

Biology and Management of the Fall Webworm, *Hyphantria cunea* (Lepidoptera: Erebiidae)

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Abstract

The fall webworm, *Hyphantria cunea* (Drury) (Lepidoptera: Erebiidae), is a widespread defoliator that is native throughout the continental United States, as well as southern Canada and northern Mexico. It has been introduced accidentally into many parts of Europe and Asia. Larvae have been recorded from >400 species of forest and shade trees, primarily hardwoods, but also several conifer species in the southern United States. This species is of minor importance in forests, but can cause serious losses in pecan and fruit tree orchards and is a major nuisance in urban parks and homelots where it often completely defoliates ornamental and shade trees. Fall webworm larvae construct conspicuous webs that start at the ends of branches and expand as the larvae grow to incorporate multiple branches. Foliage within webs is completely consumed. Two color races occur throughout the range of this moth, but pure white adults and black-headed larvae predominate in northern regions, whereas spotted adults and red-headed larvae predominate in southern regions. Populations of fall webworm are regulated naturally in its native range by host quality and abundance and by at least 50 species of dipteran and hymenopteran parasitoids and 36 species of predators and parasites. Physical removal, biocontrol, and insecticides are available for management of this moth.

Key words: forest management, pecan orchard, biological control, defoliator, insecticide

The fall webworm, *Hyphantria cunea* (Drury) (Lepidoptera: Erebiidae), is a common and conspicuous defoliator of hardwood trees throughout the United States from southern Canada to northern Mexico. Larvae have been recorded from >400 species of forest and shade trees (Warren and Tadić 1970, Greenblatt et al. 1978, Droeze 1985, Johnson and Lyon 1988, Furniss and Carolin 1992, Wagner 2005). Native to the United States, it has been introduced accidentally in many parts of Europe and Asia where it has become a major pest (Warren and Tadić 1970, Deseö et al. 1986, Johnson and Lyon 1988, Gomi and Takeda 1996, Park et al. 2000, Li et al. 2001, Kiyota et al. 2011). This species is of minor importance in forests (Droeze 1985, Furniss and Carolin 1992), but can cause serious losses in pecan and fruit tree orchards and is a major nuisance in urban parks and homelots where it often completely defoliates ornamental and shade trees (Johnson and Lyon 1988). It is among the oldest targets of control efforts, including early use of arsenicals and chlorinated hydrocarbons (Brinley 1929, Felt and Bromley 1932, Waters and Witman 1937, Ellis and Floyd 1938, Waters et al. 1939, Dickinson et al. 1941, Bromley 1947).

Although fall webworm has a wide host range, populations are controlled naturally in its native range by a variety of environmental factors, including host quality and abundance (Williams and Myers

1984, Park et al. 2000, Mason et al. 2011) and at least 50 species of dipteran and hymenopteran parasitoids and 36 species of predators, parasites, and pathogens (Swain et al. 1938, Oliver 1964a, Jaques 1967, Nordin et al. 1972, Boucias and Nordin 1977, Schaefer 1977, Wagner 2005). This species is not considered a problem in forests, because it primarily attacks tree species with little economic value (Furniss and Carolin 1992), but damage to orchards and urban shade and ornamental trees may warrant control measures (Tedd and Gottwald 1986, Johnson and Lyon 1988).

Description

The fall webworm is highly variable in appearance across its range. At one time two sympatric species, differentiated by host preferences, were recognized (Jaenike and Selander 1980), but now fall webworm is treated as a single species with distinct color races, both of which can occur throughout its range. In the northern part of its range, pure white adult moths predominate (Fig. 1), whereas in the southern part of its range, adult moths usually have dark spots on the wings (Fig. 2; Coulson and Witter 1984, Droeze 1985, Johnson and Lyon 1988). Wingspan is ~30 mm (1.1 in.). White adults are



Fig. 1. Adult fall webworm of the northern race. Photo by Gerald J. Lenhard, Louisiana State University Agricultural Center, Courtesy of Bugwood.org.



Fig. 2. Southern race. Photo by Gerald J. Lenhard, Louisiana State University Agricultural Center, Courtesy of Bugwood.org.



Fig. 3. Newly hatched larvae of the black-headed race of fall webworm on red-bud in Baton Rouge, Louisiana.

associated with black-headed larvae (Fig. 3), and spotted adults are associated with red-headed larvae (Fig. 4).

The fall webworm has one generation per year in Canada and New England, increasing to two to five generations in the southern United States (Coulson and Witter 1984, Drooze 1985, Johnson and

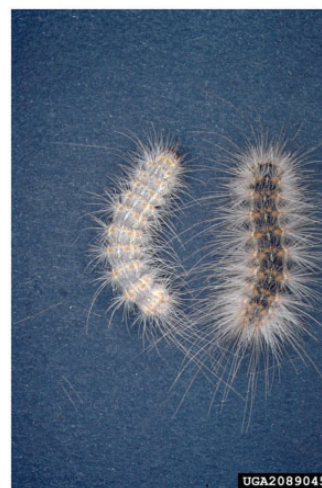


Fig. 4. Mature larvae of the red-headed race of fall webworm. Photo by Lacy L. Hyché, Auburn University, Courtesy of Bugwood.org.

Lyon 1988, Hyché 1999). Adults can be seen from March to July. Females lay several hundred eggs in masses on the undersides of leaves. Following oviposition, the female covers the egg mass with white hairs from her abdomen.

In the southern United States, females of the black-headed race lay eggs in single-layer masses during mid-March, and larvae hatch in mid-April. This race has five generations per year in Louisiana (R. Goyer, personal communication). Females of the red-headed race lay eggs in double-layer masses during mid-April, and larvae hatch about 4 wks after black-headed larvae (Oliver 1964b). This race has four generations per year in Louisiana (R. Goyer, personal communication).

When larvae hatch, the black-headed form is pale yellow to yellowish green with two rows of black tubercles along the back (Fig. 3). The head is black, and the body is covered in fine hair. Fully grown larvae are yellowish to greenish. Red-headed larvae are yellowish tan or tawny with orange or reddish tubercles and long white hair (Fig. 4). Larval coloration varies widely in both races (Fig. 4), but most larvae have a darker dorsal stripe (Wagner 2005).

Larvae undergo as many as 11 instars, feeding within a silken web. This web is a distinctive feature of fall webworm, typically enclosing branch ends rather than branch crotches as for tent caterpillars with which it might be confused (Wagner 2005). The web of black-headed larvae is thin and flimsy; that of red-headed larvae is larger and denser. The web may be as important for thermoregulation as for protection from predators (Oliver 1964a; Schaefer 1977; Rehnberg 2002, 2006). Rehnberg (2002) found that thermal heterogeneity within webs allowed for behavioral thermoregulation. Rehnberg (2002, 2006) reported that the web significantly elevated temperatures within the web by 20–30°C above ambient (shaded) temperatures for 6–8 h per day on warm days, and by 6–8°C on cool days. Rehnberg (2006) found that webs frequently reached >50°C internal temperature, and larvae reached 40 to 50°C body temperatures that were tolerated by the larvae. As larvae grow, they enlarge the web to enclose more foliage (Fig. 5). When alarmed, all larvae within the web jerk in rhythm, apparently as a defense mechanism (Johnson and Lyon 1988, Wagner 2005). At high densities, multiple branches may be enclosed (Fig. 6), and defoliation may reach 100% (Fig. 7) over areas up to several square kilometers (Drooze 1985, Johnson and Lyon 1988). Pupation occurs in thin cocoons in bark



Fig. 5. Fall webworm web on box elder in Baton Rouge, Louisiana.



Fig. 6. Multiple colonies in pecan in central Louisiana.

crevices, under stones, in the duff or just beneath the soil surface (Coulson and Witter 1984, Droeze 1985).

Ecology

Fall webworm abundance varies widely from year to year at any given location. Morris (1964) analyzed long term records of abundance in Canada and concluded that fall webworm population size peaks about every 8–16 yrs over large areas. Populations generally did not reach potential sizes favored by suitable weather or food supply, indicating the importance of predators and parasites (Morris 1964, 1976).

Fall webworm has been recorded from >400 host plants (Coulson and Witter 1984, Wagner 2005, Mason et al. 2011), including several conifer species in the southern United States (Fig. 8; Sourakov and Paris 2014). In the eastern United States, common host plants include pecan, *Carya illinoensis* (Wangenh.)



Fig. 7. Completely defoliated sweetgum. Photo by Dale Pollet, Louisiana State University Agricultural Center.



Fig. 8. Fall webworm on bald cypress in southeastern Louisiana.

K. Kochblack, hickory, *Carya* spp., black walnut, *Juglans nigra* L., American elm, *Ulmus americana* L., persimmon, *Diospyros virginiana* L., apple, *Malus* spp., cherry, *Prunus* spp., box elder, *Acer negundo* L., maple, *Acer* spp., and sweetgum, *Liquidambar styraciflua* L. (Johnson and Lyon 1988, Wagner 2005, Mason et al. 2011). In the western United States, preferred hosts include alder, *Alnus* spp., ash, *Fraxinus* spp., willow, *Salix* spp., cottonwood, *Populus* spp., maple, *Acer* spp., madrone, *Arbutus menziesii* Pursh, and various fruit trees (Johnson and Lyon 1988, Furniss and Carolin 1992). However, despite the wide host range, regular host use in a particular area may include fewer than a dozen species (Mason et al. 2011). The two host races show different behaviors and preferences for host species in the same area (Oliver 1964b, Jaenike and Selander 1980).

As for many other insects, pheromones are critical to attraction of mates (Calcote and Gentry 1973, Kiyota et al. 2011). Kiyota et al. (2011) reported that females produce a blend of (9Z,12Z)-9,12-octadecadienal, (9Z,12Z,15Z)-9,12,15-octadecatrienal, cis-9,10-epoxy-(3Z,6Z)-3,6-henicosadiene, and cis-9,10-epoxy-(3Z,6Z)-1,3,6-henicosatriene in a ratio of about 5:4:10:2. Calcote and Gentry (1973) found that males appeared about 25 min before sunrise in response to caged females; male numbers peaked 5–10 min before sunrise and subsided thereafter, although copulation could continue for several hours. Furthermore, Zhang and Schlyter (1996) and Yamanaka et al. (2001) reported that male dispersal range was limited to < 300 m per day because of the limited period of male mating activity (30–60 min per day). These data indicate that females have very restricted time for mate attraction and mating.

Host quality is an important factor affecting host selection by many herbivores (Schowalter 2016). Even among broad generalists (e.g., >300 host species), such as the fall webworm, certain host plant traits may reduce host use, growth, and survival. Mason et al. (2011) found that larval growth and survival varied widely among commonly used host species at sites in Connecticut and Maryland, indicating differences in foliage quality among host species. Keithley and Potter (2008) reported that fall webworm and Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabaeidae), both broad generalists, differed in feeding rate among plant species considered susceptible or resistant to Japanese beetle, suggesting different responses to specific defensive compounds. For example, Park et al. (2000) demonstrated that isoquinoline alkaloids from *Coptis japonica* (Thunb.) Makino deterred feeding by fall webworm. Fall webworm ability to feed on a wide range of plant species and their associated variety of defensive chemicals likely indicates broad detoxification ability by this moth (Yamamoto et al. 2007).

Foliage quality can change over time as a result of leaf development or environmental changes, such as plant stress resulting from drought or prior herbivory (Hunter 1987, Mattson and Haack 1987). Morris (1967) and Barbosa and Greenblatt (1979) found that fall webworm larvae showed a strong preference for new foliage and foliage fully exposed to sunlight. Larval growth and survival were reduced on late-season foliage, although fall webworm is a successful late season herbivore. Travis (2005) found that early feeding on black cherry, *Prunus serotina* Ehrh., by eastern tent caterpillar, *Malacosoma americanum* (Lepidoptera: Lasiocampidae), reduced subsequent feeding and performance by fall webworm, presumably as a result of defenses induced by the prior herbivory (see Hunter 1987). On the other hand, Williams and Myers (1984) reported that early feeding on red alder, *Alnus rubra* Bong., by western tent caterpillar, (*Malacasoma californicum pluviale* Dyar (Lepidoptera: Lasiocampidae), improved the performance of fall webworm larvae feeding later. However, performance declined on foliage from trees defoliated for three previous years, indicating declining foliage quality. Conversely, feeding by fall webworm apparently induces emission of volatile terpenes that attract Japanese beetles (Loughrin et al. 1995).

Host abundance also is an important factor influencing fall webworm populations. Mason et al. (2011) demonstrated that relative host use by fall webworm was nearly identical to expected use if host plants were used in proportion to their abundance. These data indicate that local patterns of host plant use by fall webworm are driven more by host species abundance than by differences in host plant quality.

Fall webworm populations are subject to a variety of mortality factors. In addition to predators and parasites described below, webworm larvae are sensitive to drought, which can cause premature foliage loss in host trees and consequent mortality of larvae (Oliver 1964a). Heavy rainfall also may kill many adults and larvae (Oliver 1964a).

Fall webworm is preyed upon by a variety of arthropods, birds, and small mammals (Morris 1972a, b). Oliver (1964a) reported 36 species of predators, including one bird, 16 insects and 19 spiders, feeding on fall webworm larvae in Louisiana. Warren et al. (1967) reported 41 species of spiders in fall webworm webs in Arkansas. Morris (1972a) and Schaefer (1977) observed wasps, *Polistes fuscatus* ssp. *fuscatus* (F.) and *Vespula maculifrons* Buysson (Hymenoptera: Vespidae), and a parasitoid, *Therion sassacus* Viereck (Hymenoptera: Ichneumonidae) penetrating webs to prey

on the larvae inside. Despite high rates of predation, predator abundance generally is independent of webworm density (Morris 1972b).

Fall webworm hosts at least 50 parasitoid species (Wagner 2005), notably *Hyposoter* spp. (Hymenoptera: Ichneumonidae) (Swain et al. 1938, Jackson et al. 1970, Nordin et al. 1972, Ravlin and Haynes 1987). Fall webworm also serves as alternate host for several biological control agents introduced for gypsy moth, *Lymantria dispar* (L.), control (Raffa 1977). Nordin et al. (1972) reported parasitism rates of 34–39% in webworm populations in Illinois.

Fall webworm populations are controlled further by baculovirus (NPV), granulovirus (GV) and *Bacillus thuringiensis* (Bt) (Boucias and Nordin 1977, Kaya 1977). Nordin et al. (1972) reported infection rates of 43% in fall webworm populations in Illinois. Microbial infection triggers expression of immune genes that may confer resistance to disease (Park et al. 1997a, b; Shin et al. 1998).

Forest and Orchard Management

Fall webworms cause relatively little economic damage in forests, but can cause substantial cosmetic damage to orchard and ornamental trees, and their conspicuous webs attract attention and complaint (Johnson and Lyon 1988). However, a number of management options are available when control is warranted. Richardson et al. (2006) suggested that control efforts should be initiated at 760 (or 420°C) degree-days above a base of 50°F (10°C), starting March 1, to target the average time of first larval appearance in the mid-Atlantic region for greatest effectiveness and to reduce abundances of future generations. This degree-day model should be confirmed by scouting and adjusted, as necessary, for more northern or southern regions.

Fall webworm colonies are limited to particular branches, making pruning and destruction of the colonies a viable option in many cases (Johnson and Lyon 1988). However, this may be difficult in tall trees. Furthermore, this may leave unsightly gaps in ornamental trees. Alternatively, leaves with egg masses may be removed from lower limbs and destroyed prior to larval emergence (Ree and Jungman 2015). Larvae may be knocked from webs, or webs may be opened to facilitate predator and parasite access to fall webworm larvae (Ree and Jungman 2015).

The fall webworm pheromone is known (Kiyota et al. 2011), but the lure (Brockerhoff et al. 2013) is no longer available. However, pheromones have been proven useful for mating disruption or mass trapping for control other species and could be useful for fall webworm (Yamanaka 2007, Brockerhoff et al. 2013). Mating disruption is more cost-effective than mass trapping because expensive traps are not required (Yamanaka 2007). Both methods are most effective in relatively small and isolated areas, such as orchards, where attraction of moths from surrounding areas is minimal (Yamanaka and Liebhold 2009). Lights also are attractive for male, but not female, fall webworms and may be useful for trapping moths in orchards (Calcote and Smith 1974).

Fall webworm colonies clearly are vulnerable to a variety of biological control agents, as described above. However, the most cost effective biological control is application of available microbial insecticides, such as the bacterium, *Bacillus thuringiensis* (Bt), which is available in a number of spore-crystal toxin formulations (e.g., Weinzierl et al. 2005). Other microbial products include spinosad (toxins derived from the bacterium, *Saccharopolyspora spinosa*). These are especially useful in orchards (Boucias and Nordin 1977, Tedders and Gottwald 1986, Weinzierl et al. 2005,

Beuzelin et al. 2016). Synthetic insecticides are available for use against fall webworm colonies, when necessary. Nonsystemic carbamates (e.g., carbaryl) and insect growth regulators (IGRs, e.g., methoxyfenozide), and systemic emamectin benzoate are available for fall webworm (Beuzelin et al. 2016).

Trees should be routinely inspected for the presence of fall webworms to facilitate management at the beginning of an infestation (Lee 2015). Application of either microbial or synthetic insecticides should be made when colonies are first observed and larvae are small; larger colonies make penetration of the web by the insecticide more difficult (Beuzelin et al. 2016). If trees (i.e. orchard trees) are sprayed for other insects, fall webworm is rarely a pest (Lee 2015). Insecticides used for managing pecan nut casebearer, *Acrobasis nuxvorella* Neunzig (Lepidoptera: Pyralidae), and hickory shuckworm, *Cydia caryana* (Fitch) (Lepidoptera: Tortricidae), in pecans also control fall webworm. Spot treatments of insecticides should be applied to foliage surrounding the web and the web, ensuring that the web is penetrated and soaked. Clearly, nonsystemic insecticides must be applied so that they reach colonies that may be high in trees. Insecticides should be used strictly according to label instructions. Systemic insecticides should be applied as directed to avoid undesirable nontarget effects, e.g., mortality of pollinators.

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