

# Chapter 15

## Tip, Shoot, Root, and Regeneration Pests



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### 15.1 Introduction

Actively growing tree tissues, such as branch and shoot tips and fine roots, are high in nutritive value and generally have comparatively lower amounts of defensive compounds than older tissues. Many arthropods have evolved to feed on or in these nutritious tree tissues, and most of these herbivores consume a relatively small amount of living tissue or fluids. These particular tissues often lack the physical or chemical defenses present in other parts of the tree, and can be easier to access by herbivores.

While removal of any living tissue or fluid has some effect on the host tree, impacts on the overall health of the tree can be highly variable, ranging from negligible to tree death. The magnitude of these impacts depends on host tree vigor, tree age or size, the amount of material consumed or removed, and the location of the damage. For example, adult *Hylobius abietis* consume the phloem from small diameter branches in the crowns of mature conifer trees in Europe, and this feeding can kill branch tips (Örlander et al. 2000). On a mature tree, however, the loss of some branch tips is not likely to be detrimental to that tree's overall health. Likewise, despite high branch tip mortality from periodical cicada (*Magicicada*) oviposition damage, branch and stem diameter growth of maples (*Acer*), dogwoods (*Cornus*), and redbuds (*Cercis*) trees in Indiana, U.S. was not affected (Flory and Mattingly 2008). Twig girdler damage (Fig. 15.1) can eliminate apical dominance and lead to a high rate of lateral bud development on branches, causing a change in tree structure (Martínez et al. 2009). Adult feeding by the weevil *Cylindrocopturus eatoni*, which occurs in Coastal Western North America, is known to injure young Ponderosa (*Pinus ponderosa*) and Jeffrey (*Pinus jeffreyi*) pine trees. Adults emerge in mid-summer and begin feeding on the bark of small branches, and late summer feeding by larvae on the phloem of

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**Fig. 15.1** Twig girdling damage by *Oncideres cingulata* on pecan (*Carya illinoensis*) results in the loss of branch ends, which can alter the structure of host trees (Photo credit: Clemson University – USDA Cooperative Extension Slide Series, Bugwood.org)

twigs and shoots can cause branch mortality, tree deformation, and death of smaller trees (Eaton 1942; Furniss 1942).

In forests managed for commercial production, insect feeding and damage on tips, roots, and shoots can kill terminal leaders and negatively impact tree growth and form, resulting in volume and economic losses. The two most common groups of insects in these situations are tip moths and root weevils. *Rhyacionia* and *Dioryctria* tip moths impact tree branches or terminal tips in conifers, while root weevils (of which there are many species) feed on branches, shoots, or root tissues in conifers and hardwoods. Many of these insects are colloquially referred to as “regeneration pests” because they often damage seedlings or recently transplanted trees and, at times, significantly impact the regeneration process. It is important to note that the same herbivorous species may act as a regeneration pest in some situations (i.e. if it attacks and damages young tree seedlings) and not in others. Other species damage mature trees and can lead to tree health declines and contribute to mortality. The biology, ecology, and management of many of these species has been well studied.

## 15.2 Similarities and Differences Between Tip Moths and Root Weevils

While superficially different, these two groups of insects share several commonalities. Both tip moths and root weevils come from highly speciose taxonomic groups. There are over 10,300 species in the Family Tortricidae (Order Lepidoptera, Gilligan et al. 2018), many of which are small, usually with a <3 cm wingspan, and having

brownish coloration as adults. The genus *Rhyacionia* contains many horticultural, agricultural, or forestry pests, and larvae exhibit a wide variety of feeding strategies, including leaf rollers, gall makers, fruit, root, or shoot borers, and seed or flower feeders (Gilligan et al. 2018). The lepidopteran family Pyralidae contains nearly 6,000 species, many of which are small to mid-sized (wingspans <4 cm) agricultural pests that are variably colored adults (Regier et al. 2012). Within this family the genus *Dioryctria* contains 79 recognized species, most of which impact cones or seeds (Whitehouse et al. 2011) though several species do cause damage to branches and shoots of conifers (Roe et al. 2011).

Within the Order Coleoptera, the Family Curculionidae (the “true” weevils) is the largest, with over 77,000 species (GBIF 2021). This family contains many insects that attack trees, including the bark beetles (Chapter 10) and ambrosia beetles (Chapter 11). Until recently, bark and ambrosia beetles were considered a separate Family, even though there was substantial evolutionary evidence to the contrary (Jordal et al. 2011), and bark and ambrosia beetles are now a subfamily within the Curculionidae. Several weevil species impact trees in forests, nurseries, urban and suburban landscapes, and natural or managed landscapes.

Both tip moths and root weevils have holometabolous life cycles, going through four morphologically distinct developmental stages: egg, larva, pupa, and adult. Adults are mobile—*Rhyacionia* and *Dioryctria* moths are active fliers, and most (but not all) root weevil adults can fly. Both tip moth and root weevil larvae are relatively immobile—*Rhyacionia* and *Dioryctria* larvae are confined to the shoot or meristem tip on which the female oviposited, and root weevil larvae either live in a tunnel under the bark or in the soil where they feed on fine roots (hence the common name). In all cases, the success of the individual larva—and of the species—depends largely on the ability of the adult female to choose an oviposition site that will be favorable to the offspring. This is known as the “mother knows best” hypothesis (Scheirs et al. 2000; Mayhew 2001) in that the mother chooses a location for her offspring that will allow them the best chance at success (i.e. reaching maturity and reproducing). Individuals who select the best oviposition sites produce offspring that survive and pass on those genetics; those that do not select favorable oviposition sites will be less likely to pass their genes on to subsequent generations.

There are significant ecological and biological differences between these two insect groups, primarily in terms of life cycle duration, location where the feeding damage occurs, and which life stages cause this damage. Adult *Rhyacionia* moths live only a few weeks (e.g. Friend and West 1933; Asaro and Berisford 2001b), which is just long enough to mate and oviposit. Eggs are laid on pine needles, and larvae first bore into needles, later entering the growing lateral and terminal shoots (e.g. Stevens 1966; Jennings 1975). Larvae seldom grow more than several mm in size, but their feeding on vascular tissue causes tip mortality. *Dioryctria* moths have between one and several generations a year (e.g. Butcher and Carlson 1962; Neunzig et al. 1964). Like *Rhyacionia*, larvae feed in tree tissues, most often cones but also shoot tips; this feeding can cause damage and mortality to branches, deterioration of tree form, and can negatively impact stand value (Neunzig et al. 1964; Speight and Speechly 1982; Hainze and Benjamin 1984).

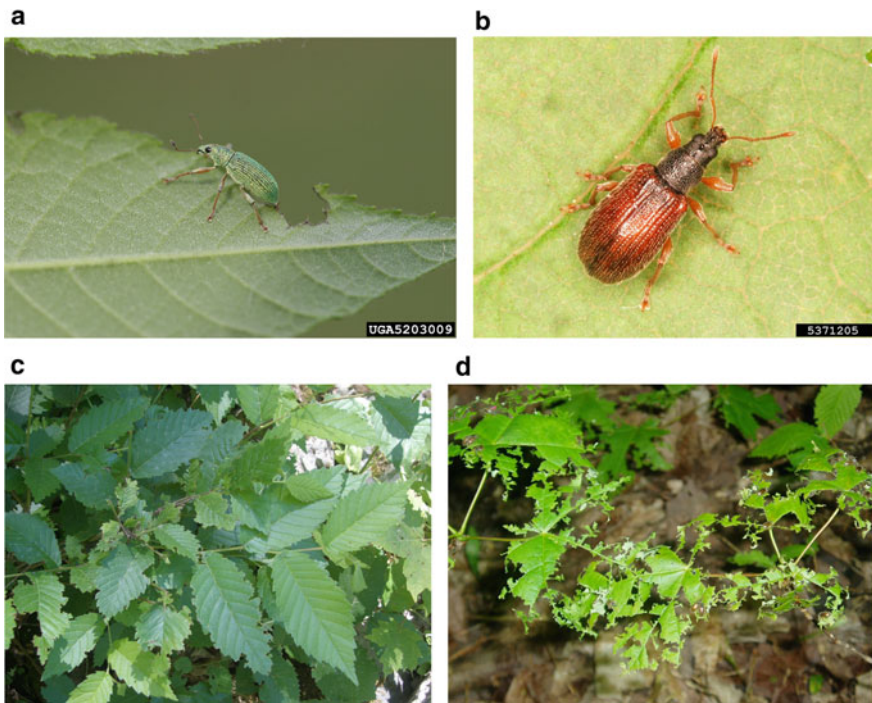
While the loss of a single growing tip is not detrimental to a mature tree's health, severe damage can occur when high pest populations infest younger trees. For instance, significant mortality of newly planted Caribbean pine (*Pinus caribaea*) resulted from shoot feeding by *Dioryctria* larvae in the Philippines (Speight and Speechly 1982) and *Dioryctria resinosa* larval feeding killed nearly a third of current year leaders on young red pine (*Pinus resinosa*) in Maine, U.S. (Patterson et al. 1983). While some of these trees had a secondary leader assume dominance, 16% assumed a forked growth form and were permanently damaged. An outbreak of the pine tip moth *Rhyacionia leptotubula* damaged 40% of growing terminals in China and caused significant long-term damage to Armand pine (*Pinus armandii*) growth and form (Yang et al. 2012). After feeding is complete, larvae pupate in the now dead shoot. In some cases, trees that were previously attacked by the Nantucket pine tip moth (*Rhyacionia frustrana*) become predisposed to additional, subsequent *R. frustrana* attacks (Coody et al. 2000). Multiple moth generations can occur during a single growing season (Powell and Miller 1978).

In contrast to shoot moths, the entire life cycle of most root weevils may take two years or more. Adults can live up to several months (Wen et al. 2004; Son and Lewis 2005) and are active feeders, sometimes causing significant damage. For example, the cypress weevil (*Eudociminus mannerheimii*) primarily impacts weakened or damaged cypress and related trees in the Family Cupressaceae. It has been reported in much of the eastern U.S. (Skvarla et al. 2015) and Central Mexico (Sánchez-Martínez et al. 2010). Confirmed and reported instances of this weevil damaging trees span the range of small diameter nursery stock (Mayfield 2017), urban landscape trees (Skvarla et al. 2015), and natural riparian areas (Sánchez-Martínez et al. 2010). This weevil damages and kills trees by infesting the stems and tunneling under the bark, consuming the phloem, eventually killing the tree.

Root weevil larvae are whitish and grublike, though not C-shaped like a typical soil-dwelling grub. Larvae feed on fine roots or within a gallery created in the phloem of the root or shoot. Like tip moths, larval damage can be significant. For instance, a weevil in the genus *Aclees*, previously undocumented as a forestry pest in its home range, became a new pest of planted Spanish cedar (*Cedrela odorata*) when this tree was planted in commercial plantations in Vietnam (Thu et al. 2010). This tree is highly valued for furniture and is native to tropical areas of the Americas. But, when planted in Vietnam as a non-native tree species, the native *Aclees* weevil became extremely prevalent in these plantings, with infestation rates of 80–100% and high damage rates on inspected trees. This particular system is an excellent example of a native pest, which was of so little economic consequence that it had not yet been identified to species, becoming a serious concern for growers due to forest management practices (i.e. installing plantations of non-native Spanish cedar trees). Pupation of root weevil larvae occurs in the ground or in small “pupal chambers” inside the tissue on which the larva fed. The amount of time a root weevil spends in each of these life stages varies greatly, and depends on the insect species, climate, local conditions, and host.

Unlike tip moths, whose larval stage is the only life stage to feed on tree tissue, feeding by both larval and adult root weevils can damage trees, but the amount and severity of damage varies greatly depending on the insect species. In most cases

adults and larvae feed on different tree tissues. For instance, several non-native root weevil species (primarily *Phyllobius oblongus*, *Sciaphilus asperatus*, *Barypeithes pellucidus*, and *Polydrusus formosus*, which is also known as *P. sericeus*, plus a few other less commonly encountered species) have established in hardwood forest stands throughout the Western Great Lakes Region of North America (Coyle et al. 2008b) (Fig. 15.2). Adults are only present for several weeks in early summer, occasionally causing extensive defoliation of sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), American basswood (*Tilia americana*), hop-hornbeam (*Ostrya virginiana*), and *Rubus* in the forest understory (Coyle et al. 2008b). This adult defoliation, coupled with fine root herbivory by larvae – densities of which can exceed 1000/m<sup>2</sup> – can lead to seedling mortality (Pinski et al. 2005; Coyle et al. 2008b, 2014).



**Fig. 15.2** *Polydrusus sericeus* (a) and *Phyllobius oblongus* (b) adults with characteristic feeding on leaf margins of *Ostrya virginiana* (c) and *Acer saccharum* (d) in northern hardwood forests of the Great Lakes Region of North America (Photo credits: Steven Katovich, Bugwood.org [a]; György Csóka, Hungary Forest Research Institute, Bugwood.org [b]; David Coyle, Clemson University [c and d])

### 15.3 Management Strategies for Tip, Shoot, Root, and Regeneration Pests in Forest Systems

Determining when and where to dedicate resources towards pest management is one of the primary decisions facing forestry professionals around the world. This decision is, in part, dictated by geography and socioeconomic factors. In places where forestry is a major industrial activity and component of the economy, keeping forest stands pest-free and healthy requires, and is given, more emphasis and resources.

Whether trees are in natural or unmanaged uneven-aged forests, or managed and even-aged forests; tip, shoot, root, and regeneration pests are usually not problematic or controlled in healthy older or larger trees, as they rarely cause widescale measurable damage. However, several types of tip, shoot, and root feeding insects, specifically root weevils, can and do feed on tissues of stressed trees. For instance, several genera of root weevils in the southeastern U.S. oviposit in dying or dead pines (Matusick et al. 2013) and the larvae feed on and develop in dying or dead roots or stumps (reviewed by Coyle et al. 2015). These insects play an important ecological role in that their feeding helps break down woody tissue. Further, by creating their feeding galleries they help several species of fungi proliferate inside the tree tissues, thus aiding in wood decomposition.

Younger trees in any forest situation are at a greater risk of damage from tip, shoot, and root pests. Managing these pests in mixed species or uneven-aged stands is often logistically difficult and economically unfeasible due to the heterogeneity of the system; conversely, in managed or planted forests control of tip, shoot, root, and regeneration pests is often a part of the overall management plan. In some cases, even-aged managed stands are at a greater risk of pest pressure. For example, uneven-aged Norway spruce (*Picea abies*) or Scots pine (*Pinus sylvestris*) stands were at a lower risk for *Hylobius abietis* damage than even-aged stands in Scandinavia (Nevalainen 2017). In contrast, even-aged stands of shortleaf pine (*Pinus echinata*) had lower levels of damage from the Nantucket pine tip moth and several species of *Hylobius* weevils than uneven-aged stands (Land and Rieske 2006). Although these studies report different effects of stand structure, both support the idea that regardless of location, smaller trees are more susceptible to damage by this group of herbivores than are larger trees.

In heavily managed systems, such as seedling nurseries or intensively managed production forests, there are often established protocols to control damage from tip, shoot, root, and regeneration pests (e.g. Coyle et al. 2005; Cram et al. 2012). These pest management strategies may include pesticides, cultural or silvicultural treatments, the use of natural enemies, or a combination of tools. Different forest systems around the world have developed methods to manage tip, shoot, root, and regeneration pests, but these are often tailored to a particular pest and tree species. Pest behavior, host preferences and choices, and different forest types and forestry management tactics around the world all influence pest management strategies.

The next portion of this chapter will highlight the biology, ecology, and management of several arthropod species that impact tips, shoots, roots, or seedlings in forest

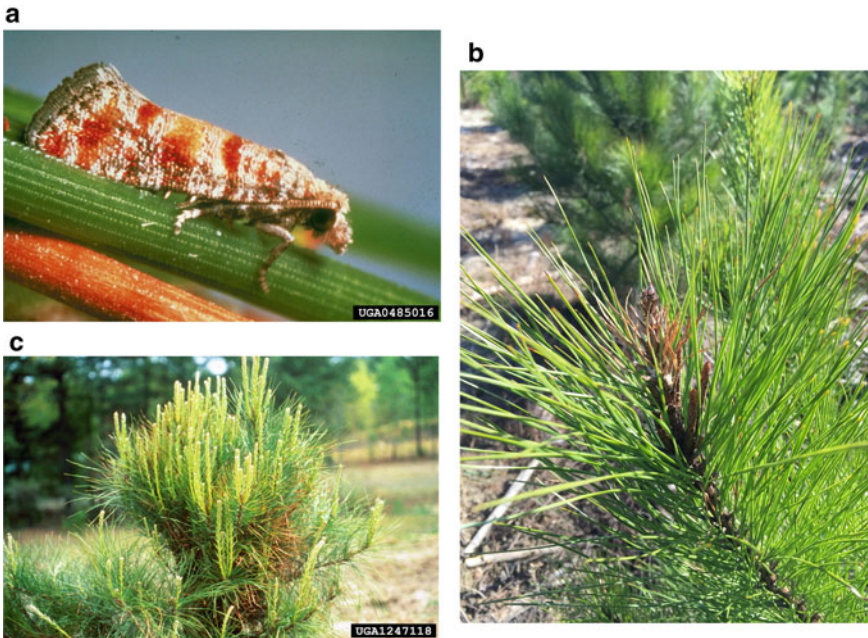
systems. Each case study will focus on a particular organism or group of organisms, and discuss how these pests can impact tree growth, form, and productivity.

### 15.3.1 Case Study: *Rhyacionia* Tip Moths

There are 44 species of *Rhyacionia* tip moths worldwide (Gilligan et al. 2018) of which several species are found in North America (Miller 1967; Dickerson and Kearby 1972; Bell 1993). All tip moths attack pine (*Pinus*) species (Powell and Miller 1978). Although adults do not feed, young larvae mine needles and older instars feed inside shoot tissue. Several *Rhyacionia* species are known to cause significant damage under certain conditions.

*Rhyacionia frustrana* is an important pest of planted and natural pine in North and Central America and several Caribbean Islands (Powell and Miller 1978; Ford 1986; Asaro et al. 2003). This moth has up to five generations annually in the U.S., with adults emerging as early as March in some areas (Fettig et al. 2000, 2003). The life cycle of *R. frustrana* is roughly synchronized so that oviposition occurs with each new flush of growth on host trees (Berisford 1988). Preferred hosts in the southern U.S. are loblolly (*Pinus taeda*), shortleaf, and Virginia pine (*P. virginiana*) (Yates 1966; Nowak et al. 2010). Adults in early generations typically emerge synchronously during a growing season, though this synchronicity can be reduced in generations later in the year (e.g. Gargiullo et al. 1985). After mating, females use volatile host terpenoids to locate oviposition sites (Asaro et al. 2004) and lay eggs on needles or shoots. After hatching, larvae bore into needles (later moving to buds or shoots), buds, or shoots, and feed inside these tissues (Asaro et al. 2003). This feeding kills the bud or shoot tip, and in response to this the tree produces additional shoots. This results in a severely forked branch or stem (Fig. 15.3). Feeding can also kill developing cones (Yates and Ebel 1972). Damage can be variable during the year, as some studies show an increasing level of tree shoot mortality as the growing season progresses (e.g. Nowak and Berisford 2000; Coyle et al. 2003) while in others the highest damage levels occurred early in the growing season (Yates 1966; Miller and Stephen 1983). Larvae pupate inside the shoot, and the entire life cycle takes just a few weeks (Gargiullo and Berisford 1983; Haugen and Stephen 1984).

Newly planted or young pine stands are considered most susceptible (Asaro et al. 2003), as *R. frustrana* attack rates decrease as trees grow taller (White et al. 1984; Sun et al. 1998). Because damage rarely kills trees, a common dogma was that trees would “outgrow” *R. frustrana* damage by the end of the harvest cycle. However, long-term studies show a lasting impact of *R. frustrana* damage on tree productivity, as loblolly pine stands in North Carolina and Georgia that received tip moth control early in the rotation had greater stem volume and better stem form after 20 and 15 years, respectively (Berisford et al. 2013). Neither fertilization, irrigation, nor vegetative competition control consistently impacts *R. frustrana* populations (Asaro et al. 2003; Coyle et al. 2003; Nowak and Berisford 2010), likely due to the highly variable *R. frustrana* and natural enemy populations on the landscape.



**Fig. 15.3** Adult *Rhyacionia frustrana* (a) oviposits on *Pinus* spp., where the larvae feed inside a shoot tip eventually causing shoot mortality (b). Repeated attacks can result in heavy terminal mortality and shoot production by the tree, resulting in a stunted, bushy tree (c) (Photo credits: James A. Richmond, USDA Forest Service, Bugwood.org [a]; David Coyle, Clemson University [b]; Terry Price, Georgia Forestry Commission, Bugwood.org [c])

Management strategies for *R. frustrana* have centered around pheromone trapping and insecticide application (e.g. Donley 1960). Pheromone components for *R. frustrana* have been identified and isolated (Hill et al. 1981) and successfully used in monitoring programs to predict infestation levels (Asaro and Berisford 2001a). For years, optimal insecticide periods for foliar insecticide applications were based on moth phenology (Berisford et al. 1984) or pheromone trapping, and detailed maps helped advise pine growers when to spray for *R. frustrana* based on degree-day accumulation (Malinoski and Paine 1988; Fettig et al. 2000, 2003). Recent advances in systemic insecticide technology have provided growers the option of applying treatments directly to seedlings at planting (or planting pre-treated seedlings), and this management method has resulted in substantial reductions in *R. frustrana* damage and, consequently, increases in tree growth and biomass accumulation (King et al. 2014).

Several other *Rhyacionia* species cause occasional damage in pine plantations around the world. The European pine shoot moth (*Rhyacionia bouliana*), long regarded as a pine pest in Europe (Friend and West 1933), has established in North America where it is primarily a pest of ornamental pines and Christmas trees. It primarily impacts red pine, Scots pine, white pine (*P. strobus*), jack pine

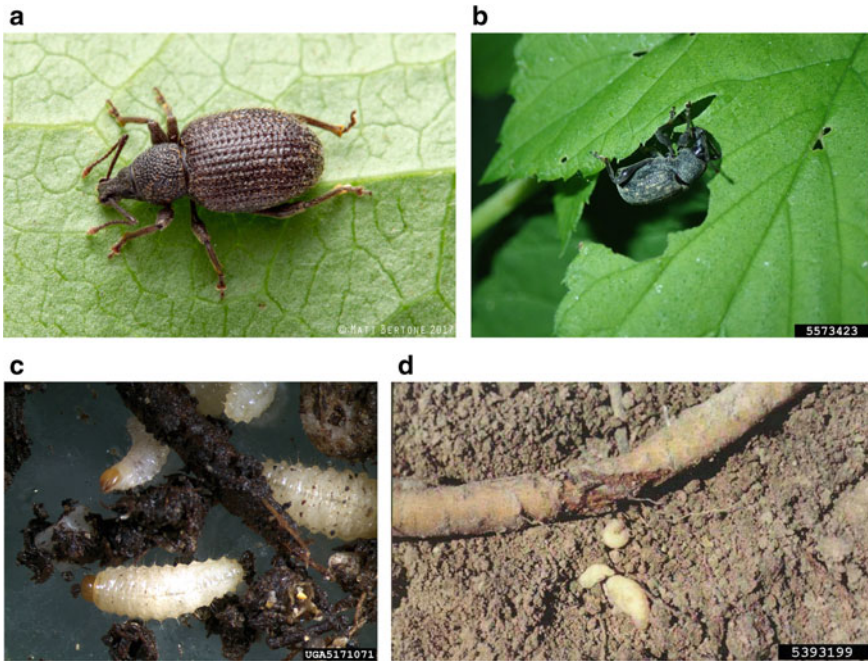


(*P. banksiana*), and Austrian pine (*P. nigra*) (Butcher and Haynes 1960). However, *R. bouliana* will occasionally damage lodgepole pine (*P. contorta*) seed orchards (Heeley et al. 2003) and red pine plantations, although trees may eventually outgrow this damage, which typically occurs early in the rotation (Miller et al. 1978). This pest is also known to cause significant damage in planted pine stands in South America, especially in loblolly pine, radiata pine (*P. radiata*), and slash pine (*P. elliottii*) (Eglitis and Gara 1974; Ide and Lanfranco 1996). As with most non-native species, *R. bouliana* populations tend to be higher in the invaded range (i.e. North America) than its native range (i.e. Europe) (Miller 1962). Additional reports of *Rhyacionia* species as occasional pests of pines appear throughout the literature. For instance, *R. duplana* occasionally causes shoot mortality and damage to Japanese black pine (*P. thunbergia*) in Japan (Kanamitsu 1965; Saito 1969), *R. leptobula* is a serious pest of Yunnan pine (*P. yunnanensis*) and Armand pine (*P. armandii*) in China (Huang 1987), and *R. neomexicana* is an important pest of ponderosa pine in the southwestern U.S. (Jennings 1975).

### 15.3.2 Case Study: *Otiorhynchus* Root Weevils

Tree seedlings are particularly susceptible to herbivory because they do not have large carbohydrate reserves from which to draw upon to help regenerate tissues and alleviate stress resulting from foliage loss. In forest nurseries, millions of tree seedlings can be present in one area, representing a highly concentrated food resource for pests. Weevils in the genus *Otiorhynchus*, native to Europe but now found in most of North America, parts of Australia, New Zealand, and Japan (Nielsen 1989), can be significant nursery pests. Adults are nocturnal and feed on the foliage of many woody plant species, though this leaf “notching” does little damage to the plant (e.g. Löf et al. 2004). Eggs are laid near the base of the seedling and larvae feed on the fine roots and lower stem, often causing significant damage (La Lone and Clarke 1981; Halldorsson et al. 2000) (Fig. 15.4). Adult *Otiorhynchus* weevils do not fly, and after emergence do not disperse far from where they developed as larvae (Moorhouse et al. 1992; Brandt et al. 1995).

The most destructive *Otiorhynchus* weevils in the northern U.S. and Canada are *O. sulcatus*, *O. ovatus*, and *O. rugosostriatus*. In northern Europe, *O. rugifrons*, *O. singularis*, *O. arcticus*, and *O. nodosus* are also known to impact young nursery-grown or planted seedlings (Halldorsson et al. 2000). Both conifer and hardwood seedlings may be impacted by *Otiorhynchus* weevils and, in some cases, damage can be severe. For instance, McDaniel (1932) detailed an infestation of *O. ovatus* in central Michigan, U.S., and noted that larval weevil feeding resulted in 33% of the seedlings being unusable in 1929, to 67% unusable in 1930, and in 1931 the entire crop of Norway and white spruce (*Picea glauca*), white pine, red pine, and ponderosa pine, and white cedar (*Thuja occidentalis*) were completely destroyed. Nearly 35% of Russian larch seedlings (*Larix sibirica*) were killed by *Otiorhynchus* feeding over a 3-year period in southern Iceland (Halldorsson et al. 2000).



**Fig. 15.4** Adult *Otiorhynchus* weevils, like this *Otiorhynchus rugostriatus* (a), are black, stout-bodied, and flightless. Adult feeding appears as leaf notches, usually on the edges of leaves, and does very little harm to the plant (b). Larvae are white and grublike (c) and consume fine roots and the phloem of larger roots (d) (Photo credit: Matt Bertone, North Carolina State University [a]; Whitney Cranshaw, Colorado State University, Bugwood.org [b]; Michael Reding, USDA Agricultural Research Service, Bugwood.org [c]; David Gent, USDA Agricultural Research Service, Bugwood.org [d])

In nurseries, management of regeneration weevils is commonly done via fumigation (i.e. insecticide) treatments, or occasionally with entomopathogenic nematodes (parasitic nematodes that live in soil and feed on weevil larvae). Other management techniques include practicing clean cultivation, allowing infested areas to remain fallow, and rotating transplant beds so weevils do not have adequate host material (Cram et al. 2012). The use of biological control, specifically soil fungi, to manage *Otiorhynchus* weevils in nurseries is being studied in Iceland (Oddsdottir et al. 2010) and thus far results seem promising—the addition of several types of soil fungi resulted in significant *Otiorhynchus* larval mortality. The cryptic nature of these beetles makes their detection difficult, and this can directly impact the efficacy of any integrated pest management program put in place to control populations. However, developing chemical attractants for *Otiorhynchus* weevils is possible (van Tol et al. 2012). Assuming that this technology is fully developed, growers could better time chemical applications and increase their management efficacy.

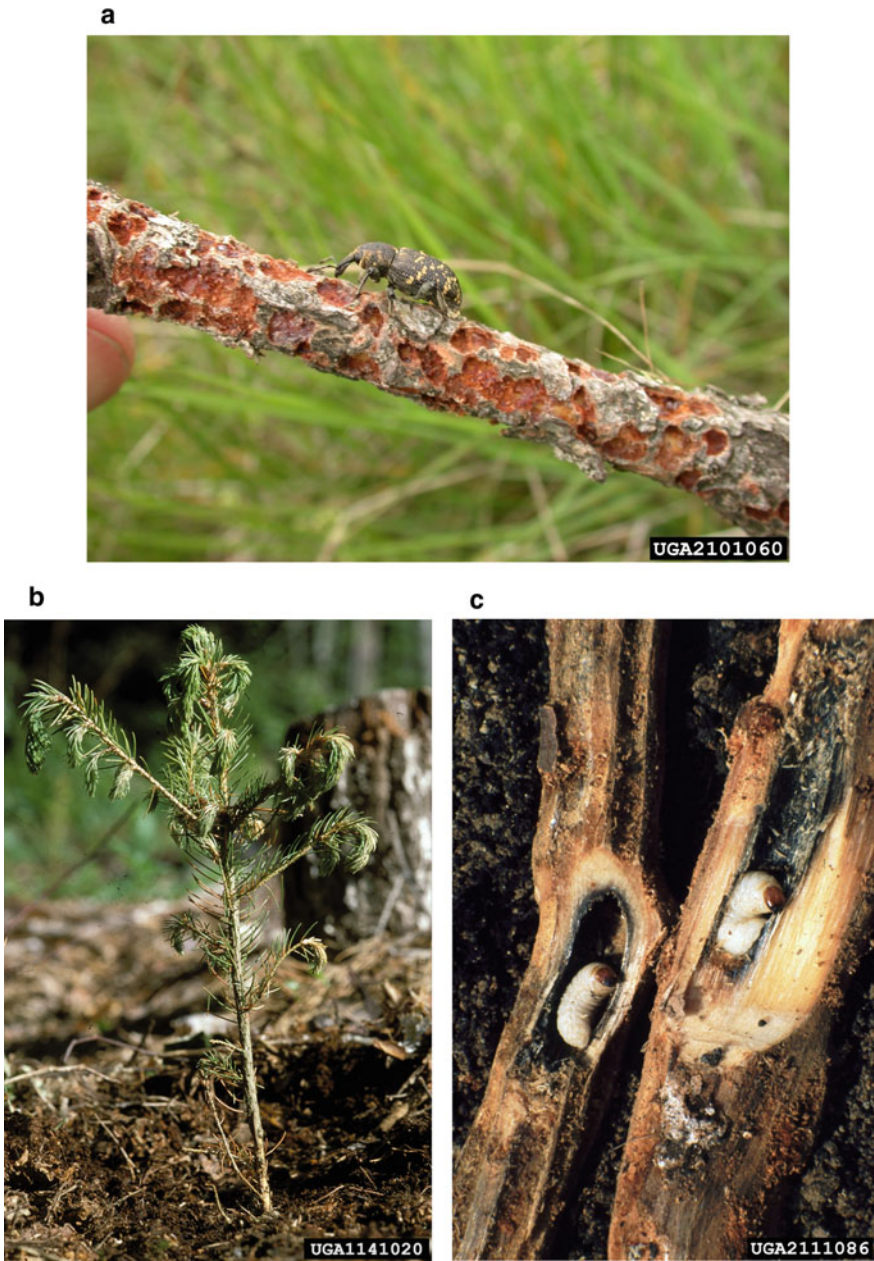
### 15.3.3 Case Study: *Hylobius abietis*

Over 1 billion ha of natural and plantation forest land occurs in Europe and Asia, of which spruces (*Picea*) and pines are major components of the native flora and local timber industry (FAO 2020). This area, specifically the Scandinavian countries and Russian Federation, is a major producer of forest products. Consequently, adequate management for pests that impact the health of these forests is essential.

The large pine weevil (*Hylobius abietis*), is one of the most serious pests of conifers in this region (Fig. 15.5). While Scots pine and Norway spruce are preferred hosts, *H. abietis* also feeds on other conifers and some hardwoods (e.g. silver birch [*Betula pendula*] and common beech [*Fagus sylvatica*]). Adults feed on the tender shoot tissue of young trees, causing stem girdling that can result in damage and mortality on over 80% of young seedlings in some areas (Gourov 2000; Hannerz et al. 2002; López-Villamor et al. 2019; Hardy et al. 2020). After mating, females deposit their eggs in the vicinity of or in notches chewed on the bark of roots of weakened or mature trees or stumps just below the soil surface. Larvae create galleries under the bark, feeding on the living tissue and disrupting nutrient transport in the tree, and pupate in chambers under the bark. Larval development and adult emergence often occurs within the same year, however, larvae may take up to five years to develop in some cases (Leather et al. 1999). Adults can live up to four years, and upon emergence require several weeks of feeding before becoming reproductively mature (Leather et al. 1999). Adults are attracted to volatiles emitted by cut stumps (Lindelöw et al. 1993) where they mate and oviposit.

Scientists have worked for decades evaluating different management strategies for *H. abietis*. Various types of physical barriers have been evaluated (e.g. Lindström et al. 1986; Eidmann and Von Sydow 1989; Nordlander et al. 2011; Lalík et al. 2020). While many are as effective as insecticides, not all are likely to be commercially viable due to cost and/or time necessary to install. Insecticides (including permethrin, cypermethrin, imidacloprid, and others, Nordlander et al. 2011; Willoughby et al. 2020) have been used as a management tool for *H. abietis*, many of which can reduce weevil feeding damage to acceptable levels. However, there is evidence that adult *H. abietis* can detect insecticides in woody tissue and actively avoid that tissue (Rose et al. 2005), calling into question the effectiveness of some insecticide treatments. Further, adult weevils may live for weeks after ingesting insecticides, during which time oviposition or new feeding damage could occur (Rose et al. 2005). However, the availability of insecticides is not perpetual (e.g. permethrin was banned from use in Europe in 2003). As the scientific community learns more about the impacts of different active ingredients, we use this knowledge to help make decisions on how these chemicals should and can be used, with human and environmental safety in mind. Sometimes, chemical formulations that were once thought to be safe turn out to be unsafe after new information is gathered. In cases such as these (e.g. permethrin), the insecticide may cease to be available for use.

We cannot simply rely on chemical control of forest pests. Hence, for pests such as *H. abietis*, much research effort has also gone towards silvicultural techniques and



**Fig. 15.5** Feeding by *Hylobius abietis* adults (a) can girdle conifer seedlings throughout Europe and Asia, resulting in seedling mortality (b). While adult damage is the most dramatic and impactful, larvae feed on roots (c) and can cause damage to already stressed trees (Photo credit: Jean-Paul Grandjean, Office National des Forêts, Bugwood.org [a]; György Csóka, Hungary Forest Research Institute, Bugwood.org [b]; Petr Srutka, Czech University of Agriculture, Bugwood.org [c])

residual stump management with a focus on determining the relationship between *H. abietis* and its host material (i.e. cut stumps, in-ground roots, and slash). Adult *H. abietis* are significantly more abundant in areas with white spruce stumps (Rahman et al. 2015; Piri et al. 2020) and increased incidence of seedling damage by adult feeding is expected and occurs in areas where seedlings are planted in close proximity to stumps (Piri et al. 2020). Site preparation, in particular the removal of stumps, which reduces volatiles that attract adults and oviposition and larval feeding sites, significantly reduces the risk of *H. abietis* damage to seedlings (Rahman et al. 2018; Wallertz et al. 2018). And, while commercial stump removal does not remove all roots from the site, Rahman et al. (2018) showed that waiting two years after harvest to remove stumps reduced larval *H. abietis* feeding and densities by 50%. *Hylobius abietis* damage was also positively correlated with the amount of slash remaining on the ground, which declined as time after harvest increased (López-Villamor et al. 2019). Planting seedlings in the summer resulted in less *H. abietis* feeding damage than planting in other seasons (Wallertz et al. 2016; Nordlander et al. 2017a). Thus, timing for certain silvicultural management strategies for *H. abietis* is critical.

Many other management methods have been evaluated with varying levels of success. Methyl jasmonate is a phytohormone present in plants that is involved in plant defenses. Exogenous application of methyl jasmonate has been shown to reduce *H. abietis* damage on maritime pine (*P. pinaster*), radiata pine, white spruce, and Scots pine seedlings in the field for two years (Zas et al. 2014). However, application of methyl jasmonate often results in growth reductions (Heijari et al. 2005), thus a trade-off between protection from *H. abietis* damage and tree growth occurs. Entomopathogenic fungi (e.g. *Metarhizium brunneum* and *Beauveria* spp.) and nematodes (*Steinernema carpocapsae* and *Heterorhabditis downsi*) can persist in the soil for up to two years and provide significant (>85%) control of *H. abietis* larvae (McNamara et al. 2018), and efficacy of different nematode species can be maximized by applying nematodes in specific ways, either directly on the stump or into the soil (Kapranas et al. 2017). Silvicultural practices such as fertilization (Zas et al. 2006) and prescribed fire (Pitkänen et al. 2008) led to increased *H. abietis* captures and damage. Further, there is significant genetic variation in *P. abies* seedling resistance to *H. abietis* feeding and mortality (Zas et al. 2017), and selection for resistant or tolerant families may be a viable management method in the future.

Decades of research has contributed to a solid understanding of factors that impact *H. abietis* damage, and because of these efforts our ability to predict where damage might occur is improving. The age of the clearcut, amount of mineral soil exposed on the ground, seedling size, and temperature are all factors that can help predict where and when *H. abietis* damage will occur (Louranen et al. 2017; Nordlander et al. 2017b). No one management method is completely effective or sustainable (Eidmann 1979), and an integrated pest management strategy for *H. abietis* is necessary for successful conifer production in the region.

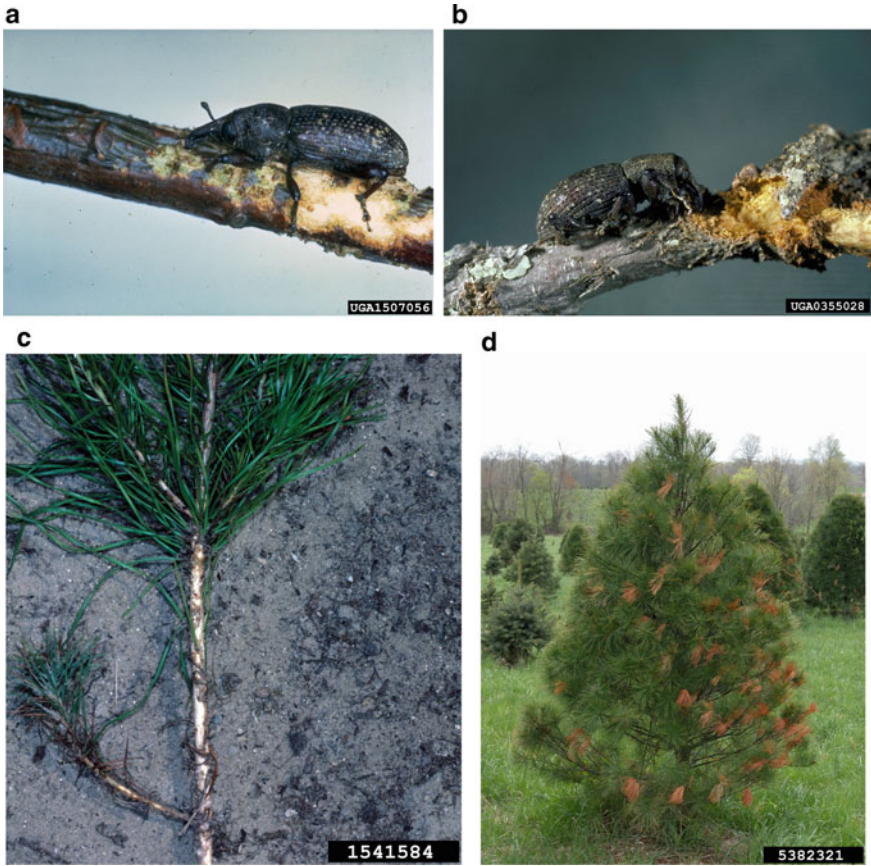
### 15.3.4 Case Study: Root Weevil Complex in the Southeastern United States Pine Forests

The most common tree species grown for commercial purposes in the southeastern U.S. are the southern pines, including loblolly, slash, longleaf, and shortleaf pine. These pines are economically and ecologically important to this region, contributing significantly to the economy and comprising some of the most biodiverse places in the world (Aruna et al. 1997; Noss et al. 2015).

Several species of root-feeding weevils, including *Hylastes salebrosus*, *H. tenuis*, *H. porculus*, *Dendroctonus terebrans*, *Hylobius pales*, and *Pachylobius picivoros* are common in pine stands throughout the southeastern U.S. (Eckhardt et al. 2007; Zanzot et al. 2010; Coyle et al. 2015). *Hylobius* and *Pachylobius* weevils are commonly called “regeneration weevils” as they can severely impact young conifer plantings by feeding on the bark and phloem of pine seedlings (Fig. 15.6). On mature trees, adults will occasionally feed on the bark and cambium of twigs, causing a “flagging” where the tip of a branch dies and turns brown. Adults of these species are attracted to recently cut pine stumps, where they breed. Eggs are laid on the roots of the stump, and larvae feed on the root tissue. The impact of this damage is negligible to a mature tree (though an exception is with Christmas tree growers, where the loss of branches can decrease the value of trees; financial losses of nearly 20% can occur in some cases [Corneil and Wilson 1986]). The majority of the damage these weevils cause is by feeding on the bark and cambium of seedlings, either in the nursery or in newly planted forest stands. This feeding often kills the seedling and can cause significant economic damage to the landowner (Thatcher 1960; Lynch and Hedden 1984).

In the late 2000s and early 2010s, reports of pines dying in several parts of Alabama and Georgia concerned landowners and foresters and prompted scientists to take a closer look at the situation. In most cases, the dying trees involved older pines, with symptoms including yellowing needles and branch dieback. This phenomenon was called “southern pine decline” and was somewhat controversial (Coyle et al. 2015). While the aforementioned weevils were commonly associated with pine mortality, they were subsequently ruled out as the primary cause. It has been suggested that management and environmental conditions have a much greater impact on tree health (Coyle et al. 2020), as these weevils are secondary herbivores and are attracted to weakened or dying trees (Helbig et al. 2016). For example, *Hylobius* spp. adults are attracted to several volatile chemicals, specifically ethanol and monoterpenes (e.g. turpentine) (Siegfried 1987; Rieske and Raffa 1991). These volatiles are released by dying or recently dead pine trees and can be common in nurseries or where harvests have recently occurred (Fox and Hill 1973). The black turpentine beetle (*Dendroctonus terebrans*) typically attacks the lower bole of pine trees, especially trees injured by fire, machines, construction damage, or stressed by drought.

Since these weevils feed on stressed, weakened, dying, or recently dead pine trees, the fact that they are commonly captured in areas with declining pine trees is not surprising—in fact, it is to be expected as this is suitable habitat for mating and oviposition. These weevils do not kill living, healthy, mature trees. Southern pine



**Fig. 15.6** *Hylobius pales* (a) and *Pachylobius picivorus* (b) are significant pests of young pines and Christmas tree plantations in North America. Adult feeding removes phloem, resulting in seedling mortality (c), or can kill branches leading to large reductions in tree value (d). Larvae feed in stumps and large roots of weak, dying, or dead trees (Photo credits: Robert Anderson, USDA Forest Service, Bugwood.org [a, b]; Lacy Hyche, Auburn University, Bugwood.org [c]; Eric Day, Virginia Polytechnic University, Bugwood.org [d])

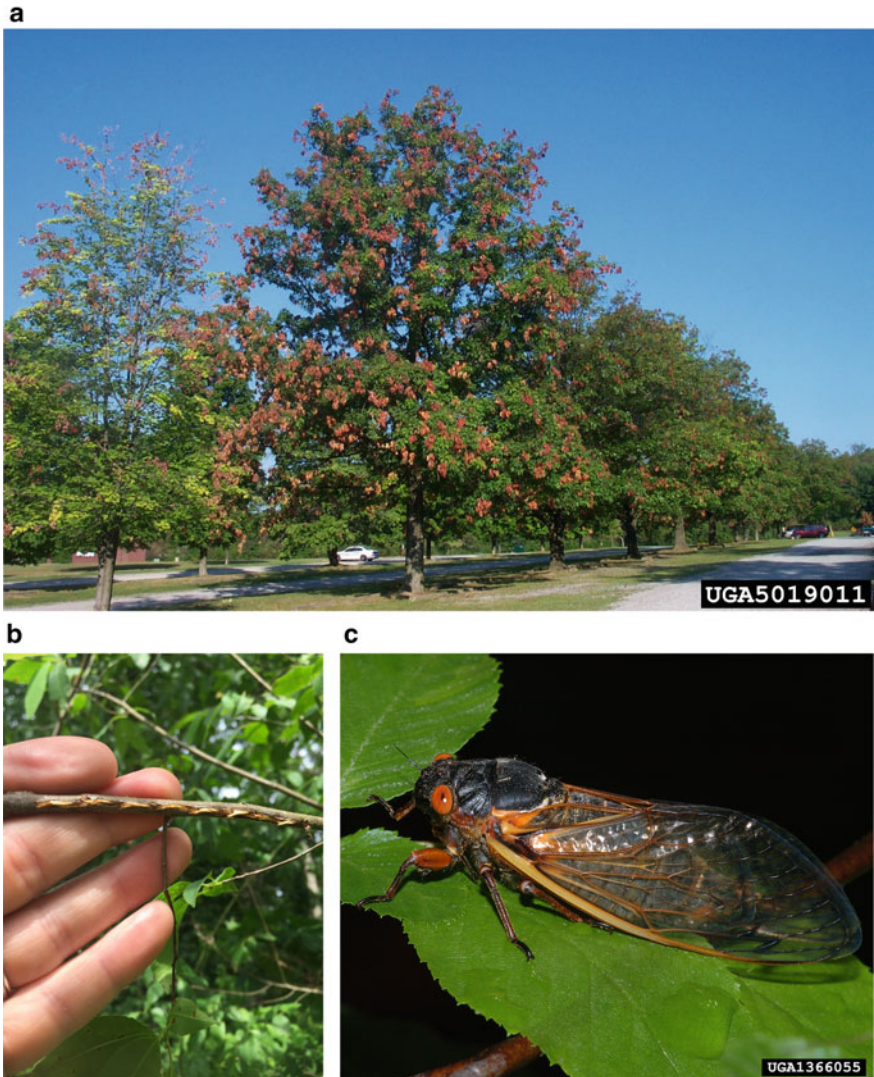
decline is a combination of many factors, including management, soil characteristics, weather and climate, and tree species. Planting the correct tree species on the appropriate site, maintaining proper basal area, and controlling competing vegetation is essential for pine growth in the southeastern U.S. The observed pine decline in the southeastern U.S is likely due to mismanagement of one or more of these factors and the root weevil complex associated with these declining pines is unlikely to be the cause of the problem.

## 15.4 Other Arthropods Affecting Tips, Shoots, and Roots of Trees

Given the great diversity of the Curculionidae, it is not surprising that many weevil species impact trees worldwide. And, while their damage is often negligible, or extremely limited in time or space, there are occasional occurrences when a typically non-impactful species causes measurable damage. For instance, although minor twig damage in Douglas-fir (*Pseudotsuga menziesii*) can occur from *Cylindrocopturus furnissi* when populations reach high densities (Douglas et al. 2013), these weevils are rarely noticed. Damage by *C. furnissi* often appears as scattered branch mortality on mature trees—hardly enough to cause any negative impacts (Furniss 1942). But weevil densities can increase rapidly, especially when trees are stressed by factors such as drought, at which point weevil damage can severely deform or even kill trees. The Norway spruce weevil (*Pissodes harcyniae*), can be an occasional pest of stressed Norway spruce in central and northern Europe, but relatively little is known about this pest's life history (Kolk and Starzyk 1996). Damage to expanding terminal shoots of lodgepole pine can occur by the lodgepole terminal weevil (*Pissodes terminalis*); this damage can cause severe forking of the stem, but delaying the first thinning of the forest stand can help manage weevil populations (Maclauchlan and Borden 1996). The elephant weevil (*Orthorhinus cylindrirostris*) is primarily a pest of vines but can occasionally impact *Eucalyptus*, *Acacia*, and *Castanospermum* trees (Froggatt 1900; Hely et al. 1982). Further, many herbivores that feed on tree branch tips, shoots, and roots are opportunistic secondary pests. Developing effective management plans for these species is not only challenging, but the need is often unanticipated. For example, the Warren root collar weevil (*Hylobius warreni*) is an insect native to Canada normally found in low populations throughout the boreal forest. However, after the mountain pine beetle (*Dendroctonus ponderosae*) outbreak in western North America in the 1990s and early 2000s, *H. warreni* populations increased and caused considerable damage on young, replanted lodgepole pine in areas impacted by the outbreak (Robert and Lindgren 2006). As *H. warreni* adults do not fly, it appears the adults migrated via walking to replanted areas from older forests in search of food (Klingenberg et al. 2010). These are just a few examples of Curculionidae species that are occasional root and shoot pests of trees.

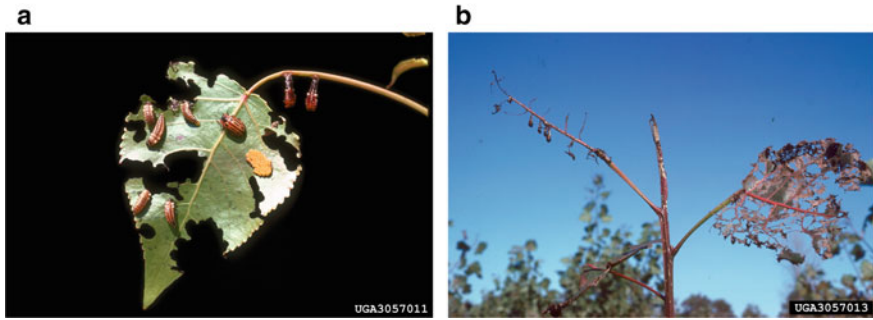
Periodical cicada emergence occurs every 17 years and is a visually spectacular event where millions of larval cicadas synchronously crawl out of the soil and emerge as adults. Found only in eastern North America (Cooley et al. 2009) *Magicicada* spp. oviposit near the ends of hardwood tree branches, in the process killing the terminal end of the branch (Fig. 15.7). Damage to host trees can be highly variable and dependent upon tree species (Cook et al. 2001; Cook and Holt 2002), with branch mortality usually less than 30% (Miller and Crowley 1998). While younger trees are more susceptible, damage from cicada oviposition generally doesn't result in long-lasting impacts on larger host trees (Miller and Crowley 1998; Cook and Holt 2002; Flory and Mattingly 2008).





**Fig. 15.7** Despite high levels of terminal mortality (a), oviposition damage (b) from periodical cicadas (*Magicidada septendecim*) (c) rarely results in long-lasting damage on trees (Photo credits: Pennsylvania Department of Conservation and Natural Resources, Bugwood.org [a]; David Coyle, Clemson University [b]; Susan Ellis, Bugwood.org (c))

Defoliators can also cause tree shoot mortality, particularly when pest populations are high and their preferred leaf material has been exhausted. For example, two defoliators of eastern cottonwood (*Populus deltoides*) trees can, where high populations occur or where host conditions are conducive to infestation, cause substantial defoliation of tree terminals and terminal mortality (Fig. 15.8). In the southern U.S.,



**Fig. 15.8** Adult and larval cottonwood leaf beetles, *Chrysomela scripta* (a), feed on foliage of *Populus* trees. In some cases, feeding on tender shoot tissue will result in terminal mortality (b) (Photo credits: James Solomon, USDA Forest Service, Bugwood.org)

the cottonwood leafcurl mite (*Tetra lobulifera*) can cause severe leaf loss and occasional terminal mortality in plantation grown cottonwood trees, particularly those that exhibit rapid growth rates (Coyle 2002). The cottonwood leaf beetle (*Chrysomela scripta*) will also kill cottonwood terminals, as both adults and larvae will feed on the tender terminal tissue if preferred leaf tissue is no longer available (Coyle et al. 2002). Terminal mortality rarely kills trees, but it can have long-lasting impacts on tree form, causing increased branching and reduced stem growth, which can negatively impact tree value. In some cases, certain *P. deltoides* clones had nearly 40% more branch biomass when subjected to intense *C. scripta* defoliation compared to trees protected from defoliation (Coyle et al. 2008a).

Root herbivory can have a significant impact on many tree species, particularly when herbivores feed on ephemeral tissues such as lower order roots (Hunter 2008). While difficult to measure due to the cryptic nature of belowground feeding and the spatially variable density of root feeding fauna (e.g. Coyle et al. 2008b), it is possible to estimate impacts based on measurements of pest or root density. One technique is to compare tree root growth responses in areas where root feeding fauna have been removed (often via chemical applications) to areas where root herbivores have not been removed. For example, chemical removal of 95% of root herbivores in Manchurian ash (*Fraxinus mandshurica*) and Gmelin larch (*Larix gmelinii*) plantations in China resulted in first and second order root biomass increases of >42% in Manchurian ash and >53% in Gmelin larch (Sun et al. 2011). The impacts can be even more profound in seedlings, which have less capacity to cope with tissue loss. In Belarus, Kozel et al. (2017) exposed Scots pine, white spruce, and silver birch (*Betula pendula*) seedlings to root herbivory by larval cockchafer (*Melolontha melolontha*). In less than two months, scarab larvae consumed up to 73% of fine root biomass. These studies indicate that root herbivory—while not obvious—can have significant impacts on tree growth, health, and productivity.

## 15.5 Conclusions

Tree damage by shoot and root feeding pests will continue to require management efforts in forest stands worldwide. Early detection of forest pests is key to effective management, and recent advances in digital imagery and audio application and acquisition may be used to improve pest management strategies in forest systems. While detection of forest pest damage is possible via landscape-level imagery (e.g. Moderate Resolution Imaging Spectroradiometer, or MODIS), increased resolution of images is necessary before this technology becomes reliably usable from a practical standpoint (Gomez et al. 2020). However, images captured by unmanned aerial vehicles (UAVs, also called drones) appear to have more promise as they are able to obtain more usable imagery (Klouček et al. 2019). Capturing images with UAVs is more labor intensive than using widely available digital imagery, and it requires the operator to be appropriately licensed, but it is clear that both of these technologies hold great promise for the detection of forest pest damage. Further, acoustic sensor technologies that are being developed for pest detection in individual trees (e.g. Ashry et al. 2020) may eventually be useful for larger-scale forest pest detection and management.

Proper silvicultural techniques and chemical management are and will remain effective management tools for many forest pests. But, as more insect species develop resistance to insecticides and the cost of insecticide development continues to rise (Sparks 2013), the forest industry needs to look to new technologies for pest management. One such technology is tree resistance breeding (Showalter et al. 2018; Naidoo et al. 2019). Breeding trees for resistance to pests, either through traditional breeding methods or genetic engineering, has great potential for improving pest management in forestry. In fact, fusiform rust [*Cronatrium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*] management on pines in the southern U.S. via resistance breeding has been very successful (Schmidt 2003), and similar strategies could be applied tip, root, and shoot feeding pests.

A major unknown in forest pest management is how climate change will impact arthropod-plant interactions and, consequently, pest management strategies. While generalities exist, there is a great deal of species-specific and system-specific heterogeneity in terms of pest responses to climate change (Pureswaran et al. 2018; Jactel et al. 2019). For example, increasing temperatures are expected to result in increased fecundity and damage by *H. abietis* (Inward et al. 2012) and also changes in voltinism, which may require more localized management strategies (Wainhouse et al. 2014). Further, as climate change impacts are not restricted to temperature changes (e.g. weather unpredictability is expected to increase) it is difficult to predict what additional impacts may affect forest pest management. Ultimately, a robust integrated pest management strategy is necessary for any economically important forest pest.

## References

- Aruna PB, Cabbage F, Lee KJ, Redmond C (1997) Regional economic contributions of the forest-based industries in the South. *For Prod J* 47:35–45
- Asaro C, Berisford CW (2001a) Predicting infestation levels of the Nantucket pine tip moth (Lepidoptera: Tortricidae) using pheromone traps. *Environ Entomol* 30:776–784
- Asaro C, Berisford CW (2001b) Seasonal changes in adult longevity and pupal weight of the Nantucket pine tip moth (Lepidoptera: Tortricidae) with implications for interpreting pheromone trap catch. *Environ Entomol* 30:999–1005
- Asaro C, Fettig CJ, McCravy KW, Nowak JT, Berisford CW (2003) The Nantucket pine tip moth (Lepidoptera: Tortricidae): a literature review with management implications. *J Entomol Sci* 38:1–40
- Asaro C, Sullivan BT, Dalusky MJ, Berisford CW (2004) Volatiles associated with preferred and nonpreferred hosts of the Nantucket pine tip moth, *Rhyacionia frustrana*. *J Chem Ecol* 30:977–989
- Ashry I, Mao Y, Al-Fehaid Y, Al-Shawaf A, Al-Bagshi M, Al-Brahim S, Ng TK, Ooi BS (2020) Early detection of red palm weevil using distributed optical sensor. *Sci Rep* 10:3155. <https://doi.org/10.1038/s41598-020-60171-7>
- Bell CS (1993) The distribution, larval survival, and impact of a tip moth guild (Lepidoptera: Tortricidae: *Rhyacionia* species) in the Northern Plains. M.S. Thesis, Oregon State University, Corvallis, OR, 125 p
- Berisford CW (1988) The Nantucket pine tip moth. In: Berryman AA (ed) *Dynamics of forest insect populations: patterns, causes, implications*. Plenum Publishing Corp., New York, pp 141–161
- Berisford CW, Garguillo PM, Canalos CG (1984) Optimum timing for insecticidal control of the Nantucket pine tip moth (Lepidoptera: Tortricidae). *J Econ Entomol* 77:174–177
- Berisford CW, Cameron RS, Godbee JF Jr, Jones JM, Dalusky MJ, Seckinger JO (2013) Long-term effects of pine tip moth (Lepidoptera: Tortricidae) control, vegetation control, and fertilization on growth and yield of loblolly pine, *Pinus taeda* L. *J Entomol Sci* 48:23–35
- Brandt JP, Smith SM, Hubbes M (1995) Bionomics of strawberry root weevil adults, *Otiiorhynchus ovatus* (L.) (Coleoptera: Curculionidae), on young ornamental conifer trees in southern Ontario. *Can Entomol* 127:595–604
- Butcher JW, Carlson RB (1962) Zimmerman pine tip moth biology and control. *J Econ Entomol* 55:668–671
- Butcher JW, Haynes DL (1960) Influence of timing and insect biology on the effectiveness of insecticides applied for control of European pine shoot moth, *Rhyacionia buoliana*. *J Econ Entomol* 53:349–354
- Coody AR, Fettig CJ, Nowak JT, Berisford CW (2000) Previous tip moth infestation predisposes trees to heavier attacks in subsequent generations. *J Entomol Sci* 35:83–85
- Cook WM, Holt RD (2002) Periodical cicada (*Magicicada cassini*) oviposition damage: visually impressive yet dynamically irrelevant. *Am Midl Nat* 147:214–224
- Cook WM, Holt RD, Yao J (2001) Spatial variability in oviposition damage by periodical cicadas in a fragmented landscape. *Oecologia* 127:51–61
- Cooley JR, Kritsky G, Edwards MJ, Zyla JD, Marshall DC, Hill KBR, Krauss R, Simon C (2009) The distribution of periodical cicada Brood X in 2004. *Am Entomol* 55:106–112
- Corneil JA, Wilson LF (1986) Impact of feeding by adult pales weevil (Coleoptera: Curculionidae) on Christmas tree stands on southeastern Michigan. *J Econ Entomol* 79:192–196
- Coyle DR (2002) Effects of clone, silvicultural, and miticide treatments on cottonwood leafcurl mite (Acari: Eriophyidae) damage in plantation *Populus*. *Environ Entomol* 31:1000–1008
- Coyle DR, McMillin JD, Hall RB, Hart ER (2002) Cottonwood leaf beetle (Coleoptera: Chrysomelidae) defoliation impact on *Populus* growth and above-ground volume in a short-rotation woody crop plantation. *Agric For Entomol* 4:293–300
- Coyle DR, Nowak JT, Fettig CJ (2003) Irrigation and fertilization effects on Nantucket pine tip moth (Lepidoptera: Tortricidae) damage levels and pupal weight in an intensively-managed pine plantation. *J Entomol Sci* 38:621–630

- Coyle DR, Nebeker TE, Hart ER, Mattson WJ Jr (2005) Biology and management of insect pests in North American intensively-managed hardwood forest systems. *Annu Rev Entomol* 50:1–29
- Coyle DR, Hart ER, McMillin JD, Rule LC, Hall RB (2008a) Effects of repeated cottonwood leaf beetle defoliation on *Populus* growth and economic value over an 8-year harvest rotation. *For Ecol Manage* 255:3365–3373
- Coyle DR, Mattson WJ, Raffa KF (2008b) Invasive root feeding insects in natural forest ecosystems of North America. Chapter 8, pp 134–151. In: Johnson SN, Murray PJ (eds) *Root feeders: an ecosystem perspective*. CABI Press, Oxfordshire, UK, 230 p
- Coyle DR, Mattson WJ, Friend AL, Raffa KF (2014) Effects of an invasive herbivore at the single plant scale do not extend to population-scale seedling dynamics. *Can J For Res* 44:8–16
- Coyle DR, Klepzig KD, Koch FH, Morris LA, Nowak JT, Oak SW, Orosina WJ, Smith WD, Gandhi KJK (2015) A review of southern pine decline in North America. *For Ecol Manage* 349:134–148
- Coyle DR, Barnes BF, Klepzig KD, Koch FH, Morris LA, Nowak JT, Orosina WJ, Smith WD, Gandhi KJK (2020) Abiotic and biotic factors affecting loblolly pine health in the southeastern U.S. *For Sci* 66:145–156
- Cram MM, Frank MS, Mallams, KM tech. coords (2012) *Forest nursery pests*. United States Department of Agriculture Forest Service, Agriculture Handbook No. 680. 212 p
- Dickerson WA, Kearby WH (1972) The identification and distribution of the tip moths of the genus *Rhyacionia* (Lepidoptera: Olethreutidae) in Missouri. *J Kansas Entomol Soc* 45:542–551
- Donley DE (1960) Field testing of insecticides for control of the Nantucket pine tip moth, *Rhyacionia frustrana*, and the European pine shoot moth, *R. bouliana*. *J Econ Entomol* 53:365–367
- Douglas H, Bouchard P, Anderson RS, de Tonnancour P, Vigneault R, Webster RP (2013) New Curculionioidea (Coleoptera) records for Canada. *ZooKeys* 309:13–48
- Eaton CB (1942) Biology of the weevil *Cylindrocopturus eatoni* Buchanan, injurious to ponderosa and Jeffrey pine reproduction. *J Econ Entomol* 35:20–25
- Eckhardt LG, Weber AM, Menard RD, Jones JP, Hess NJ (2007) Association of an insect-fungal complex with loblolly pine decline in central Alabama. *For Sci* 35:84–92
- Eglitis A, Gara RI (1974) Algúnal observaciones sobre la polilla del brote *Rhyacionia buoliana* (Den. & Schiff.) en Argentina. *Rev Chil Ent* 8:71–81
- Eidmann HH (1979) Integrated management of pine weevil (*Hylobius abietis* L.) populations in Sweden, pp 103–109. In: Current topics in forest entomology: selected papers from the XVth International Congress of Entomology, Gen. Tech. Rep. WO-8, Washington, DC, 174 p
- Eidmann HH, Von Sydow F (1989) Stockings for protection of containerized conifer seedlings against pine weevil (*Hylobius abietis* L.) damage. *Scand J for Res* 4:537–547
- Food and Agricultural Organization of the United Nations (FAO) (2020) *Global Forest Resources Assessment 2020: main report*. Rome, Italy. <https://doi.org/10.4060/ca9825en>. 184 p
- Fettig CJ, Dalusky MJ, Berisford CW (2000) Nantucket pine tip moth phenology and timing of insecticide spray applications in seven southeastern states. Res. Pap. SRS-18. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC, 21 p
- Fettig CJ, Nowak JT, Grossman DM, Berisford CW (2003) Nantucket pine tip moth phenology and timing of insecticide spray applications in the Western Gulf Region. Res. Pap. SRS-32. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC, 13 p
- Flory SL, Mattingly WB (2008) Response of host plants to periodical cicada oviposition damage. *Oecologia* 156:649–656
- Ford LB (1986) The impact of *Rhyacionia frustrana* in Costa Rica. *Turrialba* 36:559–561
- Fox RC, Hill TM (1973) The relative attraction of burned and cutover pine areas to the pine seedling weevils *Hylobius pales* and *Pachylobius picivorus*. *Ann Entomol Soc Am* 66:52–54
- Friend RB, West, AS, Jr (1933) The European pine shoot moth (*Rhyacionia bouliana* Schiff.): with special reference to its occurrence in the Eli Whitney Forest. *Yale School of Forestry Bulletin* 37. 65 pages + plates.
- Froggatt WW (1900) The reappearance of the elephant beetle *Orthorhinus cylindrirostris*, Fab. *The Agricultural Gazette of New South Wales* 11:847–851

- Furniss RL (1942) Biology of *Cylindrocopturus furnissi* Buchanan on Douglas-Fir. *J Econ Entomol* 35:853–859
- Gargiullo PM, Berisford CW (1983) Life tables for the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), and the pitch pine tip moth, *Rhyacionia rigidana* (Fernald) (Lepidoptera: Tortricidae). *Environ Entomol* 12:1391–1402
- Gargiullo PM, Berisford CW, Godbee JF Jr (1985) Prediction of optimal timing for chemical control of the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), in the Southeastern Coastal Plain. *J Econ Entomol* 78:148–154
- Gilligan TM, Baixeras J, Brown JW (2018) T@RTS: Online World Catalogue of the Tortricidae (Ver. 4.0). <http://www.tortricid.net/catalogue.asp>
- Global Biodiversity Information Facility Secretariat (GBIF) (2021) GBIF backbone taxonomy: Curculionidae. Checklist dataset <https://doi.org/10.15468/39omei> accessed via GBIF.org on 2022-04-18
- Gomez DF, Ritger HMW, Pearce C, Eickwort J, Hulcr J (2020) Ability of remote sensing systems to detect bark beetle spots in the southeastern US. *Forests* 11:1167. <https://doi.org/10.3390/f11111167>
- Gourov AV (2000) *Hylobius* species (Coleoptera: Curculionidae) from Siberia and the distribution patterns of adults feeding on Scots pine stands. *Entomol Fennica* 11:57–66
- Hainze JH, Benjamin DM (1984) Impact of the red pine shoot moth, *Dioryctria resinosella* (Lepidoptera: Pyralidae), on height and radial growth in Wisconsin red pine plantations. *J Econ Entomol* 77:36–42
- Halldorsson G, Sverrisson H, Eyjolfsdottir GG, Oddsdottir ES (2000) Ectomycorrhizae reduce damage to Russian larch by *Otiorhynchus* larvae. *Scand J for Res* 15:354–358
- Hannerz M, Thorsén Å, Mattsson S, Weslien J (2002) Pine weevil (*Hylobius abietis*) damage to cuttings and seedlings of Norway spruce. *For Ecol Manag* 160:11–17
- Hardy C, Sayyed I, Leslie AD, Dittrich ADK (2020) Effectiveness of insecticides, physical barriers and size of plating stock against damage by the pine weevil (*Hylobius abietis*). *Crop Protection* 137: article 105307. 9 p
- Haugen DA, Stephen FM (1984) Development rates of Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), life stages in relation to temperature. *Environ Entomol* 13:56–60
- Heeley T, Alfaro RI, Humble L (2003) Distribution and life cycle of *Rhyacionia buoliana* (Lepidoptera: Tortricidae) in the interior of British Columbia. *J Entomol Soc Brit Columbia* 100:19–25
- Heijari J, Nerg A-M, Kainulainen P, Viiri H, Vourinen M, Holopainen JK (2005) Application of methyl jasmonate reduces growth but increases chemical defence and resistance against *Hylobius abietis* in Scots pine seedlings. *Entomol Exp Appl* 115:117–124
- Helbig CE, Coyle DR, Klepzig KD, Nowak JT, Gandhi KJK (2016) Colonization dynamics of subcortical insects on forest sites with relatively stressed and unstressed loblolly pine trees. *J Econ Entomol* 109:1729–1740
- Hely PC, Pasfield G, Gellatley JG (1982) Insect pests of fruit and vegetables in NSW. The Australian Landscape Incarta Press, Clayton, Victoria, Australia
- Hill AS, Berisford CW, Brady UE, Roelofs WL (1981) Nantucket pine tip moth, *Rhyacionia frustrana*: identification of two sex pheromone components. *J Chem Ecol* 7:517–528
- Huang FS (1987) Forest insects of Yunnan. Yunnan Science and Technology Press, Kunming, China
- Hunter MD (2008) Root herbivory in forest systems. Chapter 5, pp. 68–95. In: Johnson SN, Murray, PJ (eds) Root feeders: an ecosystem perspective. CABI Press, Oxfordshire, UK, 230 p
- Ide S, Lanfranco D (1996) Evolución de los defectos fustales producidos por *Rhyacionia buoliana* en Chile: un ejemplo en la Décima Región. *Bosque* 17:15–19
- Inward DJG, Wainhouse D, Peace A (2012) The effect of temperature on the development and life cycle regulation of the pine weevil *Hylobius abietis* and the potential impacts of climate change. *Agric For Entomol* 14:348–357

- Jactel H, Koricheva J, Castagneyrol B (2019) Responses of forest insect pests to climate change: not so simple. *Curr Opin Insect Sci* 35:103–108
- Jennings DT (1975) Life history and habits of the southwestern pine tip moth, *Rhyacionia neomexicana* (Dyar) (Lepidoptera: Olethreutidae). *Ann Entomol Soc Am* 68:597–606
- Jordal BH, Sequeira AS, Cognato AI (2011) The age and phylogeny of wood boring weevils and the origin of subsociality. *Mol Phylogenet Evol* 59:708–724
- Kanamitsu K (1965) Length and height position of pine shoots in relation to attack by the shoot moths. *J Japanese For Soc* 47:97–100
- Kapranas A, Malone B, Quinn S, Tuama PO, Peters A, Griffin CT (2017) Optimizing the application method of entomopathogenic nematode suspension for biological control of large pine weevil *Hylobius abietis*. *BioControl* 62: 659–667
- King JS, Kelly AM, Rees R (2014) Systemic control of Nantucket pine tip moth (*Rhyacionia frustrana* Scudder in Comstock, 1880) enhances seedling vigor, plantation establishment, and early stand-level productivity in *Pinus taeda* L. *For Sci* 60:97–108
- Klingenberg MD, Lindgren BS, Gillingham MP, Aukema BH (2010) Management response to one insect pest may increase vulnerability to another. *J Appl Ecol* 47:566–574
- Klouček T, Komárek J, Surový P, Hrach K, Janata P, Vašíček B (2019) The use of UAV mounted sensors for precise detection of bark beetle infestation. *Remote Sens* 11:1561. <https://doi.org/10.3390/rs11131561>
- Kolk, A, Starzyk JR (1996) The atlas of forest insect pests. The Polish Forest Research Institute. Multico Warszawa, 705 pp
- Kozel AV, Zvereva EL, Kozlov MV (2017) Impacts of root herbivory on seedlings of three species of boreal forest trees. *Appl Soil Ecol* 117–118:203–207
- La Lone RS, Clarke, RG Larval development of *Otiorhynchus sulcatus* (Coleoptera: Curculionidae) and effect of larval density on larval mortality and injury to Rhododendron. *Environ Entomol* 10:190–191
- Lalík M, Galko J, Nikolov C, Rell S, Kunca A, Modlinger R, Holuša J (2020) Non-pesticide alternatives for reducing feeding damage caused by the large pine weevil (*Hylobius abietis* L.). *Ann Appl Biol* 177:132–142
- Land AD, Rieske LK (2006) Interactions among prescribed fire, herbivore pressure and short-leaf pine (*Pinus echinata*) regeneration following southern pine beetle (*Dendroctonus frontalis*) mortality. *For Ecol Manage* 235:260–269
- Leather SR, Day KR, Salisbury AN (1999) The biology and ecology of the large pine weevil, *Hylobius abietis* (Coleoptera: Curculionidae): A problem of dispersal? *Bull Entomol Res* 89:3–16
- Lindelöw Á, Eidmann HH, Nordenhem H (1993) Response on the ground of bark beetle and weevil species colonizing conifer stumps and roots to terpenes and ethanol. *J Chem Ecol* 19:1393–1403
- Lindström A, Hellqvist C, Gyldeberg B, Långström B, Mattsson A (1986) Field performance of a protective collar against damage by *Hylobius abietis*. *Scand J for Res* 1:3–15
- Löf M, Isacson G, Rhydeberg D, Welander TN (2004) Herbivory by the pine weevil (*Hylobius abietis* L.) and short-snouted weevils (*Strophosoma melanogrammum* Forst. and *Otiorhynchus scaber* L.) during the conversion of a wind-thrown Norway spruce forest into a mixed-species plantation. *For Ecol Manage* 190:281–290
- López-Villamor A, Carreño S, López-Goldar X, Suárez-Vidal E, Sampedro L, Nordlander G, Björklund N, Zas R (2019) Risk of damage by the pine weevil *Hylobius abietis* in southern Europe: effects of silvicultural and landscape factors. *For Ecol Manage* 444:290–298
- Louranen J, Viiri H, Sainoja M, Poteri M, Lappi J (2017) Predicting pine weevil risk: effects of site, planting spot and seedling level factors on weevil feeding and mortality of Norway spruce seedlings. *For Ecol Manage* 389:260–271
- Lynch AM, Hedden RL (1984) Relation between early- and late-season loblolly pine seedling mortality from pales and pitch-eating weevil attack in southeast Oklahoma. *Southern J Appl* for 8:172–176

- Maclauchlan LE, Borden JH (1996) Spatial dynamics and impacts of *Pissodes terminalis* (Coleoptera: Curculionidae) in regenerating stands of lodgepole pine. For Ecol Manage 82:103–116
- Malinoski MK, Paine TD (1988) A degree-day model to predict Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), flights in southern California. Environ Entomol 17:75–79
- Martínez AJ, López-Portillo J, Eben A, Golubov J (2009) Cerambycid girdling and water stress modify mesquite architecture and reproduction. Popul Ecol 51:533–541
- Matusick G, Menard RD, Zeng Y, Eckhardt LG (2013) Root-inhabiting bark beetles (Coleoptera: Curculionidae) and their fungal associates breeding in dying loblolly pine in Alabama. Fla Entomol 96:238–241
- Mayfield AE III (2017) Cypress weevil, *Eudocimus mannerheimii* (Boheman) (Coleoptera: Curculionidae). UF/IFAS, EENY 360, 4 p
- Mayhew PJ (2001) Herbivore host choice and optimal bad motherhood. Trends Ecol Evol 16:165–167
- McDaniel EI (1932) The strawberry root weevil, *Brachyrhinus (Otiorynchus) ovatus* as a conifer pest. J Econ Entomol 25:841–843
- McNamara L, Kapranas A, Williams CD, O’Tuama P, Kavanaugh K, Griffin CT (2018) Efficacy of entomopathogenic fungi against large pine weevil, *Hylobius abietis*, and their additive effects when combined with entomopathogenic nematodes. J Pest Sci 91:1407–1419
- Miller WE (1962) Differential population levels of the European pine shoot moth, *Rhyacionia buoliana*, between Europe and North America. Ann Entomol Soc Am 55:672–675
- Miller WE (1967) Taxonomic review of the *Rhyacionia frustrana* group of pine-tip moths, with description of a new species. Can Entomol 99:590–596
- Miller F, Crowley W (1998) Effect of periodical cicada ovipositional injury on woody plants. J Arboric 24:248–253
- Miller FD Jr, Stephen FM (1983) Effects of competing vegetation on Nantucket pine tip moth (Lepidoptera: Tortricidae) populations in loblolly pine plantations in Arkansas. Environ Entomol 12:101–105
- Miller WE, Wambach RF, Anfang RA (1978) Effect of past European pine shoot moth infestations on volume yield of pole-sized red pine. For Sci 24:543–550
- Moorhouse ER, Charnley AK, Gillespie AT (1992) A review of the biology and control of the vine weevil, *Otiorynchus sulcatus* (Coleoptera: Curculionidae). Ann Appl Biol 121:431–454
- Naidoo S, Slippers B, Plett JM, Coles D, Oates CN (2019) The road to resistance in forest trees. Front Plant Sci 10:273. <https://doi.org/10.3389/fpls.2019.00273>
- Neunzig HH, Cashatt ED, Matuza GA (1964) Observations on the biology of four species of *Dioryctria* in North Carolina (Lepidoptera: Phycitidae). Ann Entomol Soc Am 57:317–321
- Nevalainen S (2017) Comparison of damage risks in even- and uneven-aged forestry in Finland. Silva Fennica 51(3), article 1741, 28 p. <https://doi.org/10.14214/sf.1741>
- Nielsen DG (1989) Minimizing *Otiorynchus* root weevil impact in conifer nurseries, pp 71–79. In: Alfaro RI, Glover SG (eds) Proceedings of Conference: Insects affecting reforestation: biology and damage. Forestry Canada, Pacific and Yukon Region, Victoria, British Columbia
- Nordlander G, Hellqvist C, Johansson K, Nordenhem H (2011) Regeneration of European boreal forests: effectiveness of measures against seedling mortality caused by the pine weevil *Hylobius abietis*. For Ecol Manag 26:2354–2363
- Nordlander G, Hellqvist C, Hjelm K (2017a) Replanting conifer seedlings after pine weevil emigration in spring decreases feeding damage and seedling mortality. Scand J For Res 32:60–67
- Nordlander G, Mason EG, Hjelm K, Nordenhem H, Hellqvist C (2017b) Influence of climate and forest management on damage risk by the pine weevil *Hylobius abietis* in Northern Sweden. Silva Fennica 51(5), article id 7751, 20 p. <https://doi.org/10.14214/sf.7751>
- Noss RF, Platt WJ, Sorrie BA, Weakley AS, Means DB, Costanza J, Peet RK (2015) How global biodiversity hotspots may go unrecognized: lessons from the North American Coastal Plain. Divers Distrib 21:236–244



- Nowak JT, Berisford CW (2000) Effects of intensive forest management practices on insect infestation levels and loblolly pine growth. *J Econ Entomol* 93:336–341
- Nowak JT, Asaro C, Fettig CJ, McCravy KW (2010) Nantucket pine tip moth. *Forest Insect and Disease Leaflet* 70. U.S. Department of Agriculture, Forest Service, Washington, DC, 8 p
- Oddsottir ES, Eilenberg J, Sen R, Halldorsson G (2010) The effects of insect pathogenic soil fungi and ectomycorrhizal inoculation of birch seedlings on the survival of *Otiorynchus* larvae. *Agric For Entomol* 12:319–324
- Örlander G, Nordlander G, Wallertz K, Nordenhem H (2000) Feeding in the crowns of Scots pine trees by the pine weevil *Hylobius abietis*. *Scand J for Res* 15:194–201
- Patterson GS, Tracy RA, Osgood EA (1983) The biology and ecology of *Dioryctria resinosella* Mutuura (Lepidoptera:Pyralidae) on young red pine in Maine. *Maine Agricultural Experiment Station Technical Bulletin* 110, 28 p
- Pinski RA, Mattson WJ, Raffa KF (2005) Composition and seasonal phenology of a nonindigenous root-feeding weevil (Coleoptera: Curculionidae) complex in northern hardwood forests in the Great Lakes Region. *Environ Entomol* 34:298–307
- Piri T, Viiri H, Hyvonen J (2020) Does stump removal reduce pine weevil and other damage in Norway spruce regenerations?—Results of a 12-year monitoring period. *For Ecol Manage* 465:118098
- Pitkänen A, Kouki J, Viiri H, Martikainen P (2008) Effects of controlled forest burning and intensity of timber harvesting on the occurrence of pine weevils, *Hylobius* spp., in regeneration areas. *For Ecol Manage* 255:522–529
- Powell JA, Miller WE (1978) Nearctic pine tip moths of the genus *Rhyacionia*: biosystematics review (Lepidoptera: Tortricidae, Olethreutinae). U.S. Department of Agriculture, *Agricultural Handbook* 514. 51 p + illustrations
- Pureswaran DS, Roques A, Barristi A (2018) Forest insects and climate change. *Curr For Rep* 4:35–50
- Rahman A, Viiri H, Pelkonen P, Khanam T (2015) Have stump piles any effect on the pine weevil (*Hylobius abietis* L.) incidence and seedling damage? *Global Ecol Cons* 3:424–432
- Rahman A, Viiri H, Tikkanen O-P (2018) Is stump removal for bioenergy production effective in reducing pine weevil (*Hylobius abietis*) and *Hylastes* spp. breeding and feeding activities at regeneration sites? *For Ecol Manage* 424:184–190
- Regier JC, Mitter C, Solis MA, Hayden JE, Landry B, Nuss M, Simonsen TJ, Yen S-H, Zwick A, Cummings MP (2012) A molecular phylogeny for the pyraloid moths (Lepidoptera: Pyraloidea) and its implications for higher-level classification. *Syst Entomol* 37:635–656
- Rieske LK, Raffa KF (1991) Effects of varying ethanol and turpentine levels on attraction of two pine root weevil species, *Hylobius pales* and *Pachylobius picivorus* (Coleoptera: Curculionidae). *Environ Entomol* 20:48–52
- Robert JA, Lindgren BS (2006) Relationships between root form and growth, stability, and mortality in planted versus naturally regenerated lodgepole pine in north-central British Columbia. *Can J For Res* 36:2642–2653
- Roe AD, Miller DR, Weller SD (2011) Complexity in *Dioryctria zimmermani* species group: incongruence between species limits and molecular diversity. *Ann Entomol Soc Am* 104:1207–1220
- Rose D, Leather SR, Matthews GA (2005) Recognition and avoidance of insecticide-treated Scots pine (*Pinus sylvestris*) by *Hylobius abietis* (Coleoptera: Curculionidae): Implications for pest management strategies. *Agric For Entomol* 7:187–191
- Saito A (1969) Damage analysis of fertilized young *Pinus thunbergii* forests injured by the shoot moth. *J Japanese For Soc* 51:212–214
- Sánchez-Martínez G, Equihua-Martínez A, Gonzalez-Gaona E, Jones RW (2010) First record of *Eudocimus mannerheimii* (Boheman) (Coleoptera: Curculionidae) attacking *Taxodium mucronatum* Ten. (Cupressaceae) in Jalisco, Mexico. *Coleop Bull* 64:96–97
- Scheirs J, De Bruyn L, Verhagen R (2000) Optimization of adult performance determines host choice in a grass miner. *Proc R Soc Lond B* 267:2065–2069

- Schmidt RA (2003) Fusiform rust of southern pines: a major success for forest disease management. *Phytopathology* 93:1048–1051
- Showalter DN, Raffa KF, Snieszko RA, Herms DA, Liebhold AM, Smith JA, Bonello P (2018) Strategic development of tree resistance against forest pathogen and insect invasions in defense-free space. *Front Ecol Evol* 6:124. <https://doi.org/10.3389/fevo.2018.00124>
- Siegfried BD (1987) In-flight responses of the pales weevil, *Hylobius pales* (Coleoptera: Curculionidae) on monoterpene constituents of southern pine gum turpentine. *Fla Entomol* 70:97–102
- Skvarla MJ, Bertone MA, Fisher JR, Dowling APG (2015) New information about the cypress weevil, *Eudociminus mannerheimii* (Boheman, 1836) (Coleoptera: Curculionidae: Molytinae): Redescription, range expansion, new host records, and report as a possible causative agent of tree mortality. *Coleop Bull* 69:751–757
- Son Y, Lewis EE (2005) Effects of temperature on the reproductive life history of the black vine weevil, *Otiorhynchus sulcatus*. *Entomol Exp Appl* 114:15–24
- Sparks TC (2013) Insecticide discovery: an evaluation and analysis. *Pest Biochem Physiol* 107:8–17
- Speight MR, Speechly HT (1982) Pine shoot moths in S.E. Asia I. distribution, biology and impact. *Commonwealth For Rev* 61:121–134
- Stevens RE (1966) The Ponderosa pine tip moth, *Rhyacionia zozana*, in California (Lepidoptera: Olethreutidae). *Ann Entomol Soc Am* 59:186–192
- Sun J, Kulhavy DL, Yan S-C (1998) Prediction models of Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lep., Tortricidae) infestation using soil and tree factors. *J Appl Ent* 122:1–3
- Sun Y, Gu J, Zhuang H, Guo D, Wang Z (2011) Lower order roots more palatable to herbivores: a case study with two temperate tree species. *Plant Soil* 347:351–361
- Thatcher EC (1960) Influence of the pitch-eating weevil on pine regeneration in east Texas. *For Sci* 6:354–361
- Thu PQ, Quang DN, Dell B (2010) Threat to cedar, *Cedrela odorata*, plantations in Vietnam by the weevil, *Aclees* sp. *J Insect Sci* 10, Article 192, available online: [insectscience.org/10.192](http://insectscience.org/10.192)
- van Tol RWHM, Bruck DJ, Griepink FC, De Kogel WJ (2012) Field attraction of the vine weevil *Otiorhynchus sulcatus* to kairomones. *J Econ Entomol* 105:169–175
- Wainhouse D, Inward DJG, Morgan G (2014) Modelling geographical variation in voltinism of *Hylobius abietis* under climate change and implications for management. *Agric for Entomol* 16:136–146
- Wallertz K, Hanssen KH, Hjelm K, Fløistad IS (2016) Effects of planting time on pine weevil (*Hylobius abietis*) damage to Norway spruce seedlings. *Scand J For Res* 31:262–270
- Wallertz K, Björklund N, Hjelm K, Petersson M, Sundblad L-G (2018) Comparison of different site preparation techniques: quality of planting spots, seedling growth and pine weevil damage. *New For* 49:705–722
- Wen X, Kuang Y, Shi M, Li H, Luo Y, Deng R (2004) Biology of *Hylobitelus xiaoi* (Coleoptera: Curculionidae), a new pest of slash pine, *Pinus elliottii*. *J Econ Entomol* 97:1958–1964
- White MN, Kulhavy DL, Conner RN (1984) Nantucket pine tip moth (Lepidoptera: Tortricidae) infestation rates related to site and stand characteristics in Nacogdoches County, Texas. *Environ Entomol* 13:1598–1601
- Whitehouse CM, Roe AD, Strong WB, Evenden ML, Sperling FAH (2011) Biology and management of North American cone-feeding *Dioryctria* species. *Can Entomol* 143:1–34
- Willoughby IH, Moore R, Moffat AJ, Forster J, Sayyed I, Leslie K (2020) Are there viable chemical and non-chemical alternatives to the use of conventional insecticides for the protection of young trees from damage by the large pine weevil *Hylobius abietis* L. in UK forestry? *Forestry* 93:694–712
- Yang S, Ma M, Li Q, Chai S (2012) Distribution and damage of *Rhyacionia leptotubula* in Northeastern Yunnan. *For Pest Dis* 31:20–21
- Yates HOIII (1966) Susceptibility of loblolly and slash pines to *Rhyacionia* spp. oviposition, injury, and damage. *J Econ Entomol* 59:1461–1464
- Yates HO III, Ebel BH (1972) Shortleaf pine conelet loss caused by the Nantucket pine tip moth, *Rhyacionia frustrana* (Lepidoptera: Olethreutidae). *Ann Entomol Soc Am* 65:100–104

- Zanzot JW, Matusick G, Eckhardt LG (2010) Ecology of root-feeding insects and their associated fungi on longleaf pine in Georgia. *J Econ Entomol* 39:415–423
- Zass L, Sampedro E, Prada MJL, Fernández-López J (2006) Fertilization increases *Hylobius abietis* L. damage in *Pinus pinaster* Ait. seedlings. *For Ecol Manage* 222:137–144
- Zas R, Björklund N, Nordlander G, Cendan C, Hellqvist C, Sampedro L (2014) Exploiting jasmonate induced responses for field protection of conifer seedlings against a major forest pest, *Hylobius abietis*. *For Ecol Manage* 313:212–223
- Zas, R, Björklund N, Sampedro L, Hellqvist C, Karlsson B, Jansson S, Nordlander G (2017) Genetic variation in resistance to Norway spruce seedlings to damage by the pine weevil *Hylobius abietis*. *Tree Genet Genom* 13:111, 12 p. <https://doi.org/10.1007/s11295-017-1193-1>

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