sturdier, and has yellow and black banding, rather than orange and black. The sequoia pitch moth tends to confine attacks to the lower bole, whereas Douglas-fir pitch moth attacks may be found anywhere on the bole. Pitch masses of these species can be very large, and repeated attacks often occur, usually oriented horizontally on the stem, and sometimes resulting in stem breakage. Larvae of the two species cannot be differentiated. In eastern Canada, ***Synanthedon pini*** causes similar symptoms.

Fig. 9. Douglas fir pitch moth, Synathedon novaroensis. Photo by Brenda Dobbs – CC BY-NC

Adults of the **western pine moth, *Dioryctria cambiicola***, show the "W" pattern on the forewings typical of this large family (**the snout moths, Family Pyralidae**). The pitch masses of this species are smaller, and numerous pitch masses are often found along the vertical edges of stem rusts.

The larvae of the pyralid (western pine moth) and the sesiid (Douglas-fir and sequoia pitch moth) species can be differentiated best by the presence of dark spots on the back of the western pine moth, and a different arrangement of the **crochets** (the little hooks on the **prolegs**, which are the fleshy abdominal legs). In sesiid larvae, the crochets are arranged in two opposing bands, while in the pyralid larva they form a complete circle.

Suggested additional reading

Safranyik, L. and B. Wilson. 2006. The mountain pine beetle. A synthesis of biology, management and impacts on lodgepole pine. Natural Resources Canada, Victoria, BC, 304 pp.

Lindgren, B.S. and K.F. Raffa. 2013. The evolution of tree-killing by bark beetles: Trade-offs between the maddening crowds and a sticky situation. The Canadian Entomologist 145: 471–495, doi 10.4039/tce.2013.27.

Bark beetle management guidebook available at https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/forest-health/bark-beetles/bark_beetle_management_guidebook.pdf

https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/forest-health/forest-health-docs/field_guide_to_forest_damage_in_bc_web.pdf

Foliage Insects

FOLIAGE INSECTS LAB

In this lab, you will look at some of the insects that consume tree foliage. There are many serious defoliators in British Columbia, which mostly fall into two groups: **moths and butterflies (Order Lepidoptera),** and **sawflies (Order Hymenoptera)**. In both groups, it is the larvae that cause damage by defoliating trees. The larvae of sawflies are somewhat similar in appearance to the caterpillars of Lepidoptera, but can be differentiated by the higher number and different position of the **prolegs** (see below). Adults **do not** feed on foliage.

As you work through this material and the lab exercises, review the life cycles of the different species in your field guide or through the links provided, and make note of the major characteristics.

The Budworms (Order Lepidoptera, Family Tortricidae)

The budworms are the most important defoliators in Canadian forests. In eastern Canada, the **spruce budworm, *Choristoneura fumiferana***, has long been the most serious insect pest of spruce/balsam fir forests. In British Columbia, this species is important in the northeastern part of the province, east of the Rocky Mountains. In the rest of BC, three other species cause frequent, severe damage. Most important is the **western spruce budworm, *C. occidentalis* (=*C. freemani*)**. This species can be a severe pest of Douglas-fir in the southern and central interior. Further north, the **2-year-cycle budworm, *C. biennis***, causes significant damage in subalpine fir/spruce stands. In the northwestern part of the province, ***C. orae*** (no official common name) is an occasionally significant pest. In the wetter biogeoclimatic zones, the **western blackheaded budworm**, ***Acleris gloverana***, has caused severe defoliation of western hemlock, Sitka spruce, and true firs.

The *Choristoneura* species are difficult to tell apart. Adults are small moths with mottled reddish brown wings. The caterpillars of the *Choristoneura* species are smooth, green to brown, and often have a row of light spots on either side, e.g., the western spruce budworm (Figure 1). Egg masses are greenish and laid like shingles in masses of about 40 eggs on the underside of needles. Outbreaks of this species can last for several decades. You should be able to recognize a budworm caterpillar, as well as an adult, but you are not expected to tell species apart unless you also have information about the location and host species.

Fig. 1. Caterpillar of Choristoneura occidentalis

The Tussock Moths (Lepidoptera: Erebidae)

This family includes the **gypsy moth, *Lymantria dispar***, which was introduced from Europe in the late 1800's in Massachussetts, and more recently from Russia (**Asian gypsy moth**). It is not established in BC, and its impact once established is unknown. Most likely it will have relatively localized, but potentially serious, impacts in aspen stands in the southern part of the province, and in Garry oak in the Victoria area. The Asian gypsy moth also has the potential to affect coniferous trees.

There are several tussock moth species in the genus O*rgyia* that are important forest pests. Only one, the **Douglas-fir tussock moth, (O. *pseudotsugata*),** is a significant defoliator on a regular basis. This species is one of the most serious pests of Douglas-fir, causing widespread mortality in stands in the driest parts of the interior Douglas-fir zone, and where Douglas-fir has invaded the ponderosa pine-bunch grass zone due to fire suppression. The hairy larvae of tussock moths have two characteristic black, antennae-like hair tufts directed forward, and one to the rear, and 4 light-coloured tufts along the back. Larvae are wasteful feeders, killing much more foliage than they consume. The adult males are brownish moths with feathery antennae. The females are plump, wingless, "furry" insects that bear little resemblance to a moth. Pupation occurs inside cocoons spun on tree trunks, rocks, undersides of branches, etc. Females often lay their egg masses on top of the cocoon from which they emerged. Populations cycle on about a 10-year basis. Outbreaks last 3-4 years, after which epizootics of a **nucleopolyhedrosis virus** (NPV) cause populations to crash.

You should be able to recognize larvae and adults of tussock moths. There are several species that are similar, so species determinations are context-dependent, i.e., different species occur in different stand types and/or geographic areas.

Loopers (Lepidoptera: Geometridae)

The most serious of the loopers is the **western hemlock looper, *Lambdina fiscellaria lugubrosa***. This species has caused extensive mortality in old growth cedar hemlock stands in coastal BC, and in the interior wet belt. Like the tussock moths, the hemlock looper is a wasteful feeder, and it is also less discriminating. The larvae are typical looper or "inch worm" caterpillars. They pupate in salt-and-pepper coloured pupae in bark crevices etc. Adults are tan-grey moths with darker bands on the wings (2 on the front wings and one on the hind wings). Eggs are laid in moss or lichen. Outbreaks occur in old growth stands and are sporadic (not cyclic) in any given area. Several other loopers are occasionally serious defoliator pests, e.g., the **western false hemlock looper, *Nepytia freemani***, and the **phantom hemlock looper, *Nepytia phantasmaria***.

Fig. 2. Adult western hemlock looper, Lambdina fiscellaria lugubrosa

Sawflies (Hymenoptera: Tenthredinidae and Diprionidae)

Several species of sawfly cause sporadic outbreaks, particularly on the coast. In many species the larvae feed gregariously. The caterpillars are similar to moth caterpillars. However, sawfly larvae have more pairs of prolegs, no crochets (hooks) on prolegs, and no space between the thoracic legs and the first pair of prolegs. Adults are small insects resembling shiny flies, but with two pairs of wings. One species of note is the **larch sawfly, *Pristiphora erichsonii***. Recent outbreaks by ***Neodiprion*** spp. in coastal BC have caused considerable damage to western hemlock.

Hardwood defoliators

While hardwood defoliators are generally ignored in BC, you should make note of the **forest tent caterpillar, *Malacosoma disstria* (Lepidoptera: Lasiocampidae)**. This transcontinental species is a serious pest of trembling aspen across Canada. In the Prince George area, this species persisted at epidemic levels for more than a decade in the 1990s, and for several years in the mid-2010s. The 1990s outbreak was unusual; outbreaks normally last 3-4 years, after which NPV epizootics cause populations to crash. During outbreaks, forest tent caterpillar can be a prominent nuisance pest in urban areas. The caterpillars, which are active from early spring into June, when they are most noticeable, do not construct tents, but aggregate on trunks during cool weather (Fig. xx). The dark caterpillars can be recognized by the **key hole-shaped white spots** along the back, and blue lateral stripes (Fig. xx). Pupation occurs in a spun cocoon, which incorporates several leaves if on the host tree, but can be found almost anywhere due to the wandering habit of mature caterpillars. The tan coloured, stocky adults (Fig. xx) appear in late June or July. Females deposit egg masses on twigs, usually high in the crown of aspen trees. The eggs hatch the following spring.

Fig. 3. Aggregation of forest tent caterpillar, Malacosoma disstria, larvae on aspen

Fig. 4. Larva of forest tent caterpillar, Malacosoma disstria

Fig. 5. Adults of forest tent caterpillar, Malacosoma disstria

Other aspen defoliators of note are the **large aspen tortrix, *Choristoneura conflictana* (Lepidoptera: Tortricidae)**, which is common around Prince George, and the **satin moth** (Fig. 6 and 7)**, *Leucoma salicis* (Lepidoptera: Erebidae)**. The latter is an exotic species introduced to the east coast around the same time as gypsy moth. It has long been established in south-central BC, and has also been found near Prince George, Vanderhoof and McBride. High populations have been present in Quesnel for some years, and considerable defoliation occurred in 2018 between Prince George and Vanderhoof. Adults are a satin white, and the colourful caterpillars are hairy.

FIg. 6. Satin moth (Leucoma salicis) caterpillar

Fig. 7. Satin moth (Leucoma salicis) adult

Consult the web and the field guide for additional species of defoliators not available for viewing in the lab.

Suggested additional reading.

Duncan, R.W. 2006. Conifer defoliators of British Columbia. Natural Resources Canada, Victoria, BC. 359 pp.

Defoliator management guidebook. Available at http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/defoliat/defoltoc.htm

This is where you can add appendices or other back matter.