Chapter 11: Damage

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General Guidelines

This chapter addresses biotic and abiotic causes of damage to conifer seedlings, saplings and young trees. It starts with general guidelines for assessing, preventing and mitigating damage, followed by more detailed information and illustrations of the most common causes of damage. Damaging agents are grouped and discussed as follows: insects, diseases, vertebrates, and abiotic. Understanding and diagnosing the broad topic of damage draws from multiple disciplines and specialties. A basic understanding of damaging agents is assumed. Competing vegetation can also be thought of as a cause of damage. However, it is discussed extensively elsewhere in the manual, and thus is not specifically addressed here.

Damage to young conifers comes in many forms. Pest organisms – insects, pathogens, and vertebrates - often are involved, but adverse environmental conditions can lead to damage without the involvement of any pests. Knowledge of what damage has previously occurred in an area or under similar circumstances can allow land managers to anticipate what might occur, recognize the source of the damage, and act accordingly. Ultimately, it is difficult to anticipate and recognize *all* the variables that might lead to damage. When damage does occur, land managers mainly want to know "will this damage continue and if it does, is there anything that can be done to prevent it?" To answer these questions, an accurate diagnosis of the situation is essential. Regardless of your level of skill or comfort at making a diagnosis, the process of assessing damage is invaluable because it will sharpen your skills of observation and enable you to better understand the situation. You may then either feel confident to make a diagnosis or decide to consult an expert.

Assessing Damage

A simple but useful model to keep in mind when evaluating damage is the Pest Triangle (fig. 11.1). Pests are strongly influenced by host and environmental conditions. All three points of the triangle interact to produce the resultant damage and all three points must be considered when formulating a diagnosis, and, ultimately, a prognosis of what is to come.

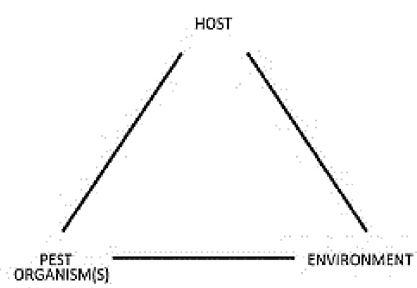

Figure 11.1 Pest Triangle

Common mistakes made during diagnosis include an imbalanced interpretation of how points of the triangle are interacting, and a misidentification, or lack of recognition, of one or more of the factors that have contributed to damage. If a pest organism is present or easily identifiable, it is not uncommon for most of the blame to be placed on it, with the belief that eliminating the pest will bring an end to damage. If a key pest organism is misdiagnosed or unrecognized, time and resources may be wasted trying to manage the wrong pest or condition.

It is important to thoroughly investigate both the damage and the context in which it occurs. Look for clues at multiple levels – on the damaged tree(s), within the stand, and across the region. Explore the patterns and extent of damage, associated environmental conditions, and other clues that may arise during an on-site assessment. Obtain as much background information as possible on site conditions such as soil properties, weather events, source of growing stock, history of damaging agents onsite, and management actions – anything that could have had bearing on the damage. Context is invaluable since many types of damage are associated with predictable conditions.

Inspect damage on all or a representative number of trees, and inspect entire trees to the extent possible. The source of damage may not be obvious, especially if the damage is old or multiple organisms are present. It is common for insects and disease organisms to invade wounded or stressed tissue and, in doing so, mask more relevant signs and symptoms of damage. The sooner an inspection is conducted after damage has occurred, the better. Roots should not be overlooked since above-ground symptoms can be caused by below-ground damage or conditions.

Trees are only able to respond to damage in a limited number of ways. Symptoms are the generic expression or consequence of damage. As such, they may allow an educated guess as to what is occurring, but they typically do not provide a definitive answer. For example, brown needles at the ends of branches are a symptom that can be caused by insects, diseases, vertebrates, or abiotic factors. Additional clues collected at the tree, stand, and regional levels may help to narrow the choices, such as size and species of trees impacted, type of damage (e.g. length of brown needles), and distribution of damage within tree crowns and across the stand and region. Validate a diagnosis by looking for signs of a pest organism or evidence of a specific type of injury. Signs of biotic damage include evidence that a pest organism is or has been present, such as insect life stages or remains (e.g. larvae, pupal cases, dead adults), tunnels and galleries, chewed tissue, frass, fungal staining, mycelium, zone lines, fruiting bodies, or parasitic plants (e.g. mistletoe). Signs of abiotic damage include physical wounds and tissue death that often occur in distinct patterns and are not associated with living organisms.

Damage that occurs to a cohort of trees over a relatively short or otherwise distinct period of time is usually caused by a specific set of conditions. It is important to mentally reference the pest triangle and look for patterns in the symptoms of damage, species and size of trees impacted, associated environmental conditions, and signs of pest organisms. If a pest organism is a principal contributor to damage, it should be possible to identify signs or symptoms of that organism on all or most of the trees inspected. Finding such evidence, however, may be limited by how thoroughly the tree is inspected. If evidence for a specific pest organism is inconsistent, consider that a different organism may be contributing to the damage or that pest organisms are primarily acting in a secondary role.

Also, consider that certain pests are frequently found together in what are referred to as pest complexes. Bark beetles and root diseases are a good example of this. While bark beetles can kill trees on their own, quite often the success of their attack is facilitated by a preexisting condition that weakens the tree, such as root disease, injury, or drought stress. An awareness of pest complexes and investigating their presence is an important aspect of diagnosis.

In most cases, signs and symptoms will lead to a diagnosis in the field. Occasionally, samples of damaged tissue may need to be taken to a lab for dissection, incubation, or some other diagnostic procedure (see Additional Resources section of this chapter). If the lab diagnostician has not seen the damage in the field, it is important that they be provided with as much relevant information as is possible (e.g., geographical location, elevation, aspect, tree species, tree size). A prognosis can only be made once damage has been accurately diagnosed.

Damage caused by abiotic factors is often limited in duration, for example a late frost, hail, or herbicide treatment. It also tends to be more uniformly and widely distributed, both on individual trees, across tree species, and across the landscape. In some cases, the damage may be vague and non-specific, with no or inconsistent signs of pest organisms. Abiotic factors typically cause no further damage, although it may take time for damage to be fully expressed. Secondary insects and disease organisms may initially be absent, but often invade damaged tissue over time. Usually their contribution to damage is minimal.

Pest organisms vary widely in the damage they cause and their ability to persist on site. A prognosis depends on the biology of the individual organism(s) as well as an accounting of factors that influence future pest abundance and damage. The probability of future damage coupled with management options makes a prognosis complete. Are pest organisms still present and at what level? Are they likely to increase or decrease? What factors, including treatment options, will influence their abundance and ability to cause additional damage? An initial evaluation may be sufficient to answer these questions, or it may be desirable to conduct follow-up surveys.

Preventing Damage – Best Management Practices

A certain amount of pest damage is preventable to the extent that it is related to management choices. Prevention practices that are specific to one or a small group of pests are discussed in the individual pest sections. Generic considerations are discussed here. Prevention practices should be thought of as best management practices since the intent is to produce the best possible outcome.

Because tree genetics are closely aligned with environmental conditions, it is essential that locally-adapted seed or seedlings are used for reforestation (see discussion of Seed Zones in this manual). There are many examples of "off-site" plantings suffering pest damage. While such trees may initially grow well, they are poorly suited for the site and often succumb to pest damage before reaching merchantable size.

Reducing competition between trees and associated vegetation improves tree growth and is an important factor in reducing pest damage on drier sites. Treatments include thinning (stocking control) of plantation trees and various methods of controlling competing vegetation. There are some precautions to take when thinning since it can lead to pest damage under certain conditions. These are discussed in the individual pest sections.

On forestlands that naturally support a mixture of tree species and ages, one of the challenges of reforestation efforts is to promote and maintain a diversity of these two characteristics. Reforestation following wildfire is a challenge because only a limited number of tree species may be able to survive when planted into a post-fire landscape. With large wildfires, there is the additional challenge of finding sufficient amounts of seed or seedlings adapted to the local area. Pest-caused damage often occurs in large plantations with little diversity in tree age and species. Planting stock that is not well matched with local conditions may further contribute to damage.

Mitigating Damage – Options for Response

Mitigation or management options usually depend on the specific pest(s) and circumstances involved. In the following pest sections, the most commonly encountered plantation pests are discussed, including information on identification, life history, and management. Direct control of a pest is one of many options that might be considered under the more holistic strategy of integrated pest management (IPM). Understanding the ecological relationships between host / pest / environment (fig. 11.1) is central to the concept of IPM. Thus, a variety of options are weighed and integrated into an ecologically sound response. Modern definitions of IPM also typically incorporate the concepts of economic efficiency and social acceptance. When thinking about mitigation, it is important to have a realistic expectation of what is possible from both an ecological and cost/benefit standpoint. Some pest damage may be difficult to avoid or too costly to mitigate. Doing nothing is sometimes the best or only alternative.

Insect Pests

Much of the insect damage that occurs to young trees is insignificant, not encountered, or is simply different on older trees. Thus, plantation insect pests are, for the most part, a distinct subset of the larger group of insects that damage trees.

Insects that Attack Roots and the Lower Stem

Recognition and Significance: The first year or two of a tree's life is a critical time for root damage from insects. The insects involved are rarely primary pests of conifers, but have largely been studied as agricultural or ornamental pests. Often, they cause damage when conifer seedlings grow along side of or replace vegetation that the insects were feeding upon. Sites where herbaceous vegetation is well established are prone to damage. Removing this and other competing vegetation by chemical or cultural means will lead to the insect populations dying out, but the effect is not immediate. See Forest Nursery Pests, USDA Handbook # 680, for coverage of the most common of these pests (https://www.fs.fed.us/sites/default/files/legacy_files/Forest%20Nursery%20Pests-web.pdf)

These insects come in many forms and typically do not need to be identified precisely. Common names include white grubs (larvae of beetles in the family Scarabidae), cutworms (caterpillars of moths in the family Noctuidae), root weevils (beetle larvae in the genus *Otiorhyncus*), and sod webworms (caterpillars of moths in the family Pyralidae). Immature stages of the insects (larvae and caterpillars) live in the soil and feed on roots, the lower stem, or sometimes foliage. An initial symptom of root or lower stem feeding is a change in the foliage color of seedlings. Heavily damaged seedlings continue to fade and die, while less damaged seedlings may survive with reduced growth. Some adult weevil species will girdle seedlings, while their larvae feed on other plants.

Any time the entire top of the tree appears off color or shows reduced growth, suspect an issue with the roots. These symptoms can be the result of poor planting (e.g. J-roots), vertebrate pests, diseases, herbicides, or insects. Inspect the roots and lower stem for insect feeding damage, including missing bark, consumption of finer roots, or young shoots clipped at the soil line. Look for larvae, caterpillars, or evidence of insects, such as frass and webbing, in the soil near roots. Cutworms and weevils may also feed on needles. Be aware that vertebrates can cut or tear foliage and stems with their teeth, causing damage in the absence of insects or disease. Intact, apparently healthy roots combined with foliage discoloration may indicate herbicide or abiotic damage. Other signs and symptoms may indicate disease (see Disease Section below).

Management Options: While direct control of insects may be prescribed for seedlings in nurseries, it is rarely recommended for seedlings and young trees in forest plantations because damage is typically limited in scope and duration. Damage is rare when plantations are established soon after the harvest of over-story trees. Damage is possible if herbaceous and other vegetation becomes well established, such as when a site remains free of trees for an extended period. On such sites, control competing vegetation and consider a fallow period before planting trees to reduce the possibility of insects surviving in the soil and feeding on seedlings.

Insects that Attack the Main Stem

These insects feed in the cambial region, girdling the stem and killing the entire tree or a portion of it. Bark beetles and some weevils can do this to advanced regeneration under drought stress, particularly to species of pine. Other factors that stress young trees potentially predispose them to attack by this group of insects.

Pine Reproduction Weevil

Recognition and Significance: The pine reproduction weevil, *Cylindrocopturus eatoni,* kills young pines, in whole or in part (fig. 11.2). Ponderosa pine is the primary host, but Jeffrey, sugar, foothill, and other pines are attacked. Trees taller than 5 feet in height are rarely killed.

Figure 11.2 Ponderosa pines killed by the pine reproduction weevil.

The weevil life cycle is one year. Adults are tiny, about 2.5 mm long (fig. 11.3) and emerge from dead trees in the spring (May-June), creating small exit holes in the bark.

Figure 11.3 Adult pine reproduction weevil.

Adults do minor feeding on the host, creating diagnostic puncture wounds on needles (fig. 11.4). Females lay eggs one at a time on the stems of live trees in early summer. Larvae tunnel in the cambial region, girdling the stem, and eventually enter the wood or pith to overwinter.

Figure 11.4 Ponderosa pine needles with puncture wounds from pine reproduction weevil.

A blue fungal stain discolors the wood (fig. 11.5). Pupation occurs in the spring prior to adult emergence. Foliage of killed trees begins to change color (fade) in the fall or the following spring. Diagnosis is readily made based on these signs and symptoms.

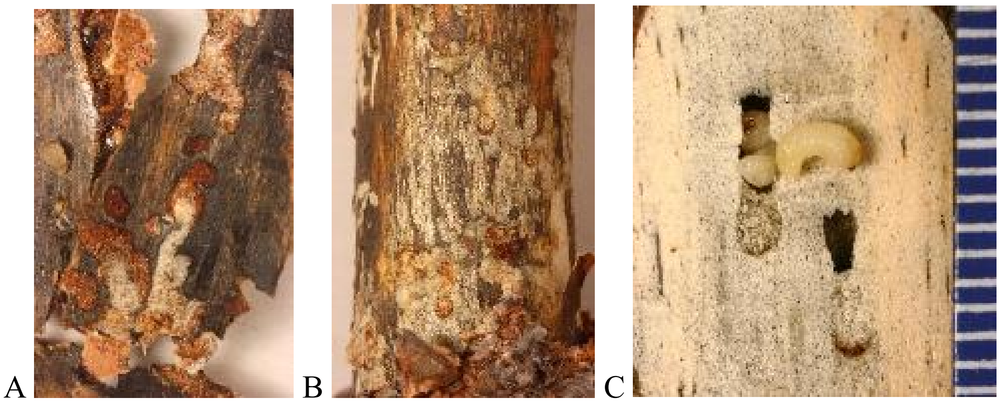

Figure 11.5 Evidence of pine reproduction weevil in a killed ponderosa pine. (A) Inner bark surface and (B) surface of wood show mines and staining. (C) Larvae tunnel in to the wood prior to pupation; associated stained wood.

A related insect, the Douglas-fir twig weevil, *Cylindrocopturus funissi,* is similar in appearance, life cycle and the damage it causes, although mortality is usually restricted to twigs and branches. Management is the same for both insects.

Management Options: Direct control of weevil populations is done by destroying infested trees or applying contact pesticides to kill the adults, but does not produce a lasting solution. Weevils reinvade plantations where trees are under stress, allowing populations and damage to rebuild. Controlling vegetation that competes with trees for limited water is the recommended treatment, as it enables trees to better resist attacks by weevils and other insects. On sites that are marginal for conifer growth and survival, the costs of keeping planted pines alive may outweigh the benefits.

Bark Beetles Attacking Young Pines

Recognition and Significance: Several bark beetle species can kill young conifers during drought. These beetles also attack older trees, but are not primary killers of mature trees. Susceptible tree height and diameter are greater than for trees damaged by *Cylindrocopturus* weevils. Mortality events are typically short-term and often precipitated by thinning stressed host trees at an inappropriate time. In pine plantations, species of *Ips*, especially California five-spined Ips, *I. paraconfusus,* can kill sapling and pole-size trees. The red turpentine beetle (RTB), *Dendroctonus valens*, can kill pole-size trees. Bark beetle attacks are distinguished from those of the pine reproduction weevil by the larger size of tree attacked and the presence of boring dust or pitch tubes on the main stem. Key factors in bark beetle-caused mortality are drought and a productive breeding site for the beetles. For *Ips*, the breeding site is cut green stems and larger limbs from within the plantation or nearby. Green material that is generated from winter through early summer and is greater than 3” in diameter presents the greatest risk. For RTB, the breeding site is fresh stumps.

Management Options: To prevent mortality from either of these beetles, avoid thinning plantations during drought or thin later in the growing season, such as August through October, when risk is lower.

Other Bark Beetles

Other pole-size conifers, besides pines, will on rare occasions experience similar mortality from bark beetles. Douglas-fir attacked by the Douglas-fir engraver, *Scolytus unispinosus,* is an example. It breeds in green stems and larger limbs of Douglas-fir, and may leave this material to attack nearby trees. Avoid creating large amounts of breeding material when drought-stressed Douglas-firs are nearby.

Winter storm damage - windthrow and stem breakage – also produces breeding material for bark beetles. Most damage resulting from these events has not involved the beetles mentioned above or occurred to young trees. Beetles such as the western pine and Douglas-fir beetles, which attack older, larger trees, are more likely to be involved. Consider the potential for damaging bark beetle activity whenever large amounts of green slash are created and susceptible trees are nearby.

Insects that Attack Shoots

The most damaging insects in this group attack pines and include: the western pine shoot borer (WPSB), *Eucopina (Eucosma) sonomana,* ponderosa pine tip moth, *Rhyacionia zozana*, and gouty pitch midge, *Cecidomyia piniinopsis*. The latter two insects are recognized for killing shoots, while WPSB more often reduces terminal shoot growth. Weevils in the genus *Pissodes* occasionally kill terminal shoots of pine and spruce, but reports of damage are rare in California.

Western Pine Shoot Borer

Recognition and Significance: Western pine shoot borer typically restricts its attacks to the terminal shoot (leader) of the tree and completes its life cycle without killing the terminal. Attacks on lateral shoots are less common but are more likely to kill the shoot. Ponderosa pine is the principal host, but Jeffrey and other pines are also attacked. WPSB's principal impact is reduced height growth. Loss of dominance by the terminal shoot and stem deformity also occur. Chronic infestations can have a significant impact on wood production over the life of a stand of trees, especially on more productive sites. Because shoots are rarely killed, damage may be overlooked. The sex pheromone of WPSB has been identified, synthesized, and used in various treatments to disrupt mating and prevent damage.

WPSB moths (fig. 10.6) emerge and begin flying in early spring, just as snow cover is disappearing from many sites. Eggs are laid singly on expanding terminal buds and shoots. One larva typically mines a shoot, but occasionally there may be two. Mines follow the pith and are packed with dark brown, somewhat resinous frass (fig. 10.7A). Larvae exit shoots in late spring near the lower end of the mine, leaving a small hole and resin droplet on the surface. They drop to the ground where they pupate and overwinter. There is one generation per year.

Figure 11.6 Western pine shoot borer moth. Length varies from ¼ to not quite ½ inch.

Infested terminals become stunted, causing needles to bunch together and shorten relative to needles on non-infested shoots (fig. 11.7B). The entire shoot may be impacted, or initial growth of the shoot may look normal, while later growth, i.e. younger needles closest to the top, are clearly impacted.

Figure 11.7 Terminal shoots of ponderosa and Jeffrey pines infested by the western pine shoot borer. (A) Shoot cut open to reveal a WPSB mine, and (B) external symptoms of infestation.

Suspect WPSB whenever terminal shoots exhibit these symptoms. Moths can be caught in pheromone-baited traps, but otherwise are rarely seen. Larvae are off white with a tan to brown head capsule and can be found in mines during the spring. The best time to recognize and survey for damage, however, is after trees have finished height growth and damage is finished for the year, i.e. summer onward. Confirmation of WPSB is made by cutting into one or more symptomatic shoots and finding the characteristic mines.

Damage is first noticed when tree height is 3-4 feet and can continue for a couple of decades, or more. A good time to begin monitoring for damage is early in this period of susceptibility since a steady increase in damage is likely as a plantation grows. A single infestation results in a one-time loss of height growth of about 25%. Trees with the largest terminal buds are preferred for oviposition and may represent the best growing trees in a plantation. Multiple factors have bearing on the decision of when to control damage, including age of the stand, percentage of terminals infested, and cost of treatment(s) versus benefit. Studies indicate that the greatest benefit is achieved when stands are treated at a young age after reaching a certain level of infestation. Benefits of control drop off for stands over 20 years old, are considered negligible for light infestation levels (25% or less), and will be greatest for heavily infested (50% and higher) high value stands.

Management Options: Infestation levels can be reduced by use of a commercial product (MalEx™ ShootBorer) which utilizes the pheromone and a pesticide in a formulation that attracts and kills male moths. Treatment is applied by hand in the spring just before or as close to moth emergence as possible, which can be monitored . Thinning a plantation can cause the infestation level to increase significantly as damage is concentrated on fewer trees. To avoid this, application of the pheromone treatment in the spring following a thinning is recommended. This combination of thinning / pheromone treatment will help plantations to quickly grow through the time when they are most susceptible to damage. Because moths will reinvade a treated area, one or two additional pheromone treatments, two years apart, may be warranted.

Ponderosa Pine Tip Moth

Recognition and Significance: The ponderosa pine tip moth is one of several *Rhyacionia spp.* that mine buds and shoots of young pines, killing the shoots and stunting the growth of trees that are repeatedly attacked (fig. 11.8). As the name suggests, ponderosa pine is the principal host, although other pines including Jeffrey, lodgepole, and sugar pines may be attacked. Damage is predominantly on trees less than 6 feet in height on dry sites.

Figure 11.8 Trees and shoots damaged by the ponderosa pine tip moth.

Moths emerge in the early spring, overlapping with, but starting slightly later than WPSB emergence. Eggs are laid on elongating terminal and side shoots. Larvae are initially found externally on shoots, where they form a bubble-like shelter of silk and resin, and create a hole through which the shoot is entered for feeding. Eventually they stay within the shoot. Multiple larvae feed inside a single shoot, where they consume nearly everything, creating a maze of tunnels and frass (fig. 11.9).

Figure 11.9 Mines of the ponderosa pine tip moth within a killed shoot.

Needles on the shoot fail to develop and remain short (fig 11.8). Needle color begins to fade in late spring and becomes more noticeable as the summer progresses. An occasional larva will pupate in a shoot, but most will leave and pupate at the base of the tree in mid-summer. There is one generation per year.

Tip moth damage is often concentrated on individual trees and in certain areas of a plantation. It is easily recognized by the dead or dying shoots that are consumed on the inside. Slight pressure on a heavily mined tip causes it to crumble. Intact older dead tips may be present, but over time they disintegrate, leaving a resinous stub at the end of the damaged shoot. Larvae, present from late May through much of July, are orange-brown and develop a slight rose color as they mature (fig. 11.10). They are 10-12 mm (slightly less than ½ inch) when fully grown. Pupae are dark brown and roughly half this length.

A B

Figure 11.10 (A) Young larva of ponderosa pine tip moth. (B) As larvae mature, the head and prothoracic shield lighten in color, and the body takes on a slight rose-colored tinge.

An accumulation of tip moth cocoons can be found at the base of infested trees at or near ground line. Cocoons are tightly lodged in gaps and crevices of the outer bark. They consist of loosely woven silk and dried resin, and depending on the time of year may contain pupae (late July through March / April) (fig. 11.11).

A B

Figure 11.11 (A) Old cocoons on bark near ground level and (B) pupae of ponderosa pine tip moth.

Management Options: The sex pheromone of *Rhyacionia zozana* has been identified and shown to be effective at disrupting mating and reducing damage. However, no commercial products for control are currently available. The WPSB pheromone attracts males of *R. zozana*, so there is speculation that pesticide treatments containing it may control tip moth damage, but this has not been tested. While both moths can be found in the same plantations, significant damage from the tip moth is restricted to drier sites. Most trees quickly outgrow tip moth damage and the fastest growing trees appear to receive little damage from it. Any treatment that improves tree growth will help reduce damage.

Gouty Pitch Midge

Recognition and Significance: Midges in the genus *Cecidomyia* form pits beneath the bark of new shoots or live in exuded resin masses on pines and are known as pitch or resin midges. The gouty pitch midge, *C. piniinopsis,* primarily attacks ponderosa pine. Damage ranges from scarring to shoot dieback, depending on the level of infestation. Chronic infestations can deform trees and retard growth.

Confirming pitch midge as the cause of shoot dieback can be somewhat confusing because infested shoots are alive and then die after the insects have exited. There is a one generation per year. In the spring, tiny adult midges emerge from cocoons on needles and females lay eggs on expanding pine shoots. Eggs hatch and salmon-colored larvae enter new shoots where they develop in resinous pits just beneath the bark. The cocoons are distinctive (fig. 11.12), but neither the adults nor eggs are easy to find.

Figure 11.12 Cocoons of the gouty pitch midge.

Fully developed larvae are 4-5 mm (3/16 of an inch) long (fig. 11.13). Infestation may produce slight stem swelling, but shoots otherwise look normal and remain alive through the one-year period of infestation. In late winter, larvae exit the shoots and make their way to needles where they pupate. The previously infested shoots can continue to live or may die in the spring.

A  B 

Figure 11.13 Gouty pitch midge larvae. (A) Within an infested shoot and (B) close-up.

Management Options: Trees differ in their likelihood of becoming infested and damaged. Damage is heaviest on trees with viscid or sticky shoots, a heritable trait. Trees with dry or waxy shoots can become infested, but damage is less (fig. 11.14). In most plantations, damage is unlikely to be severe and trees will continue to grow at a normal rate. Selectively removing damaged trees is an option, but only is recommended if height growth is being significantly impacted. Trees over 16 feet in height are unlikely to be damaged. Attempts to control the midge with pesticides have not proven successful. While it should be possible to breed resistant planting stock, low demand makes this impractical.

Figure 11.14 Ponderosa pines with different levels of attack by gouty pitch midge. The tree on the left has viscid shoots, while the tree on the right has dry shoots.

Insects that Attack Foliage

In general, this group of insects presents a limited threat to young trees. Insects with piercing / sucking mouthparts, such as aphids and scales, are unlikely to reach damaging levels. Populations of some other insects may reach damaging levels on occasion, but natural enemies – parasites and predators – play a significant role in controlling outbreaks and maintaining populations at endemic levels. Some of the more common insect defoliators are discussed.

Grasshoppers

Recognition and Significance: A small number of grasshopper species are a potential threat to seedlings and young trees up to a few years in age. Trees are not favored food, but grasshoppers will feed on and damage trees when their preferred food, green grasses and forbs, dries and becomes unpalatable. Endemic grasshopper populations are not a threat, but outbreaks can cause significant damage, including complete defoliation and mortality of young trees.

Grasshopper outbreaks are sporadic and difficult to predict. Similarly, outbreaks are not likely to be noticed until some level of damage is seen. Most grasshoppers have a one year life cycle and it is the older stages that damage trees by consuming needles and buds. By the time damage is noticed, there may be little that can be done during the current year. Control, if it is needed, is aimed at the next generation, which hatches in the spring. Young grasshoppers are the easiest stage to control and their numbers indicate the level of damage that may occur later in the season. Although they are easily recognized, young grasshoppers do not feed on trees, so look for them on adjacent vegetation.

Management Options: There is no established economic threshold for controlling grasshoppers in tree plantations. A logical approach, however, would be to survey grasshopper numbers at the time of damage to get an estimate of the density that is causing damage. The number of grasshoppers per square yard is a commonly used metric. Monitor grasshopper densities the following spring to determine if control is warranted.

Eliminating or reducing the levels of grasses and forbs in the spring will cause young grasshoppers to either starve or leave, reducing local populations. Alternatively, young grasshoppers can be treated with a pesticide to reduce their numbers. Because grasshopper populations may be an issue over a larger area, it is recommended that the situation be reported to and discussed with the County Agricultural Department.

Pine needle-sheath Miner

Recognition and Significance: The pine needle-sheath miner, *Zelleria haimbachi*, is a defoliator of 2 and 3 needle pines, including ponderosa, Jeffrey, and lodgepole pines in California. Outbreaks have periodically occurred in pine plantations where trees are 4 or more years old. Heavy defoliation can cause temporary growth loss and limited shoot dieback. Natural enemies play an important role in controlling populations.

Eggs are laid, one per needle, on current-year needles in late spring to mid-summer by female moths. They also may be laid on older needles, especially when populations are high and the complement of current-year needles has been greatly reduced by defoliation. Eggs hatch in summer and the first 2 instars of the insect are spent as a tiny, thread-like caterpillar feeding within a needle until the spring. Individual needle mines are barely visible with the naked eye and amount to insignificant damage (fig. 11.15).

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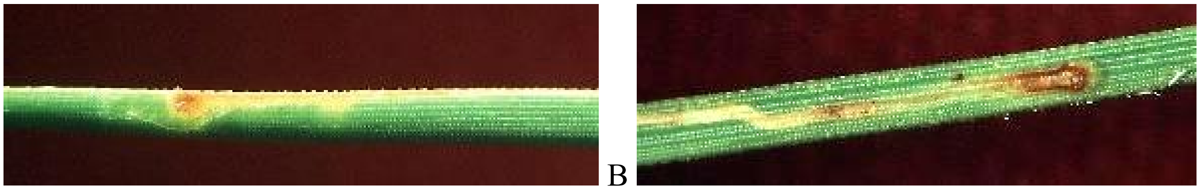

Figure 11.15 Close-up of mines of the pine needle sheath miner. The first instar larva mines along the edge (A) of a needle and then moves toward the center (B) during the second instar. Completed mines range in length from about 50-80 mm.

As new shoots and needles begin to elongate, caterpillars exit these mines and begin feeding on developing needles by chewing a round hole through the needle sheath and eating the bases of needles (fig. 11.16). This feeding begins in May and lasts about 3-4 weeks. Needles are severed and die before finishing elongation, and are easily pulled from their sheaths. Damage depends on the number of caterpillars feeding, and anywhere from a handful to all the needles on a shoot may be killed (fig. 11.17). Severed, green needles initially remain within the sheath, but eventually fade and begin falling out.

Figure 11.16 Holes mark where the pine needle sheath miner fed at the base of the needle fascicle.

Figure 11.17 Ponderosa pine shoot heavily damaged by the pine needle sheath miner.

During the sheath feeding phase, caterpillars are found on new shoots at the base of needles, along with silk webbing and frass. Caterpillars initially are tan, but take on orange and green overtones as they develop (fig. 11.18A). They reach a length of 12-13 mm (about ½ an inch). Pupae are half this length and found in silk webbing on damaged shoots in June (fig. 11.18B). Tiny white moths with tan markings begin flying in the later part of June and may be present into August.

A B

Figure 11.18 Pine needle sheath miner (A) larva and (B) pupa.

Outbreaks are not common and often are short-lived. Natural enemies and host quality both likely contribute to this. Heavy defoliation kills current year's needles, which are the preferred oviposition site for the next generation. If these needles are gone, eggs are laid on older needles, which presumably are less suitable for insect survival. Little information exists on impacts of defoliation, but what does exist indicates that most outbreaks are unlikely to cause significant damage. A rare, worst case would involve multiple years of defoliation.

Management Options: Direct control has been shown to be highly effective at reducing populations - insecticide treatment is applied when most caterpillars have exited mines and entered the sheath feeding phase, usually in the latter half of May. The synthetic pyrethroid insecticide esfenvalerate has been used successfully in aerial applications, but other insecticides are likely to be effective as well.

If direct control is being considered, an estimate of the population should be made by sampling trees in mid-late April when caterpillars are still in needle mines. Shoots, including the full complement of last year's needles, are collected from a subset of trees. On each shoot, a portion (e.g. 50%) of last year's needles are inspected for needle mines, which are relatively easy to see by April, but not before. The number of mines is counted and multiplied by the appropriate factor (times 2 if 50% of needles are inspected) to estimate the number of larvae per shoot that will enter the sheath mining phase. One or two caterpillars per shoot cause negligible defoliation. Slightly more, and defoliation begins to stand out. When numbers approach 10 caterpillars per shoot, defoliation is heavy. If most of the previous year's needles were killed, it will be necessary to look at the complement of needles from the year prior to that and to distinguish between old, unoccupied mines and those that contain caterpillars of the current generation.

White fir Sawfly and Douglas-fir Tussock Moth

Recognition and Significance: These two insects defoliate white fir in distinctly different patterns. Sawfly larvae restrict their feeding to old needles, while tussock moth caterpillars initially feed on young needles and then may feed on needles of all ages as the caterpillars mature. It has been noted that if their outbreaks coincided, this would have a devastating impact on trees since defoliation would be rapid and nearly complete. While this is plausible, it is not likely. Both insects feed on trees of all sizes, but defoliation is heaviest on the youngest trees. This distinction is more pronounced with the sawfly.

Outbreaks of the white fir sawfly, a *Neodiprion* species, have occasionally occurred in stands of white fir. Damage is limited for two reasons: outbreaks typically are short-lived, i.e. a year or two, and feeding is restricted to old foliage (fig. 11.19). Feeding starts in the spring slightly before or when new growth begins. While feeding on old foliage can be heavy, new foliage remains undamaged. A major outbreak occurred in northern California in the 1950s, but mostly minor activity has been noted otherwise.

Figure 11.19 Foliage damaged by the white fir sawfly. Newly flushed needles are untouched.

The sawfly has a one year life cycle. Adult flight, mating, and oviposition occur from October to early November. Females insert eggs singly into needles where they overwinter. Larvae hatch in the spring and feed gregariously. They are olive green, essentially hairless, and reach a length of slightly less than an inch at maturity (fig. 11.20). In contrast, tussock moth, O*rgyia psuedotsugata,* caterpillars are quite hairy and do not feed gregariously. By July, sawfly larvae stop feeding and begin to leave trees to pupate in the duff. An occasional pupa may be found among foliage.

Figure 11.20 White fir sawfly larvae.

Outbreaks of the Douglas-fir tussock moth are much more frequent and extensive than those of the sawfly, occurring somewhere in California on average about every 7-10 years. White firs of all ages can be heavily defoliated and put at risk for mortality. Douglas-firs receive little, if any defoliation. In the past, treatments to control outbreaks were applied over large areas, but it is now recognized that heavy defoliation and damage is limited to local hot spots within larger outbreaks. White fir stands on ridge tops, upper slopes, and poorer sites are likely to receive the heaviest defoliation. Because trees can be killed or damaged by a single season of heavy defoliation, early detection and evaluation of building populations is critical.

Endemic populations of the tussock moth are virtually undetectable, except through monitoring with pheromone-baited traps. Depending on the area, the USDA Forest Service or CAL FIRE may be monitoring tussock moth populations. Such efforts provide area-wide information on population fluctuations and can be a cue of when to look more closely for tussock moth. Trap results can indicate if an outbreak is likely, but do not predict where it will occur. Aside from extensive sampling, a next best option for early detection is to keep an eye out for defoliation (fig. 11.21) or any other signs of the moth.

Figure 11.21 Light defoliation of white fir caused by the Douglas-fir tussock moth. Brown needles are partially eaten.

This can be done during normal duties and by planned visits to high risk sites. The tussock moth has a one year life cycle. Caterpillars (fig. 11.22), present from June through most of July, and egg masses (fig. 11.23), laid on foliage from late summer through October, are the most visible stages of the insect. Finding these or other evidence of the moth would be reason to request a local evaluation, which is best done by an entomologist or forest pest specialist.

Figure 11.22 Douglas-fir tussock moth caterpillars come in different color variations. The distinctive tufts and other markings become more pronounced as the larvae mature.

Figure 11.23 Douglas-fir tussock moth egg mass and cocoon.

Management Options: Direct control of the sawfly might be considered for an outbreak of multiple years that coincided with other damage or stress to produce significant impacts. The 1950s sawfly outbreak was easily controlled with an insecticide, although natural enemies likewise exerted control in untreated areas. While direct control of the tussock moth is feasible, an evaluation is essential to determining an appropriate course of action. Evaluations on state and private lands are conducted by CAL FIRE; on federal lands, by the USDA Forest Service.

Diseases

Most diseases of significance in plantations are found on trees of all sizes and are a component of the environment in to which young trees become established. Direct control of forest pathogens is rarely an option, but there are management strategies that will reduce the incidence or impact of many tree diseases.

Many bark beetles and some woodborers and weevils attack trees under stress, including diseased trees. Some of these associations are well studied, while others have been observed but not rigorously documented. If cambium-feeding insects are attacking a tree, the possibility of disease and other causes of stress should be investigated as well. The primary agent impacting the tree is deduced based on what is known of the organisms or other factors involved.

Root Diseases

Heterobasidion (Annosus) Root Disease

Recognition and Significance: Most conifers in California are potential hosts for one of two fungi that cause Heterobasidion root disease. In live trees, the pathogen acts as either a decay that weakens root systems or as a root disease capable of girdling and killing trees. In the root systems of stumps or dead trees, the pathogen can persist for up to fifty years as a saprophyte. Young trees are infected and killed when their roots contact the roots of an infected stump or nearby live or dead tree. Once a tree is infected, the pathogen can grow and spread to adjacent live trees via underground root-to-root contacts. If the dead, infected roots in the soil are large and extensive, the pathogen can persist on site and kill young trees for decades, creating an opening that is difficult to reforest.

Most openings or "disease centers" caused by Heterobasidion root disease are found in relatively pure ponderosa or Jeffrey pine forests, or true fir forests composed of white or red fir. Another characteristic of these centers is the presence of a single or multiple large infected stumps. The diseases in pine and fir are different both in terms of the species of fungus that causes them and the damage done. Live pines are infected by *Heterobasidion irregulare* (formerly known as the "p" type of the fungus) and experience cambial girdling and mortality, whereas true firs are infected by *Heterobasidion occidentale* (formerly the "s" type of the fungus) which causes wood decay in mature trees and may kill young firs. Diseased mature true firs are subject to windthrow. Stress resulting from infection by either fungal species often leads to increased mortality from bark beetles, particularly during drought. Strategies to manage the disease in pine and true fir are slightly different. Note that the host specificity that is exhibited by *Heterobasidion spp.* in live trees does not apply to cut stumps. From a practical standpoint, *H. occidentale* can infect a pine stump and subsequently move to a live fir. Movement of *H. irregulare* from a fir stump to a live pine, however, is unlikely.

Management of Heterobasidion root disease is a matter of recognizing risk and implementing preventative strategies. Tree failure can be a significant risk to people and structures in all forest types where the disease occurs. On timberlands, mortality of young trees is primarily an issue in pine, especially on drier sites that are naturally suited to support a high percentage of pine. Such sites may have a history of Heterobasidion root disease and thus be recognized as higher risk for the disease. Aside from site conditions, larger pine stumps are an essential component of risk. A freshly cut stump surface can be an important route for the pathogen to become established on site. Without large pine stumps to saprophytically harbor the pathogen, risk is nil.

Heterobasidion root disease can be diagnosed by a variety of signs and symptoms. One key symptom is the association of dead young trees with larger stumps. Fruiting bodies (conks) (fig. 11.24) of *Heterobasidion* spp. often can be found within old stumps or on the roots of killed seedlings and young trees. A perfectly formed conk is a semi-circular shelf with a gray to brown top and an off-white pore surface on the bottom. Many conks, however, take on a more amorphous shape that conforms to their substrate and the space in which they developed. They vary in size from less than an inch to many inches across.

A B C

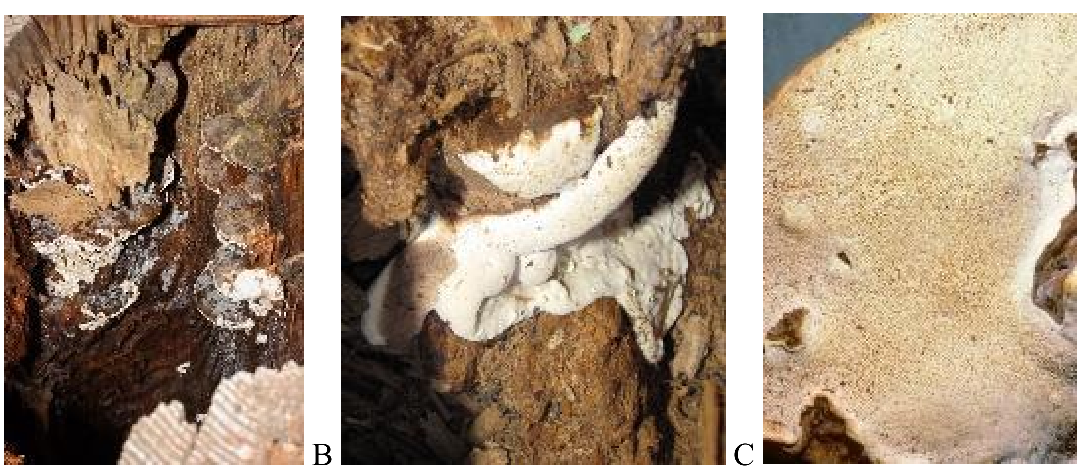

Figure 11.24 Conks of *Heterobasidion occidentale* from white fir. (A & B) In a stump, and (C) close-up of the lower pore surface.

They typically are hidden from view and must be revealed by removing duff and soil around the root collar or excavating decayed stumps. Wood with advanced decay is straw yellow, separates in a stringy or laminate fashion, and may have elongate white pockets and small black flecks (fig. 11.25). The roots of dead seedlings and young trees are discolored brown, often resinous, and may have tiny "popcorn" conks (fig. 11.26) attached.

(A) (B)

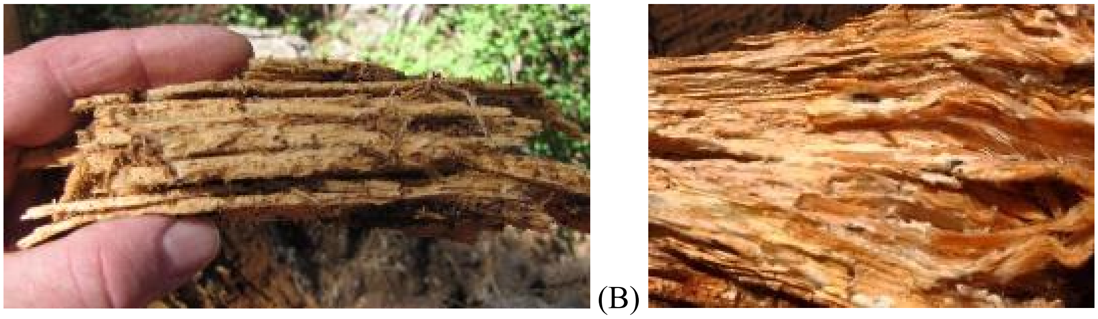

Figure 11.25 Lower stem and root wood of a white fir decayed by *Heterobasidion occidentale* illustrating (A) laminate separation and (B) white pockets and black flecks.

Figure 11.26 Popcorn conks of *Heterobasidion irregulare* at the root collar of a young ponderosa pine killed by the fungus.

In mature stands, openings (disease centers - fig. 11.27) are created by outwardly expanding mortality of trees over the course of many years. Trees near the center of the opening have been dead the longest, while those on the edge may exhibit symptoms or be dying. Trees with advanced disease have thin, chlorotic crowns. Crowns thin from the bottom up, so the top of the tree may look relatively normal. It may be possible to find roots or portions of the root crown that have been killed by disease. Phloem turns brown, underlying wood may have light brown streaking, and areas of resin accumulation are common in both wood and bark. Tree reproduction within disease centers is poor because seedlings and young trees are killed. Often there are large, old stumps in the disease center that suggest the pathway by which the opening was initiated. Black stain root disease causes similar crown symptoms and openings, but rarely kills young pines and produces very different signs within infected trees.

Figure 11.27 Heterobasidion root disease center in a ponderosa pine stand.

Management Options: When cutting live pines on high risk timber sites, stump surfaces can be treated with a borate fungicide to prevent colonization by *Heterobasidion* spp. Small stumps, i.e. less than 14 inches in diameter, present little risk for Heterobasidion root disease and can be left untreated. Stumps should be treated immediately or as soon as possible after cutting. If two days pass, the borate application will be ineffective. A benefit from treating true fir stumps on timber sites has not been proven for a variety of reasons: the pathogen is known infect true firs via other routes, infection is believed to be more common in true firs, and the impacts from infection are slower to develop in true firs versus pines. On sites where there is risk to people or infrastructure from tree failure, consider treating stumps of all conifer species down to a 3-inch diameter.

Black Stain Root Disease

Recognition and Significance: Black stain root disease, caused by the fungus *Leptographium wageneri*, occurs in several pine species and Douglas-fir. Although trees of all ages may be killed, it is not a common disease of young pines. Pole-size and larger Douglas-firs are more readily infected and killed, especially in single-species plantations. Unlike *Heterobasidion* spp*., L. wageneri* does not persist well as a saprophyte. Hence, if an infected stand is cut and replanted, seedlings have limited exposure to the pathogen. As plantations age they become more susceptible to disease. Plantations of Douglas-fir apparently reach a susceptible age sooner than those of ponderosa pine.

The fungus is moved from one location to another by insect vectors, i.e. certain root-feeding bark beetles and weevils. Thinning or other disturbance in a plantation can attract vectors and result in the fungus becoming established. It then can move from tree to tree through root contacts and grafts, as well as insect transmission. Once established, there are no proven methods for slowing or stopping the disease. There are three different varieties of the fungus and the variety that infects Douglas-fir will not infect pines and vice versa. Thus, planting non-host tree species within a disease center is an option.

Recognizing black stain is usually straight forward. It is easiest to diagnose in dying or recently dead trees, but can be difficult to diagnose in trees that have been dead for a few months or more. A progression of tree mortality over time (disease center) is one clue, although individual dead or dying trees are also common, particularly in Douglas-fir. Locate recently dead trees or, even better, nearby trees with thin crowns (fig. 11.28) or yellowing needles. Advanced black stain root disease often causes a well-defined area of resin streaming on the bark surface at the base of the main stem (fig. 11.29).

Figure 11.28 Douglas-firs with advanced crown thinning due to black stain root disease.

Figure 11.29 Resin streaming at the base of the main stem associated with black stain root disease on Douglas-fir.

If the disease is the cause, a characteristic stain will be found in the sapwood beneath (fig. 11.30). Use a long-handled axe to cut into the wood. The stain is dark brown and usually, but not always, resinous. In cross-section, it looks like a blotchy arc that roughly follows the curves of the outer growth rings. In longitudinal-section, it looks like dark brown streaks coming up from the roots. Blue stain (fig. 11.31) is also found in dead and dying trees, but it is bluish grey, usually not resinous, and is radially oriented in cross section. A lack of resin streaming on the bark does not mean that black stain is absent. Checking the sapwood around the base of the tree and on larger roots may still yield stain. Once a tree dies, the invasion of the wood by other microorganisms and insects makes the stain more difficult to recognize.

A  B 

Figure 11.30 Typical stain produced by black stain root disease in the lower stem of a ponderosa pine. (A) In cross-section and (B) longitudinal-section.

Figure 11.31 Blue stain.

Management Options: Reducing the likelihood of disease establishment is the preferred option for plantations that have no evidence of black stain root disease. Studies have shown that the timing of thinning and other disturbances is important to establishment. Thinning during the spring and the months leading up to it create the greatest risk of disease establishment, while summer has the lowest risk. This is because spring is a peak flight period for insect vectors as well as having cool / moist soil conditions which favor infection. Fall and winter have elevated risk because cut or injured host tissues remain fresh and attractive to vectors into spring months.

If seedling survival is expected to be good, it may be desirable to avoid or minimize future thinning by planting at a lower density. On sites that will support it, consider planting non-host tree species or a mix of host and non-host species.

Other Root Diseases

Port-Orford-cedar root disease (POCRD), caused by *Phytophthora lateralis,* and Armillaria Root Disease, caused by *Armillaria spp.*, can both kill young conifers, but are primarily of concern for other reasons. POCRD is a non-native invasive pathogen that is spread via infested soil and water. Port Orford cedar trees are highly susceptible to this lethal disease. Timber operations and other human activities have contributed to disease spread and are primary routes by which long distance spread occurs. Regulations and best management practices designed to prevent the spread of POCRD are available and should be known to all who manage lands with Port Orford cedar.

For the most part, Armillaria root disease is a minor issue in California's conifer forests. This is mainly because the most virulent species of Armillaria do not occur in California. Most observed conifer mortality from the disease has occurred in situations where living, large diameter oaks have been cut adjacent to conifers. The residual oak stumps and roots become a reservoir for the pathogen, which then infects and kills conifers. Mortality is typically limited to the area immediately around the cut oak. Significant mortality was observed in one situation where all oaks were cut with the intent to convert to all conifers. Conifer mortality is less likely when large oaks senesce and die naturally.

Dwarf Mistletoes

Recognition and Significance: Dwarf mistletoes, *Arceuthobium* spp*.,* infect most conifer timber species in California, including species of true fir, pine, spruce, Douglas-fir, and hemlock, but not incense cedar. These parasitic plants rarely kill trees, but can have a profound impact on growth or lead to secondary attack by other insects and pathogens. The greatest impacts occur where site conditions are less than optimal and added stress from dwarf mistletoe further weakens trees.

Recognition of dwarf mistletoe is simple, but it is not unusual for the disease to be overlooked or underestimated by land managers. Branch swelling and formation of witches' brooms (see below) are common symptoms. Dwarf mistletoe plants (fig. 11.32) or their remains confirm the disease. Propagation is by seeds which are forcibly ejected by female plants in the late summer and fall.

Figure 11.32 Female dwarf mistletoe plants on lodgepole pine.

They only go a short distance, tens of feet or less, and have a sticky coat which adheres them to whatever they land on. New infections are thus initiated on the same tree or nearby trees. Birds and animals can transport seeds longer distances. Infection only occurs on young stem tissue, i.e. less than 5 years old, on an appropriate host. Mistletoe growth is initiated within the stem, and plants begin to emerge 2-5 years after initial infection. Swelling (fig. 11.33) of the stem is typical, and older branch infections lead to the development of witches' brooms (fig. 11.34). Plants are small, no more than a few inches tall, green to yellow in color, and sometimes difficult to see. They eventually detach, leaving behind small round structures embedded in the bark called basal cups (another way to confirm the disease). Detached plants often litter the ground beneath heavily infected trees.

Figure 11.33 Branch swelling from dwarf mistletoe on lodgepole pine.

(A)  (B)

Figure 11.34 Witches brooms of dwarf mistletoe in (A) ponderosa pine and (B) Douglas-fir.

Individual infections have a limited effect on the tree and it takes the cumulative impact of numerous infections, acquired over time, to have a significant impact. Disease severity rating is based on the amount of the tree crown that is infected. Infections remain active as long as the infected tissue remains alive. Infections are likely to spread and intensify over time, with stand structure having a significant influence.

Bole infections, which are less common than those on branches, are of additional concern because they can lead to future stem defects. Several aspects of dwarf mistletoe biology are important to disease management: dwarf mistletoe species are highly host-specific, i.e. only one or a few closely related hosts are infected by each *Arceuthobium spp*.; spread of the pathogen is slow; and dwarf mistletoes are obligate parasites that only survive on living hosts.

Single-species, multi-storied infected stands are a worse-case scenario. If young trees are overtopped by infected overstory trees, the chances of infection are high because mistletoe seeds will rain down upon the trees below. Single-species, single-storied infected stands fare better, especially if height growth is rapid. Upward spread of dwarf mistletoe within a tree crown is slow. If no mistletoe seeds are coming from above, this allows fast growing infected trees to outpace this upward spread of the pathogen and thus produce substantial amounts of disease-free crown. A mixture of tree species slows the spread of dwarf mistletoe, but many infected sites are not well suited to grow a mixture of trees or are difficult to regenerate as a mixture.

Management Options: Tree harvest and reforestation practices can greatly influence future levels of dwarf mistletoe within a stand of trees. Infected single-species stands are typically regenerated using even-aged management, i.e. clearcutting, group selection, seed tree, and shelterwood. Complete removal of infected overstory trees prevents the transfer of disease to regeneration; if residual seed and shelter trees are present, these are removed as soon as is practical. The configuration and size of openings can be adjusted to minimize the likelihood of disease entering from adjacent infected stands. Align edges of the opening with natural barriers to disease spread, such as ridges, rock outcroppings, groups of non-host trees, etc. When barriers are absent, larger openings will slow disease spread to the interior of the opening. Thin infected plantations to improve tree growth and maintain a canopy of uniform height. Remove slower growing trees, especially ones with infection.

Mixed conifer stands are less likely to have high levels of dwarf mistletoe. When they do, it usually is in pockets where host trees are concentrated. With minor exceptions, dwarf mistletoe species are limited to a single host genus, and within a genus, they are limited to one or a few species. Pines, Douglas-fir, and true firs all are infected by separate species that will not cross over to another host genus. Ponderosa pine shares dwarf mistletoes with other pine species, but notably does not share a dwarf mistletoe with sugar pine. A single species of dwarf mistletoe infects true firs in California, but different (sub-generic) forms of the mistletoe mean that the pathogen only occasionally spreads between red and white firs. These host differences provide natural barriers to disease spread and can be utilized when harvesting and regenerating mixed conifer sites.

Rusts

White Pine Blister Rust

Recognition and Significance: This non-native invasive disease, caused by the rust fungus *Cronartium ribicola*, is a serious threat to white pines - sugar, western white, whitebark, and limber pines - in California. Resistance to the disease is low. Young trees often are killed, while mature trees may be damaged but survive. The blister rust pathogen requires an alternate host to complete its life cycle and past control efforts were aimed at eliminating a principal alternate host, *Ribes* spp., without success. Currently, efforts by the USDA Forest Service in California are aimed at identifying and breeding resistance in sugar pine, which may be the best option for protecting regeneration. Federal, state, and private land managers cooperate in the program.

As with many pathogens, weather can significantly influence the infection process. Widespread infections typically occur during "wave years" when environmental conditions are favorable, i.e. high humidity in late summer or early autumn. Infection occurs through a needle and progresses to the stem where a canker is produced. Cankers take time to develop, but many will eventually girdle the stem, killing the distal portion of the stem (fig. 11.35). Cankers are spindle-shaped (fusiform) with cracked and sunken bark (fig. 11.36). Bright orange spores may be present within cankers in the spring. Limited numbers of infections may occur most years, but damage from infections that occurred during wave years can be dramatic.

Figure 11.35 Western white pine with upper stem girdled by blister rust.

Figure 11.36 Cankers of white pine blister rust on sugar pine stems.

Older trees are protected somewhat because a high proportion of their stem tissue is not associated with needles and thus can't be infected. Just the opposite is true for young trees. Trees that survive dieback will have evidence of cankers and may have thin, ragged crowns depending on the severity of damage. Young trees can be killed directly by a canker on the main stem, or may die from the cumulative effect of cankers throughout the crown.

Management Options: Except for the extreme southern end of the range of sugar pine, in and south of the Tehachapi Mountains, most of the state's white pines are potentially exposed to the pathogen, although damage has varied across sites. In areas where disease incidence is low to moderate, sanitation thinning and pruning may be beneficial. Target the most damaged trees for removal during thinning. Pruning infected branches from lightly infected trees can improve their chance of survival provided branch cankers are no closer than 4 inches from the main stem. Prune from the bottom of the crown up starting with infected branches. Removal of the lower most non-cankered branches may also be beneficial, but no more than 50% of live branches should be removed overall. Once an infected tree or branch is cut, the pathogen dies as well. Individual trees which show limited, slow, or no disease development relative to other trees in the area may be candidates for resistance testing. For sites where disease has been severe, consider regenerating with non-host tree species.

Western Gall Rust

Recognition and Significance: Western gall rust is a native disease caused by the fungus *Endocronartium harknessii*. It infects many species of hard pines, but is most common on Monterey, lodgepole, and ponderosa pines. Like blister rust, heavy levels of infection occur during wave years and young trees are impacted the most. Mortality, however, is rare and restricted to the youngest trees. No alternate host is needed to complete the life cycle. The disease is most common in areas where moist air favors infection. Some higher levels of disease in ponderosa pine are seen in the northern Coast Range and west side of the northern Sierra Nevada.

Infection occurs on young shoots, producing a persistent, globose gall that gradually increases in size over time. Yellow/orange spores are produced by galls in the spring and early summer (fig.11.37). Branch ends distal to the gall may die, either directly from the expanding gall or from secondary pests that invade it. Infections on the main stem of young trees may persist for years, necrose and be invaded by secondary pests. This produces a weakened, cankerous area on the stem of the mature tree that is subject to failure (fig.11.38).

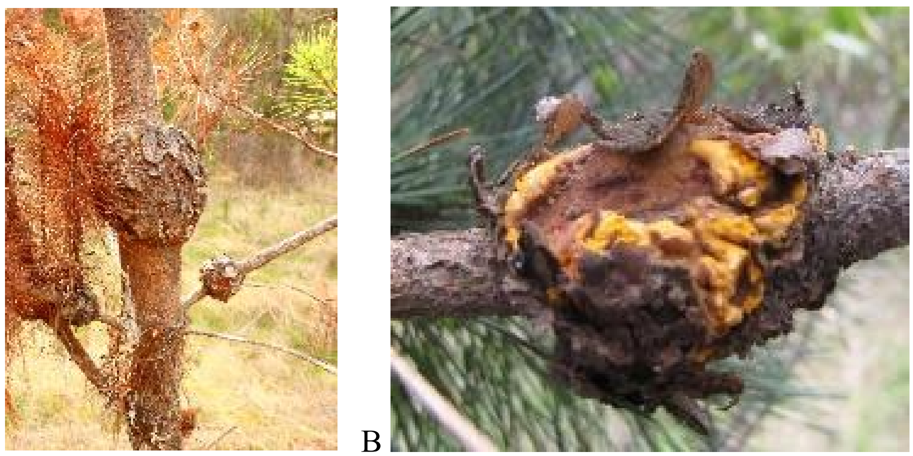
A B

Figure 11.37 Western gall rust (A) on Monterey pine and (B) producing spores on ponderosa pine.

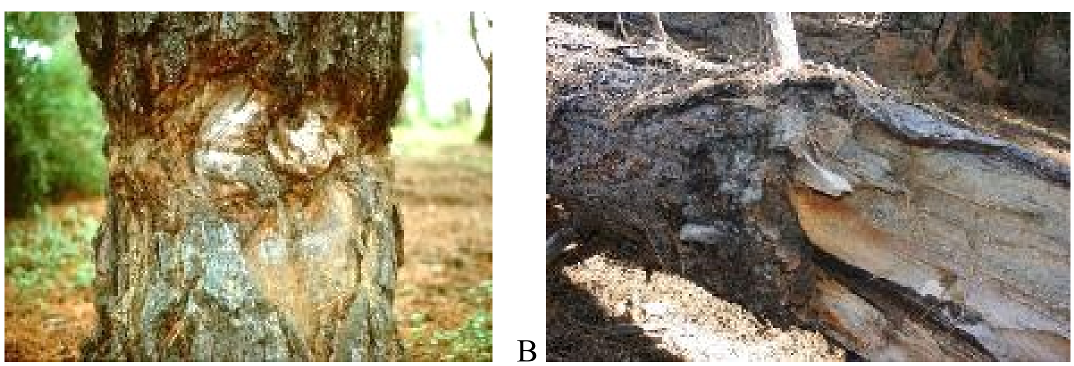
A B

Figure 11.38 Stem infections of western gall rust that occurred when the trees were young and continued to impact the trees throughout their lives. (A) Canker on Monterey pine. (B) Stem failure at an infection site on ponderosa pine.

Management Options: To avoid future impacts, remove young infected trees from plantations, especially ones with high levels of disease or a main stem infection. Consider planting other conifers in areas with high risk for disease (riparian areas, around meadows, and in other areas where moist air collects).

Needle Diseases

Most needle diseases are of minor importance because widespread infection occurs infrequently and impacts a limited complement of needles. Specific environmental conditions are needed for infection and pathogen biology is tuned to take advantage of this, typically during a once-per-year window of suitability. Trees that experience a one year episode of infection and needle loss typically recover well. The youngest trees may be impacted the most, but also would be expected to recover. Recovery may be slower for trees suffering from other stresses. Rarely does widespread infection occur in consecutive years.

There are some exceptions to this scenario. Red band needle blight, caused by *Mycosphaerella pini,* can be particularly damaging to Monterey pine planted on the northern California coast outside of its native range. Another exception is Elytroderma disease, caused by *Elytroderma defomans*. In addition to causing needle loss, the pathogen can persist within branches and result in long term impacts.

Elytroderma Disease

Recognition and Significance: This disease of pines primarily impacts ponderosa and Jeffrey pines. Like other needle diseases and rusts, widespread infection occurs during wave years. Current year needles are infected and die the following year. Widespread fading of these needles in the spring (fig. 11.39A) is what garners the most attention, but unlike other needle diseases, trees that have previously been infected harbor the fungus within branches, buds and growing tips, causing other symptoms and impacts, including poor needle retention, witches' brooms, and reduced growth.

Initial infections are from airborne spores that infect through needles. Once the pathogen is established in a branch, it continues to grow along with the branch and can infect new needles directly. Branch infections thus allow the pathogen to colonize new needles when environmental conditions do not favor airborne infection. These infections also lead to witches' brooms. Internal infections persistent on a branch, but do not spread to uninfected portions of the crown.

Fruiting bodies of the fungus are dull black, elongate structures (fig. 11.39B) that may or may not be present on needles that died in the spring. Witches' brooms are relatively globose, compact, and have up turned branches.

(A)  (B) 

Figure 11.39 Jeffrey pine infected by *Elytroderma* deformans. (A) Needles fading in the spring and (B) with fruiting structures.

In contrast, brooms from dwarf mistletoe are more spread out, have greater branch swelling, and often have mistletoe plants. One of the most useful signs for identifying Elytroderma is the presence of brown necrotic flecks within the inner bark of infected twigs (fig. 11.40). Cut into tissue that is at least 3 years old to see it.

Figure 11.40 Brown necrotic flecks in the inner bark are a sign of Elytroderma disease.

Sites that favor a higher frequency of infection include areas around lakes, in canyons, and north-facing slopes. If mature trees in such areas show symptoms through much of their crown, this indicates repeated infection and high hazard for the disease. Young trees in high hazard areas may experience growth loss, deformity, and have little opportunity for disease-free growth during their life.

Management Options: Tree mortality from Elytroderma disease is unlikely, but may increase susceptibility to other pests. Little can be done to prevent the disease, but removal of highly impacted trees and thinning should improve the growth of residual trees. Offsite pine plantings should be avoided.

Non-host conifers can be favored on high hazard sites. Needle loss can be widespread following wave years, but most trees outgrow the effects of disease on sites where infection frequency is low.

Cankers

A canker is a localized area on stems or branches where the cambium and adjacent bark has died, typically from fungal or dwarf mistletoe infection. Cankers can also be caused by abiotic factors, including weather extremes, fire or mechanical damage. In contrast, the term "canker" is not applied to insect damage.

Fungi that cause cankers are not usually aggressive pathogens, but can be damaging when the host is under stress. They enter susceptible tissues through wounds or other openings in the bark, such as branch stubs. Most canker fungi are restricted to bark and cambium tissue and do not penetrate the wood. As the dead tissue dries and shrinks, it becomes sunken relative to surrounding live tissue (fig. 11.41). Eventually the dead bark is sloughed off and wood may be exposed. Callus forms at the edge of the canker and may close the wound with time, unless the damaging agent girdles the stem or continues to expand. Secondary organisms may colonize the killed tissue.

Figure 11.41 Phomopsis (*Diaporthe*) canker on Douglas-fir.

Canker diseases are not a significant threat to young conifers, but two fungi, *Diaporthe lokoyae* and *Dermea pseudotsugae,* are notable for causing cankers on young, stressed Douglas-fir, especially those stressed by drought. These two fungi can girdle and kill stems. Most damage is limited and repairable by the tree, but the youngest trees may experience significant dieback or be killed. Thinning and vegetation control can help ease drought stress. Chronic dieback of Douglas-fir is a good indication the site is better suited to more drought-tolerant species.

Pitch canker, caused by *Fusarium subglutinans,* sp. *pini*, is an invasive disease primarily restricted to pines growing near the coast. Serious damage has occurred in natural stands of Monterey and Bishop pines, and to a lesser extent knobcone pine. Young trees can be killed outright, while older trees experience dieback and may be killed by bark beetles. Although resistance occurs within native populations and damaged trees can recover, significant impacts still take place, especially in areas where the disease is recently introduced. Visit the Pitch Canker Task Force website (http://ufei.calpoly.edu/pitch_canker/index.lasso) for information on managing the disease and preventing its spread. Although work has been done to develop resistant stock, none is commercially available.

Phytophthora ramorum, the cause of sudden oak death, is another invasive pathogen that occurs near the coast, causing a wide range of impacts on trees and other plant species. Although direct impacts to conifers are minor, the disease has caused significant changes to some native ecosystems. Federal and State quarantines, and a Zone of Infestation established by the California State Board of Forestry and Fire Protection, are designed to prevent disease spread via human activities. See the California Oak Mortality Task Force (COMTF) website at www.suddenoakdeath.org for more information.

Vertebrate Pests

What is a vertebrate? Put simply, it's any animal with a backbone including fish, amphibians, reptiles, birds and mammals. What is a vertebrate pest? A pest can be defined as any organism creating an unwanted condition, i.e. invasive fish eating native fish; a rattlesnake in a wood pile; bird droppings on a park bench; or a roof rat living in an attic. In a forest condition, it usually means an animal or population of animals that is creating an undesirable condition to negatively impact a reforestation outcome.

Vertebrates (wildlife) are a natural, vital and desirable component of a healthy forest. They provide vital functions in dispersing mycorrhizal fungal spores throughout the forest floor (some voles and squirrels); disperse conifer seeds (birds and many rodent species); aerate soil and recycle soil nutrients (pocket gophers); and recycle plant nutrients (ungulates).

However, there are times when, for a variety of reasons, vertebrate populations may inhibit reforestation efforts requiring some level of human intervention to minimize negative impacts. As with any pest management scenario *one size usually does not fit all* situations thus requiring a thoughtful analysis of the impact, a review of management options, and diligence in application and monitoring. The science of Integrated Pest Management (IPM) has emerged since the first printing of this publication back in the early 1970s when most vertebrate pest management strategies focused solely on lethal options calling for the removal of the animal(s). The strategy back then was simply "*no animals….no problem.*" Since then, political and social realities have changed, causing forest managers to address pest management scenarios very differently, resulting in more thoughtful…and challenging…ways to address vertebrate pests.

This section provides vertebrate management strategies for the 21st century as forests and their managers face the reality of increased droughts, wildland fires, urban encroachment, and needs to protect threatened and endangered species.

Pocket Gophers (*Thomomys* spp.)

There are five recognized species of pocket gophers in California:

- Mountain pocket gopher (*Thomomys monticola*) occurs in the Sierra Nevada above 5,000' from Fresno County north to Shasta and Lassen Counties.
- Western pocket gopher (*T. mazama*) found in wet meadows and grasslands of the Klamath and western Cascade Ranges.
- Northern pocket gopher (*T. talpoides*) occurs from Mono County north into Alpine, eastern Sierra, eastern Plumas, Lassen, Modoc and eastern Siskiyou counties where it is abundant in juniper habitats.
- Townsend's pocket gopher (*T. townsendii*) found only in the western portion of Honey Lake Valley in alkali desert shrub.
- Botta's pocket gopher (*T. bottae*) is by far the most widely distributed pocket gopher species in California occurring in all habitats except the eastern Sierra Nevada and portions of Lassen, Modoc and Siskiyou counties above 5,000'. This species is responsible for most damage caused to both agricultural and forest trees. Optimal habitats are perennial meadows, and grass and forb stages of most riparian deciduous and conifer forests. They are less common in mature stages of forest habitats. The focus on this portion of the chapter will be on Botta's pocket gopher.

Pocket gophers (fig. 11.42) are so named because of the fur-lined, external cheek pouches used to carry food back to their cache. They are herbivorous, feeding mainly on roots, tubers, bulbs, stems and leaves of forbs and grasses. They can and do damage young forest conifer seedlings (fig. 11.43). They prefer to forage from underground tunnels where they can chew on roots in tunnels and may pull entire plants into the tunnel (fig 11.44). During winter they build surface tunnels above the ground through the snow to forage.

Figure 11.42 Pocket gopher.

Figure 11.43 Pocket gopher damage.

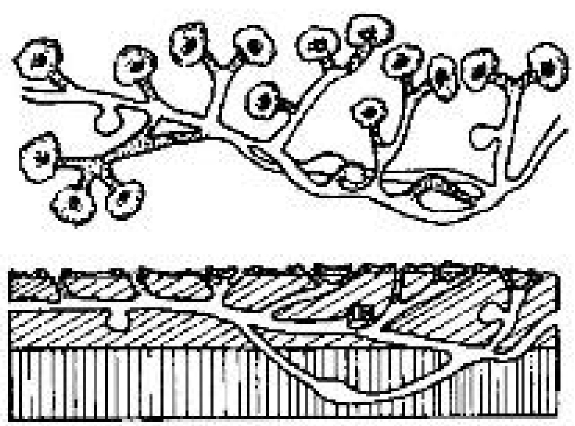

Figure 11.44 Example of a pocket gopher burrow system.

Reproduction and Life Traits: Pocket gophers nest in their burrows with deep chambers excavated for nurseries (females only). Litters are born in the spring with juveniles dispersing and expanding their tunnel systems. Males are larger than females. Males grow throughout their lives, whereas females stop growing after their first pregnancy, so older males can be much larger than females. Pocket gophers live in small, local populations, spending almost their entire lives underground in their network of burrows (fig. 10.44). Pocket gophers are solitary animals that defend their tunnels from marauders from intersecting tunnel systems in search of food. Consequently, each tunnel has one resident animal (except when a female is rearing her young) at a time. Pocket gophers do not hibernate and are active throughout the year.

Symptoms, Signs and Significance of Damage: The greatest risk to conifers from pocket gopher feeding damage occurs in the early stages of reforestation when the trees are at their smallest stage. Gophers will eat the roots and main stems of seedlings leaving the tops dead. During winter months, they strip twigs and bark from tree parts buried in snow. After snow melt, long winding strips of soil on the surface show where pocket gophers had tunneled and backfilled with soil. They often kill trees in the first three years of planting and in severe cases can affect the stand's ability to achieve regulatory stocking standards.

Management Options: Like all pest management strategies, diligence is required to detect and monitor pocket gopher activity centers. Addressing a *potential* problem often results in less time, energy and costs being needed to resolve the problem later.

There are few viable, non-lethal options to address pocket gopher damage to conifers. Fencing, both above and below ground, has not proven effective in minimizing damage as gophers can dig beneath, and climb over, most fences. Live trapping pocket gophers only results in moving the problem to a new location.

Lethal options include 1) predator attraction; 2) trapping; 3) toxic baits; and 4) fumigants.

1. Predator attraction can be achieved by leaving or providing structure adjacent to the planting site. Trees, artificial perches and snags can provide sites from which predatory birds can hunt for gophers. However, once a predator captures and consumes a gopher its dietary requirements will be addressed for some time until the animal needs to hunt again. Though predators will eat pocket gophers, they most likely will not achieve economic control without the aid of other management options.

2. Trapping is an effective way to reduce populations while simultaneously monitoring efficacy. Trapping is only effective if the effort is given the time required to: 1) place sufficient number of

traps per unit area to capture many animals simultaneously; 2) check the traps daily; and 3) relocate a trap to another burrow after an animal has been captured.

3. Toxic baits provide a relatively time conserving approach to covering large areas, but do not provide as quick and direct an evaluation of efficacy as does trapping. Toxic baits are placed underground in active burrows and are reliant on the animal consuming ample amounts to deliver a lethal dose. Bait acceptance can be affected by the composition of the bait, age and freshness of the bait, and soil moisture which can be absorbed by the bait causing it to dissolve or mold.

4. Fumigants can be effective if used properly. Soils need to contain some moisture to minimize venting of fumigant gases through soil pores; since pocket gophers do not hibernate, fumigants may prove useful throughout the year if soil conditions are right. Several types of fumigants are available:

    - Incendiary devices (smoke bombs, flares) often release sulfur gas, asphyxiating an animal below ground. Caution needs to be exercised during dry months when grasses may ignite.

    - Carbon Monoxide gas has been legal to control fossorial (below ground) pests since 2012. Both commercial and self-designed devices have been developed to deliver CO gas to burrows.

    - Aluminum Phosphide tablets are a Restricted Materials Pesticide requiring a permit from the County Agricultural Commissioner. A training certificate from the manufacturer or distributor often is required before the permit is issued.

Voles (Clethrionomys spp., Phenacomys spp., Microtus spp., Lemmiscus spp.)

There are 10 recognized species representing 4 genera of "voles" in California. The 5 species affecting regeneration efforts are all members of the *Microtus* genus and are found regionally throughout the timber growing regions of California.

Voles are stubby bodied mice with tails shorter than their head and body. They have small, rounded ears, live in burrows (fossorial) but all their forage activities take place on the surface. Unlike pocket gophers, vole burrow entrances are never closed and several burrow openings are often found near each other. Burrow openings are about the size of a golf ball.

Reproduction and Life Traits: Voles, differ from pocket gophers in that they are highly social animals comfortably sharing space with their own kind. Nests are constructed of grasses below ground with breeding generally occurring in spring months between April and May, although the breeding seasons of some southern populations extends into the summer months. Litter sizes average 4-5 young and some populations can have multiple litters in a year. Gestation is generally about 21 days. Females can reach sexual maturity in 30 days. Densities can achieve extremely high numbers in optimal habitats. Voles are crepuscular, meaning their daily rhythms are tied closely with dawn and dusk. Populations usually begin to increase with the first rains in autumn, peaking in the spring when grass growth is greatest. Voles do not hibernate.

Symptoms, Signs and Significance of Damage: Voles generally prefer grassy habitats. Grass management is a key component in addressing vole population fluctuations. Seedlings planted in heavy grass cover in the presence of voles are at risk of feeding to the lower trunks where the damage often goes undetected until the seedling begins to fail (fig. 11.45). Field grown seedlings in the absence of grass control are at risk of being heavily impacted by voles (fig. 11.46), often resulting in a major crop loss. If damage occurs in the winter the signs can go unnoticed until the plants are lifted.

Figure 11.45 Vole damage on coast redwood.

Figure 11.46 Redwood mortality from vole damage.

Management Options: Grass and other herbaceous management around seedlings is key to monitoring and evaluating vole damage. Voles are small, secretive animals susceptible to predation from birds of prey, foxes, mustelids and coyotes. They are not comfortable feeding in an exposed area. Creating a weed-free zone around a seedling is an important consideration when trying to minimize feeding damage.

Trapping: is a useful method of determining vole presence and abundance but may have limited application over a large area. Snap traps can be set (unbaited) perpendicular across the paths leading away from burrow openings. Voles are highly restricted to movements within their pathways and will simply blunder into a set trap.

Toxic baits: are the most often used means of achieving population control. The common toxicant used is Zinc Phosphide applied on a grain bait. Pre-baiting (using an untreated grain bait) is highly effective in preconditioning voles to bait sites. Once the pre-bait has been consumed, replacing it with toxic bait can achieve very high efficacy while minimizing the chance of non-target impacts by limiting the time toxic bait is exposed to the environment.

Exclusion: Vexar™ tubes and TreeShelters™ are effective deterrents in field applications. To improve effectiveness of the tubes they must be positioned tightly to the ground to prevent voles from going underneath and reaching the seedling.

Predator attraction can be achieved by leaving or providing structure adjacent to the planting site. Trees, artificial perches and snags can provide sites from which birds of prey can hunt for voles. However, once a predator captures and consumes a vole its dietary requirements will be addressed for some time until the animal needs to hunt again. Though predators will eat voles, they most likely will not achieve economic control without the aid of other management options.

Rabbits and Hares

Rabbits and hares are members of the Order Lagomorpha distinguished from rodents by having a double set of front incisor teeth, one behind the front. Rabbits are burrowing animals, born in an altricial state (helpless at birth, fully dependent on the mother, much like puppies and kittens). Hares do not use burrows, are born above ground in a precocious state (eyes open) able to leave the nest within days of being born.

There are eight species of Lagomorphs found in California. The Pika (*Ochotona princeps*) is not discussed in this chapter. There are four species of true rabbits, often called cottontails (*Brachylagus* sp., and *Sylvilagus* spp.), and three species of hares (*Lepus* spp., Snowshoe hare (*L. americanus*), White-tailed jackrabbit (*L. townsendii*), and Black-tailed jackrabbit (*L. californicus*).

True rabbits are not often associated with extensive damage in forestry restoration as they are closely associated with briar patches and other heavy cover, never straying far from cover. Hares on the other hand are very mobile and wide ranging.

Reproduction and Life Traits: Female hares can have up to four litters per year with two to eight young per litter under optimal habitat conditions. Daily movements up to 2 miles are common when food and shelter resources are separated. Rabbits and hares are active day and night, though true rabbits tend to be crepuscular, and neither rabbits nor hares hibernate.

Symptoms, Signs and Significance of Damage: Foliage and twigs of seedlings and young trees are eaten (fig. 11.47). Rabbit feeding can be distinguished from deer browsing as rabbits turn their heads when biting a seedling leaving a distinctive 45° angle clean cut. Bark can be stripped from seedlings and shoots and stems. Hares can have severe impacts to young plantations and seedlings. Small trees can be completely consumed and stripped bark often leads to the death of the seedling.

Figure 11.47 Rabbit damage.

Legal Status: Rabbits and snowshoe hares are considered small game mammals in California with a set season and bag limits requiring a hunting license to legally take rabbits. Jackrabbits may be taken all year and there is no daily bag limit.

Management Options:

Exclusion: Vexar™ tubes and TreeShelters™ are effective deterrents in field applications. To improve effectiveness, tubes must be positioned tightly to the ground and checked regularly to insure proper positioning.

Shooting and Hunting: This method may have applications in forestry settings and can control localized populations. Hunting regulations must be consulted when using this method for rabbits.

Repellents: A number of commercially available chemical repellents are available, but little efficacy data exists for forestry applications.

Toxic baits: There are no toxic baits currently registered in California for use on rabbits or hares.

Porcupine (Erethizon dorsatum)

The porcupine (fig. 11.48), like the beaver, is a large rodent. Once abundant, their numbers have plummeted in the state over the past 30 years for unknown reasons. Its historical range included all the Sierra-Nevada, the Cascade Range and much of the Coast Range. Recent studies have shown that it is now uncommon at elevations below 6,000'. The porcupine is arguably one of the most recognizable animals in the forest.

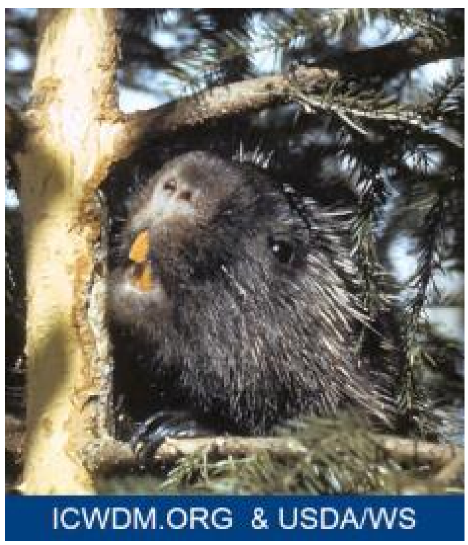

Figure 11.48 Porcupine.

Reproduction and Life Traits: Porcupines den in caves, crevices in rocks, cliffs, hollow logs, snags, and burrows of other animals. They are primarily nocturnal but can be seen in daylight. They are active all year and do not hibernate. When ambient temperatures become very cold (below 9°F), they become lethargic and limit their activity to a single tree. They mate in fall or winter with a gestation of seven months. The usual litter size is one, rarely two. Females are attentive and juvenile mortality is considered low. Porcupines have been documented to live up to 10 years.

Symptoms, Signs and Significance of Damage: Pole-size timber is at the greatest risk from porcupine feeding damage (fig. 11.49). Pines (Ponderosa and Jeffrey) are preferred species, but they will feed on aspen, cottonwood and willow. They will feed on herbaceous plants, inner bark, twigs and leaves of host plants. Tooth marks often indicate porcupine feeding, and bark and wood chips can often be found at the base of a tree being fed upon by porcupines. The tops of pines are often killed, especially in winter months when an animal may limit its movements to a single tree or cluster of trees. Porcupine damage in young, open stands and plantations can be significant if left unchecked. Top-killed trees result in abnormal growth patterns affecting timber values.

Figure 11.49 Porcupine damage.

Management Options: Historic methods of using above ground, strychnine-laced salt blocks to reduce porcupine populations is no longer legal. Use of toxicants requires consultation with the local Agricultural Commissioner or the USDA Wildlife Services prior to use.

Tracking and shooting: During winter months when snow is on the ground porcupine tracking is an effective, albeit time consuming, method of finding individual animals roosting in trees. Where legal, shooting is one method of population reduction.

Exclusion: Porcupines do not jump from tree-to-tree like squirrels. Trunk guards and wraps are effective in limiting the ability of porcupines to climb trees.

Predation: Porcupines are susceptible to predation from mountain lions, bobcats and fishers. Fishers, in particular, are adept at preying on porcupines and have been shown to reduce populations in some areas.

Ground Squirrels

There are *at least* 23 species of ground squirrels in California. These include marmots, ground squirrels (California, Belding, antelope, and golden-mantle), and chipmunks. Fortunately, only a few species can be a problem in reforestation efforts.

Reproduction and Life Traits: Ground squirrels (fig. 11.50) are diurnal, social animals often living near their cohorts sharing burrows and food resources. All ground squirrels hibernate. This means that they are in their burrows during winter months and population surveys can easily under-estimate numbers. Burrows are obstructed (plugged) below ground when the animals are hibernating and are difficult to control during this time.

Figure 11.50 Ground squirrel.

Following hibernation, ground squirrels emerge from their burrows and establish and defend breeding territories. It is during this time that they are most active and visible to help determine population distributions and densities. Young are born and tended below ground in a nursey chamber of the burrow. Litter sizes can vary between 5-8 young, with young emerging from the burrow at about six weeks of age. By six months of age, young resemble the adults.

Symptoms, Signs and Significance of Damage: Damage by ground squirrels was a problem when reforestation used aerial seeding, as the conifer seeds where readily eaten by squirrels and other rodents. With the shift to planting seedlings for reforestation, damage by ground squirrels is limited to a few species. These include:

- California ground squirrel (*Otospermophilus beecheyi*);
- golden-mantled ground squirrel (*Callospermophilus lateralis*); and
- Belding's ground squirrel (*Urocitellus beldingi*) with the golden-mantle considered the most potentially destructive to conifer seedlings.

Damage is non-descript and variable with newly planted seedlings being most at risk from direct feeding (clipping) to the terminal or lateral roots, or from complete loss of the seedling. Some forest managers have observed that the seedling planting soil matrix can attract feeding by golden-mantle squirrels. It therefore may be worth investigating this with the nursery of origin.

Golden-mantle squirrels generally benefit from moderate timber harvesting that opens the canopy and allows greater production of food. Seedlings would be considered another food source in such a scenario.

Management Options: Since ground squirrels hibernate, all management options attempting population control must be during times of activity (March – September).

Exclusion: Vexar™ tubes and TreeShelters™ are effective deterrents in field applications. To improve effectiveness tubes must be positioned tightly to the ground and checked regularly to insure proper positioning.

Trapping: Snap traps and Conibear Model 110 (for the larger California ground squirrel) traps can be effective in controlling ground squirrels. Traps need to be set during daylight hours, leaving traps after dark increases capturing non-target predatory species.

Toxic baits: The common toxicant used is Diphacinone applied on a grain bait. Pre-baiting (using an untreated grain bait) is highly effective in preconditioning ground squirrels to bait sites. Once the pre-bait has been consumed, replacing it with toxic bait can achieve very high efficacy while minimizing the chance of non-target impacts by limiting the time toxic bait is exposed to the environment. Using home-made or commercially available bait stations is an effective way of minimizing exposure to non-target species. Baits are best accepted by ground squirrels late in the summer when their dietary focus shifts to seeds.

Fumigants: can be effective if used properly. Soils need to contain some moisture to minimize venting of fumigant gases through soil pores; since ground squirrels hibernate, fumigants are only effective after the animals awake from hibernation. Several types of fumigants are available:

- Incendiary devices (smoke bombs, flares) often release sulfur gas, asphyxiating animals below ground. Caution needs to be exercised during dry months when grasses may ignite.
- Carbon Monoxide gas has been legal to control fossorial (below ground) pests since 2012. Both commercial and self-designed devices have been developed to deliver CO gas to burrows.
- Aluminum Phosphide tablets are a Restricted Materials Pesticide requiring a permit from the County Agricultural Commissioner. A training certificate from the manufacturer or distributor is often required before the permit is issued.

Shooting: Where safe, shooting can eliminate a small number of animals. It is often time consuming and efficacy is dependent on the skill of the marksman.

Tree Squirrels (Sciurus, Tamiasciurus, and Glaucomys)

The western gray squirrel (*S. griseus*), the Douglas squirrel (chickaree) (*T. douglassii*) and the northern flying squirrel (*G. sabrinus*) are the three native species of tree squirrels found in California's forests. Of these, the western gray and Douglas squirrels can damage conifers.

Reproduction and Life Traits: Tree squirrels are diurnal (except for the flying squirrel which is nocturnal). Tree squirrels **do not** hibernate and remain active throughout the year. Whereas ground squirrels will climb trees, tree squirrels **never** go below ground. Tree squirrels are primarily herbivorous, feeding on conifers, seeds and fruits, and fungi. They will cache food for eating during winter months. They forage in trees or on the forest floor. Tree squirrels nest in abandoned woodpecker cavities, snag cavities or make a nest of branches lined with bark, grass, lichens and moss. Young are born between March and June, with one litter of 3-5 per year.

Symptoms, Signs and Significance of Damage: Tree squirrel feeding and associated damage is most often near the top of pole and saw-log sized trees. Douglas squirrel feeding in seed orchards can be a problem if feeding is heavy and the seed cones are eaten. In winter months, tree squirrels often feed on and remove the tips of lateral branches. Generally, this is not considered a long-term impact to the tree and is not considered a negative impact to reforestation efforts.

Tree squirrels have been known to kill the tops of pines and coast redwoods. This feeding behavior often happens in the spring when sap flow is high. Bark is removed and feeding impacts the cambium. It's not clear if bark is also removed for nest building during this time. Impacted trees are not killed, but the damage can affect log quality and can lead to secondary pest problems (pine). The economic impacts from squirrel damage are not well documented in California as the damage is often localized and transient.

Legal Status: Tree squirrels are considered small game mammals in California with a set season and bag limits requiring a hunting license to legally take them. California Fish and Wildlife regulations should be consulted prior to taking tree squirrels.

Management options: Given their legal status few management options are available in forestry to control squirrel populations:

Toxicants – None are registered

Fumigants – None are registered

Trapping – Live or kill trapping is not allowed under California law.

Shooting – Under appropriate hunting statutes tree squirrels may be legally taken by shooting during the defined hunting season.

Silvicultural options – younger stands are at greatest risk from squirrel damage. If damage is occurring and limiting regeneration efforts, concentrating control measures in these stands may lessen the threat.

Woodrats (Neotoma fuscipes)

Of the three species of woodrats found in California, only the dusky-footed woodrat may be of concern to coastal forest managers. Found primarily in the coast redwood – Douglas-fir belt of coastal California and foothills of the Sierra Nevada, the species has been known to damage regeneration efforts in coast redwood stands. They are mostly nocturnal.

Reproduction and Life Traits: Woodrats feed on woody plants, fungi, flowers, grasses and acorns. They prefer moderate canopy cover and are often abundant in chaparral habitats. Nests are constructed of sticks in or at the base of a tree. Woodrats breed from December to September with peak breeding in the spring. Woodrat populations have been shown to be highest in coastal redwood stands between 15-30 years old. They are considered a primary prey species for northern spotted owls (*Strix occidentalis)* in coast redwood forests.

Symptoms, Signs and Significance of Damage: Woodrat feeding damage is often seen within the clumps of sprouting coast redwoods (fig. 11.51) or on the terminal leader of redwood saplings. They have been known to remove the outer bark for nest material without exposing or removing the sapwood. Damage within stands is often sporadic and unpredictable. Stands become less attractive, and consequently less populated by woodrats after 30 years.

Figure 11.51 Woodrat damage to a clump of redwoods.

Management options:

Toxicants – Given the importance as prey for spotted owls, consult the local Agricultural Commissioner prior to any use of toxic baits.

Fumigants – None are registered

Trapping – The use of snap traps may be effective at a single sight, but is not generally considered effective in a larger forestry context.

Shooting – Given that woodrats are nocturnal, shooting is not considered an effective control method.

Silvicultural options – younger stands are at greatest risk from woodrat damage. If damage is beyond economic thresholds re-examining silvicultural practices may be the best option.

Mountain Beavers (Aplodontia rufa)

Mountain beavers (fig. 11.52), AKA "mountain boomers", and "sewellel beaver", "ground bear", and "giant mole" are considered the oldest type of rodent in North America. Found throughout the Cascades, Klamath and Sierra Nevada ranges and sporadically along the coast range. They are often found near water and need soft, friable soils to construct underground burrows. They will feed on thimbleberry, salmonberry, lupines, willows, ferns and young conifers. They will cache food in their burrows.

Figure 11.52 Mountain beaver.

Some populations of mountain beavers are afforded special protections in California. Consult with the local Agricultural Commissioner prior to initiating any management measures with this species.

Reproduction and Life Traits: Mountain beavers do not concentrate their urine and require large daily intakes of water. They do not hibernate and are active throughout the year. They are non-migratory and sedentary. They will defend their burrows but territories will overlap and most activity occurs relatively close to the burrow. Mountain beavers breed from December through March with the peak in February. Litter size varies between 2-3 young with females not reproductively active until their second year.

Symptoms, Signs and Significance of Damage: Mountain beavers are known to damage young seedlings. Damage can be heavy and severe in Douglas-fir plantations where mountain beavers will select lateral and terminal branches on the seedlings, saplings and pole trees. Lateral and terminal branches have been damaged up to 10'. Basal girdling and under-mining of tree roots from burrowing can occur in young stands.

Management options:

Exclusion: Vexar™ tubes and TreeShelters™ are effective deterrents in field applications. To improve effectiveness of the tubes they must be positioned tightly to the ground to prevent mountain beavers from digging below or climbing over and feeding on the tree. Depending on the size of the seedling being impacted, tubes up to 30" may need to be considered.

Trapping: Conibear Model 110 traps set (un-baited) in the entrance of the burrow can be used to catch mountain beavers.

Toxic baits: Consult with your Local Agricultural Commissioner to determine if this is a legal management option.

Fumigants: Consult with your Local Agricultural Commissioner to determine if this is a legal management option. Fumigants can be effective if used properly. Soils need to contain some moisture to minimize venting of fumigant gases through soil pores; since mountain beavers do not hibernate, fumigants may prove useful throughout the year if soil conditions are right. Several types of fumigants are available:

- Incendiary devices (smoke bombs, flares) often release sulfur gas, asphyxiating an animal below ground. Caution needs to be exercised during dry months when grasses may ignite.
- Carbon Monoxide gas has been legal to control fossorial (below ground) pests since 2012. Both commercial and self-designed devices have been developed to deliver CO gas to burrows.
- Aluminum Phosphide tablets are a Restricted Materials Pesticide requiring a permit from the County Agricultural Commissioner. A training certificate from the manufacturer or distributor often is required before the permit is issued.

Ungulates (deer, elk, livestock)

A variety of wild and domesticated ungulates are found throughout the forests of California. Most are sedentary and non-migratory (except for some eastern mule deer populations) and can have repetitive impacts on forest regeneration efforts. Domestic species include cattle, horses, sheep and goats, while wild ungulates in a forest setting are restricted to deer and elk. Cattle, elk and horses are grazers while deer, sheep and goats tend to be more omnivorous browsers. Deer and elk population densities are set by the carrying capacity of the habitat and are present throughout the year; while livestock densities can be arbitrary and seasonal.

Legal Status: Deer and elk are game species with strict harvesting restrictions. Depredation permits can only be authorized by the California Department of Fish and Wildlife. Livestock are private property under the control of the owner.

Symptoms, Signs and Significance of Damage: Ungulates are big animals that can eat up to 3% of their body weight in a day. Damage can be from direct feeding to lateral and terminal buds, rubbing from antlers (fig. 11.53) or other body parts (cattle), or trampling. Deer can reach terminal branches up to 5', while elk can reach even higher; horses and goats can remove bark from trunks. Damage can be localized and severe depending on density and duration of the grazing or browsing pressure.

Figure 11.53 Deer antler rub damage.

Management options:

Exclusion: Vexar™ tubes and TreeShelters™ are effective deterrents in some field applications. Depending on the size of the seedling being impacted, tubes up to 30" may need to be considered. Tubes may be useful for deer and smaller ungulates, but are not considered effective for larger animals such as elk, cattle or horses. Fencing may be needed to exclude larger animals for a period of time until the regeneration effort grows beyond their reach.

Repellants: though commercial repellants are available, their utility in forestry operations is limited by the need for constant application. Some products are packaged in small bags or pouches to hang on the tree, but their effectiveness has not been substantiated in the scientific literature.

Behavior modification: Livestock can be conditioned to avoid sensitive areas by placing salt blocks, mineral supplements, and water sources away from the area needing protection. Placing "rubbing posts" away from planted areas can condition livestock to seek out alternative sites for scratching and rubbing.

Bears (Ursus amercicanus)

The American black bear is widely distributed in forested regions throughout the state and is the only species of bear found in California. Though the name implies a single-color variation, the "black" bear can be black, brown or "cinnamon" in color.

Reproduction and Life Traits: Black bears are omnivorous. They will readily feed on grasses, forbs, fruit, nuts, carrion and will prey on living animals. They tend to be seasonal specialists feeding on grasses, forbs, and insects during the spring, berries in the summer and acorns and fish carrion in the fall. They have been known to kill adult deer, and livestock. Young are born in winter dens in January and February. Young will stay with the female for at least 1.5 years, with individuals living up to 25 years in the wild.

Legal Status: Black bears are game species with strict harvesting restrictions. Depredation permits can only be authorized by the California Department of Fish and Wildlife.

Symptoms, Signs and Significance of Damage: Bear damage usually occurs during the later spring months prior to the emergence of summer fruits. This is a time of year when bears are losing weight and lactating females are under stress caring for their young. Bear feeding removes the bark of coast redwoods (fig. 11.54), Douglas-fir and Port-Orford cedar, exposing the cambium which is scraped with the canine teeth. Damage is often associated with roads, but damaged trees can be found randomly in a stand. Feeding is initiated by increased spring sap flows and is often associated with pre-commercial thinning (PCT) activities which further increases sap flows. Feeding is often initiated by females in search of food to meet their lactating energy demands, thereby exposing her young to the behavior. Trees are often "tested" and not fed upon, only to be revisited later in the season when resin flows have increased. Damage can be localized, sporadic, minor or severe. Stands experiencing bear feeding damage often share similar characteristics. Cohorts are often even-aged stands, between12-20" dbh (fig. 11.55), have been pre-commercially thinned, and have good road access.

Figure 11.54 Bear damage.

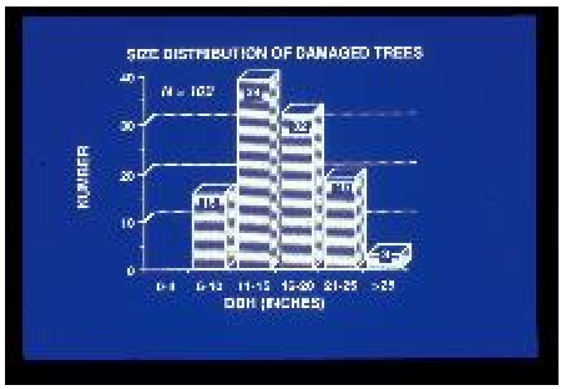

Figure 11.55 Amount of bear damage varies by tree diameter.

Management options:

Silvicultural practices: Long-term transition to alternative silvicultural treatments, even-aged to uneven-aged, may make stands less attractive by abandoning the need for PCT. Though anecdotal evidence suggest that stands above 160 ft^2 basal area may be less susceptible to bear feeding, that has not been validated through long-term studies.

Hunting: Areas targeted for recreational hunting can reduce bear numbers during the authorized hunting season.

Alternative foods: Though not currently allowed in California, research in Washington State has demonstrated some success using alternative food sources (sugar-wood pellets) during the time of year when bear damage is predicted to occur.

Abiotic Damage

Abiotic damage is caused by non-living, non-infectious agents that physiologically or physically impact a plant. Abiotic damage can result from a broad range of interacting host and environmental conditions, either natural or human-induced, that are often only partially understood. Weather events and climatic conditions (e.g. hail, frost, drought) produce the most common abiotic damage seen in forest plantations. In situations where best management practices are followed, extreme or uncommon conditions are typically needed to produce damage. Extreme is a relative term because it depends on what is extreme for a given site, time of year, tree species, or genetic stock. It may relate to abnormal highs or lows, how quickly conditions change from one to the other, how long adverse conditions persist, or the influence of coincidental factors.

Diagnosis of abiotic damage is complex and may require making some subjective determinations with respect to changes in the environment and their possible effects. Confirmation of certain abiotic damage (i.e., road salt and mineral deficiencies) may require laboratory analysis. An excellent resource for identifying abiotic damage is the USDA Forest Service Agricultural Handbook No. 521, Diseases of Pacific Coast Conifers, available on-line. The possible permutations of abiotic damage mean that not every situation will fit a text book description. Often the event or condition that produced damage is not directly observed and it may be necessary to review records of past events to identify likely causes. Conversely, cause and effect may be relatively simple to deduce, such as with the pattern of wounding that is caused by hail.

An important aspect of diagnosing abiotic damage is recognizing that the damage is not caused by a biotic agent. In general, damage caused by abiotic factors tends to be more uniform, non-specific and widespread. For example, damage caused by freezing temperatures can affect multiple tree species in a similar way across an elevational band or geographic feature. Note that symptoms of biotic and abiotic damage can overlap, and secondary organisms can enter damaged tissue. It is useful to learn the signs and symptoms of the most common and significant causes of biotic damage so that these can be looked for. Confirming their absence is a strong case for abiotic damage. When secondary organisms invade damaged trees, their presence is often inconsistent. Sometimes they are present, other times not, or different organisms may be present on different trees.

In many situations, abiotic damage is the result of an unusual event with a low probability of reoccurrence. It may be a learning experience that influences future management decisions, but otherwise cannot be mitigated directly.

Drought

Drought is a reoccurring feature of California's Mediterranean Climate that impacts conifers of all types and ages. The extent of damage depends on the severity and length of drought. Impacts can be particularly severe on young trees, which have less well developed root systems. Damage often is concentrated in drier locations, but is also influenced by host genetics, microsite (e.g. local areas of shallow soil), or even planting irregularities. Reduced moisture availability also increases the susceptibility of trees to insects and diseases. Damage and mortality of drought-stressed trees is often attributed to insect pests, but with the youngest trees the role of insects may be minimal compared to the direct effects of drought. Stocking control and control of vegetation that competes with young conifers for water is the single most important action that can be taken to improve tree survival.

Drought also suppresses growth. Visible manifestations are reduced height and shoot growth, shorter than normal needles, and if several years of needles are present, the premature loss of older needles (fig. 11.56). The crowns of chronically stressed trees develop a characteristic thin appearance due to poor growth and needle retention. Severe or chronic drought may also lead to shoot and top dieback.

Figure 11.56 Premature shedding of older needles on incense cedar due to drought stress.

Drought can interact with other factors to produce increased levels of damage. In spring of 2003, young incense cedar exhibited dieback and mortality over a large area of northern California and southern Oregon. The damage was speculated to be the result of both drought and a sudden shift to unusually low temperatures in late October of 2002. The classic example of increased damage occurs when drought-stressed conifers are killed by bark beetles such as the western pine beetle, Ips species, and fir engravers (see insect section).

Hail

Foliage and smaller diameter stems are directly injured by the impact of hail. Young tissue is particularly susceptible. Damage occurs on many different plant species, but can vary significantly by species. Douglas-fir is more susceptible than other conifers. Look for scattered spots of tissue bruising or wounding on the upper sides of foliage and branches (fig. 11.57). Damage can be heaviest on one side of the crown and main stem depending on the direction and intensity of wind-driven hail. Needles may be lost. With heavy damage, spots of injury will coalesce and shoots and tops may be weakened or killed (fig. 11.58). Crown dieback can affect tree growth for many years after injury. Lighter damage may not immediately be apparent, but become more obvious as tissue dies and calluses.

Figure 11.57 Partially healed wounds from hail damage on sugar pine.

Figure 11.58 Dieback in the crown of a sugar pine damaged by hail.

Frost

Damage from frost is most likely in the spring. It occurs when new tissues are exposed to unusually late below-freezing temperatures. Damage can vary from one tree to the next based on species, how much new growth is exposed, and position on the landscape. Damage often is restricted to cold air sinks or "frost pockets." Classic spring frost damage kills most new growth on a young tree (fig 11.59). Larger trees respond with additional new growth and recover well, while seedlings and small trees are at risk of significant dieback and mortality because of their small size and higher ratio of new to old growth. Although less common, damage can also occur in the fall when the current year's growth has not yet been conditioned to the coming cold season.

Figure 11.59 New shoots and needles of Douglas-fir damaged by spring frost.

Prevention is the best means of avoiding frost damage. When establishing a plantation, it is important to recognize frost pockets and avoid planting trees unlikely to survive there. Douglas-fir planted on the eastern edge of its range in the Cascade Mountains of northern California has suffered frost damage in these situations. Utilize planting stock from the appropriate seed zone.

Winter Needle and Shoot Desiccation

This type of injury can be caused by a variety of winter conditions that promote the drying of foliage and sometimes stems, with inadequate uptake of moisture by the roots to replace what is lost. A common form of this damage is referred to as "red belt" because it occurs in a distinct band or belt on the landscape that follows an elevation contour. It occurs when a temperature inversion causes affected trees to be exposed to warm daytime air while the soil is too cold for water uptake. Another situation that can lead to desiccation is a low or non-existent mid-winter snow pack, due to drought, at elevations were young trees would normally be covered by snow. Foliage is exposed to sun and wind while roots and soil remain cold.

Milder cases of desiccation result in needles browning from the tip downward (fig 11.61). Once new growth begins in the spring, older, damaged needles are retained or lost, depending upon the amount of necrosis (browning). If needles dry completely, shoot tips may also be impacted. Mild desiccation is primarily cosmetic. Trees with partially brown, desiccated needles can appear dead (fig. 11.60), but closer inspection of foliage and shoots should reveal that they are still alive. Such trees "green up" when new growth begins in the spring. However, severe desiccation of young trees can cause dieback and mortality.

Figure 11.60 Ponderosa pine with winter needle desiccation commonly referred to as red belt.

Herbicide Damage

Best management practices for herbicide use are covered extensively in this manual. Following these practices provides insurance against damage from herbicides, but not a guarantee. Damage may be due to an error made during herbicide application or perhaps some unrecognized host or environmental condition. Symptoms of herbicide damage vary with the type and amount of herbicide used and include distortion and dieback of shoots, and twisting, stunting, discoloration, desiccation, and loss of needles. Diagnosis is usually based on three conditions - symptoms, no evidence of other causes, and a recent history of herbicide application.

Other Abiotic Damage

The possible causes of abiotic damage are wide-ranging. Additional causes include solar radiation, soil mineral imbalances, road salt, pollution, fire, excess water, and various types of mechanical damage.

Additional Resources

More is being learned about pest organisms and their ecological roles all the time, which in turn influences how land managers respond to their damage. Invasive pests are significantly impacting certain conifer species and the threat of new invasive pests is ever present. Climate change is also producing new impacts. Consequently, the pests and abiotic factors considered important are expected to change over time.

The California Forest Pest Council offers education on forest pests through its annual meeting, various field meetings, and targeted training sessions. The University of California, CAL FIRE, and the USDA Forest Service also provide a variety of educational services, and assistance from technical experts who are located throughout the state.

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