Notes on the Biology and Release of *Caloptilia* sp. nr. *schinella* (Walsingham) (Lepidoptera: Gracilariidae), a Biological Control Moth for the Control of the Weed Firetree (*Myrica faya* Aiton) in Hawaii

George P. Markin
USDA Forest Service, Rocky Mountain Research Station
Forestry Sciences Laboratory, 1648 South 7th Avenue, Bozeman, MT 59717-2780

Abstract. In Hawaii, the weed *Myrica faya* Aiton has invaded many native ecosystems where it is rapidly replacing many native plant species. The moth *Caloptilia* sp. nr. *schinella* is a native of the Azores and Madeira Islands in the eastern Atlantic where its natural host is *M. faya*. This insect was released in Hawaii in 1991 as a potential biological control agent. Eggs are laid singly on the underside of young leaves and hatch in 7 days. The first instar larvae enter the leaf where they mine under the epidermis of the lower surface. The mines eventually coalesce into a blotch. Later instar larvae exit the blotches and externally roll the apical tip of the leaf into a cylinder that forms a distinctive feeding shelter. The last instar larvae leave their shelters and spin oval-shaped, flat cocoons in which they pupate. Development from egg to adult required approximately 2 months. Extensive feeding studies conducted in quarantine in Hawaii to determine this insect's host range indicated that it can complete its development on only one additional plant, the very closely related *M. cerifera* L. The host test results were used in a petition submitted to the Hawaii Department of Agriculture requesting permission to release this moth as a biological control agent in Hawaii. The permit was granted in 1991. Between July 19 and October 29, 1991, 725 adults and/or pupae were released within the Volcanoes Golf Course subdivision located adjacent to the Hawaii Volcanoes National Park on the island of Hawaii. Post-release monitoring conducted in October 1992 indicated that establishment had occurred. By July 1994, the population had spread throughout the golf course subdivision and up to 5 km southward into Hawaii Volcanoes National Park.

Introduction

The introduced plant *Myrica faya* Aiton (Myricaceae), known in Hawaii as firetree, firebush, or faya tree, is a native of the Azores, Madeira, and Canary Islands of the North Atlantic. It was introduced to Hawaii before the turn of the century, probably by immigrant Portuguese (Fosberg 1937; Kim 1969) as an ornamental. The plant was also used in the 1930s for reforestation (Neal 1965; Little and Skolmen 1989) before its aggressive nature was realized. In Hawaii, the plant is most frequently encountered as a 3 to 5 m tall shrub with multiple stems and dark, 5 cm long, waxy evergreen leaves. However, if allowed to grow undisturbed, the plant will mature into a tree 20 m tall with a single trunk up to 75 cm in diameter (Lutzow-Felling et al. 1995).

By 1954, the plant had become established on at least 4 of the major Hawaiian islands, was a serious problem on 3,300 hectares of pasture and sugarcane land on the H?m?kua coast on the island of Hawaii, and was listed as a noxious weed (Yamayoshi 1954). Despite an almost continual effort since 1955 by the Hawaii Department of Agriculture (HDOA) to suppress this pest, it has continued to expand its range, covering 8,000 hectares in 1962

(Anonymous 1962), 21,800 hectares in 1982 (Watanabe 1982), and an estimated 34,365 hectares on 5 major islands in the most recent survey (Whiteaker and Gardner 1985, 1992).

Besides being a problem on agricultural lands, *M. faya* is also a pest in many other Hawaiian ecosystems. Its ability to fix nitrogen allows it to rapidly outgrow and out-compete native tree species, such as ’?hi’a (*Metrosideros polymorpha* Gaud) (Turner and Vitousek 1987). In nitrogen-poor areas, like recent lava flows and cinder fields, it generally excludes other native species by creating an environment favorable to introduced plants (Vitousek et al. 1987; Vitousek and Walker 1989). *Myrica faya*’s spread in Hawaii Volcanoes National Park and potential for large-scale ecological modification led to its being identified as one of the most serious threats to native, dry forest ecosystems (Gardner and Davis 1982). For a complete review of this plant, see Lutzow-Felling et al. (1995).

Along with the original efforts at mechanical and chemical control in the early 1950s, attempts were made to locate and identify potential biological control agents of *M. faya* in its homeland. Hawaiian Sugar Planters’ Association entomologist Fred Bianchi traveled to the Atlantic islands in 1955 (Bianchi 1955) and was followed by Noel Krauss, HDOA exploratory entomologist (Krauss 1964). Both scientists shipped numerous potential biological control agents back to Hawaii, but in quarantine the insects could not be propagated.

A small moth, *Strepsicrates smithiane* Walsingham (Lepidoptera: Olethreutidae), feeds on the foliage of the closely related species *M. cerifera* in the southeastern United States. This insect was eventually tested, cleared, and released in Hawaii in 1955 with hopes it would also attack *M. faya* (Davis and Krauss 1962; Weber 1957; Krauss 1964). *Strepsicrates smithiane* is now established in Hawaii but has not expanded its range to *M. faya*, and its only known population remains restricted to its original host *M. cerifera* in the Panaewa area near Hilo.

Interest in biological control of *M. faya* resumed in the early 1980s as the plant’s spread and impact on native ecosystems at Hawaii Volcanoes National Park became apparent. In 1984, a new survey of 3 North Atlantic island groups for potential plant pathogens and insects was sponsored by the National Park Service (NPS) (Hodges and Gardner 1985). Two additional exploratory visits to the Madeira and Azores Islands were conducted by NPS in 1987 and 1988 (Gardner et al. 1988; Markin 1991).

The surveys indicated that a number of different insects were associated with *M. faya* in its homeland (Markin et al. 1995). One of the most common and widely distributed insects encountered was the small moth *Caloptilia* sp. nr. *schinella*.

After being selected as a potential biological control agent, pupae collected on the Azores and Madeira Islands were shipped to Hawaii and a colony established in 1987 at the Hawaii Volcanoes National Park Insect Quarantine Facility (elevation 1,140 m). Host testing and biological studies were completed in 1990.

Taxonomy

This moth was first identified as a potential biological control agent for *M. faya* by N. Krauss (1964), who collected it on the island of Madeira and identified it as *Lithocolletis* sp. Several shipments were made to HDOA quarantine in Honolulu, but it could not be propagated. During the present study, specimens collected on the Azores and Madeira were tentatively identified as *Phyllonorycter myricae* Deschka by local entomologists, which was the name used in earlier reports (Gardner et al. 1988; Markin 1991).

Obtaining a positive identification proved difficult. The family Gracilariidae is a very large, poorly known group of over 2,000 species with no taxonomists actively working on the group. Final choice of a name was obtained in 1993 based on the recommendations of Dr. G. S. Robinson, curator of Lepidoptera in the British Museum of Natural History in

London. He compared specimens of this moth with the original type specimens of *P. myricae* and other Gracilariids from the Azores, Madeira, and Canary Islands. He found this moth similar to *Caloptilia schinella*, but smaller and darker in color. His recommendation was that final identification would probably depend upon a comparison of the genitalia of species within this group, but he knew of no Gracilariidae taxonomist who might do the work. For the time being, the name *Caloptilia* sp. nr. *schinella* has been selected for this insect.

Phyllonorycter myricae is a slightly smaller Gracilariid moth that is also a leaf miner of *M. faya*. It was frequently collected and shipped to quarantine as a potential biocontrol agent under the name "unknown leaf miner" (Markin 1991). Both species often attack the same *M. faya* plant, although *C.* sp. nr. *schinella* feeds on the newer foliage near the tips of branches, while *P. myricae* mines the older, coarse leaves further back on the branch, usually in shaded locations.

Biology

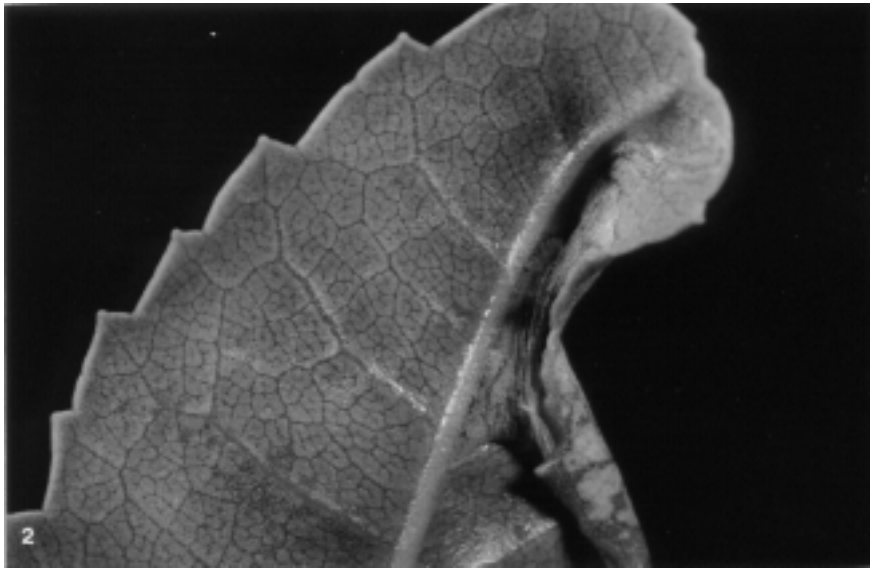
Field observations. The distribution of *C.* sp. nr. *schinella* on the Azores Islands (latitude 38° N) is probably temperature-limited since the insect was not recovered above 330 m, although the range of *M. faya* extended to 660 m. Below 330 m, the insect was encountered at all sites surveyed on 4 major islands – Pico, Faial, Santa Domingo, and Terceira (Markin 1991). On the island of Madeira (latitude 32° N), *P. myricae* was found throughout the entire range of *M. faya* from sea level to 1,000 m and in areas with considerable differences in rainfall. All life stages were present in the field at the same time, from early spring to late fall, indicating that reproduction is continuous and that several generations occur in a year.

In general, the insect was more abundant on the Azores Islands than on Madeira, but even on the Azores, incidence of damage was usually found on less than 1 percent of the leaves. At only 2 locations was a higher frequency of attack observed (5.8 percent and 15 percent), but these damage estimates are probably low since attacked leaves are generally dropped earlier than unattacked leaves.

On both Azores and Madeira Islands, *C.* sp. nr. *schinella* was found to be attacked by a wide range of natural enemies, including a pathogenic fungus that attacks the larvae and pupae, a small parasitic Hymenopteran that attacks the larvae, and a large predator—possibly an ant—that opens the rolled leaf tips to feed on the late instar larvae. The most common form of mortality, however, appeared to be a predatory insect that locates the larvae while inside the blotch and then punctures the leaf with is proboscis to kill and feed on the larvae.

Laboratory Observations. ***Adults.*** The adult moth is a small, slender, nondescript, light brown insect about 1 cm long. Its most characteristic feature is a peculiar resting stance where the body is held at a 45° angle to the substrate and the first 2 pair of legs are held together to make them appear as if they are a single pair (Fig. 1). When resting on a shoot, the insect is well camouflaged, as it resembles a broken leaf petiole. Male and female adults occur at the ratio of 50:50, are approximately the same size, and have the same general appearance. The antennae of both males and females are very slender and longer than the body. The forewings are elongated and slender; the hind wings are plumose or featherlike. At rest, both wings are folded tightly around the abdomen. The moths are quick, active diurnal fliers and can maneuver rapidly between the branches and leaves of *M. faya*. Adults of both sexes have a well-developed proboscis and were observed feeding on sugar water, streaked honey, and flower nectarines.

At the Hawaii Volcanoes National Park Insect Quarantine Facility (1,140 m) maintained at ambient temperature by the circulation of filtered, outside air, the insects were raised in a



Figures 1–2. *Caloptilia* sp. nr. *schinella*. **1.** Adult in typical resting position. On a *M. faya* twig, the adult resembles a broken leaf petiole or loose piece of bark. **2.** Feeding chamber formed by early instar larva in folded-over edge of *M. faya* leaf.

45 x 45 x 53 cm sleeve cage. Mating took place 3 to 5 days after adults emerged. Females readily deposited their eggs on developing leaves of *M. faya*. Egg laying was gradual over the 1 month life span of the female, with 2 to 5 eggs (an extreme of 20 eggs) laid per day per female. The moths completed a life cycle, egg to adult, spanning about 55 days in summer and 65 days in winter.

Oviposition sites. Given a choice, females are very specific where they deposit their eggs. They prefer the underside of expanding, soft new leaves between 1 to 2 cm long and light, yellowish green in color at the tips of *M. faya* shoots. If new leaves are not available, older, larger (2 to 4 cm) leaves that have turned green, but are still soft, will be used. Occasionally an egg will be found on the harder, dark green, mature leaves. While these eggs hatched and the larvae began mining, these attacks rarely progressed beyond the blotch stage.

If *M. faya* foliage were withheld from the sleeve cages for more than 1 day, females would lay their eggs on almost any plant with a small, smooth, soft leaf. This characteristic was used to force oviposition on other plant species in studies of its host range (Markin 1990).

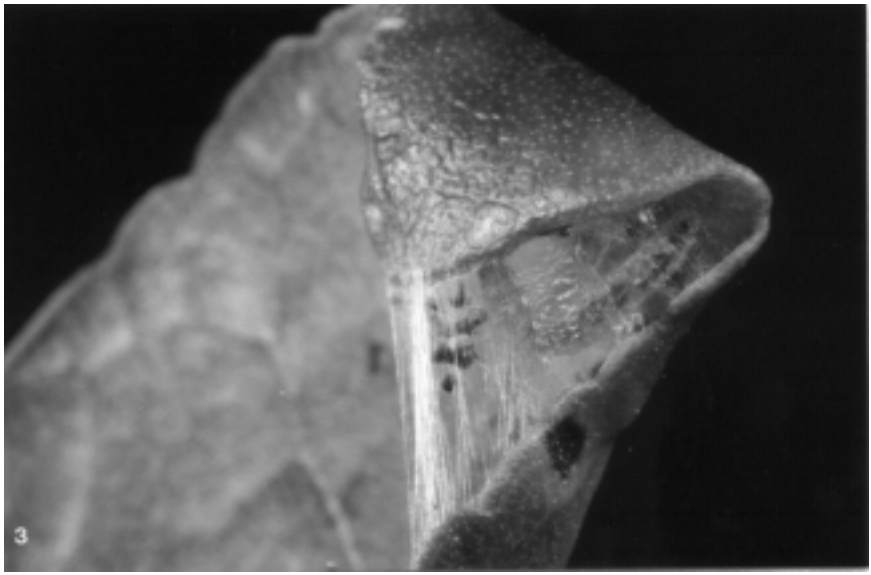
Eggs. Eggs, which are laid singly, are small, oblong (0.5 mm long, 0.3 mm wide, and less than 0.2 mm high), and are attached tightly to the lower leaf surface. Under 50-power magnification, the eggs are featureless. Newly laid eggs are light gray, but within a few hours become transparent and colorless. When searching for eggs on a leaf under low magnification, it is easy to miss them unless the angle is correct for the light to reflect off them. A general outline of the head capsule of a developing larva can be seen about 1 day before egg hatch, but the body of the larva remains transparent until hatching (approximately 7 days after oviposition).

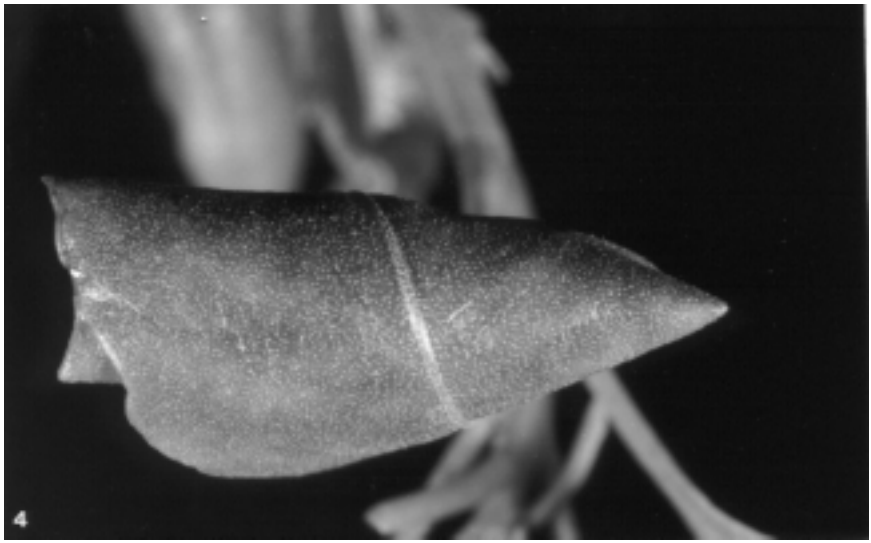
Larva—early mining stage. The first instar larva does not resemble typical caterpillars. Like other members of the Gracilariidae, they are highly modified for mining within the leaf tissue. The larva is flattened with an expanded thorax about twice as wide as the rest of the body. A newly hatched larva is approximately 1 mm long, with head capsules 0.3 mm wide. The head capsule is highly flattened and wedge-shaped in profile, light brown in color, and triangular when viewed from above. The mandibles are small, slightly curved, needlelike, located at the tip of the head capsule, and pointed forward (prognathous). The larva is legless and depends on contact with the mine surfaces for traction.

The first instar larva begins mining without completely leaving the egg. The head and thorax protrude from the side of the chorion, but the abdomen remains in the egg and anchors the larva while it begins chewing an opening in the epidermis of the leaf immediately adjacent to the egg. Once a cavity is created, it abandons the egg and begins mining under the epidermis of the leaf. The tunnel is 0.5 mm wide and shallow, mostly just a narrow space forced between the epidermis and mesophyll cells. The mine initially is indistinct, but after a few days, discoloration of the tissue and a trail of dark frass particles make it easily visible. The mine wanders about the lower surface of the leaf, increases gradually in width as the larva grows, and may reach a length of 2 to 3 cm. This mining stage lasts 3 to 5 days.

Larva—blotch mining stage. When 1.5 to 2 mm long, the larva begins to concentrate feeding in one area, forming a 1 x 0.5 cm blister-like chamber adjacent to the edge of the leaf. The larva is still flattened and capable only of feeding on the contents of the ruptured mesophyll cells. After completion of this blotch, the larva is about 3 mm long and molts to a typical eruciform caterpillar with legs, vertically aligned head (hypognathous), and normal mandibles. The leaf blotch is not enlarged further, but the larva begins to feed directly on the mesophyll content of the leaf, and for the first time, feeding penetrates the leaf tissue to the upper epidermis.

Larva—leaf edge roller stage. After feeding in the blotch for several days, the larva lines





Figures 3–4. *Caloptilia* sp. nr. *schinella*. **3.** Larva in process of rolling *M. faya* leaf tip. **4.** Leaf tip rolled into a completed feeding chamber.

Figure 5. Cocoons of *C.* sp. nr. *schinella* attached to *M. faya* leaf. The adult, on emerging, leaves the old pupal case protruding from the cocoon.

the underside of its chamber, the epidermis on the lower surface of the leaf, with silk. The silk contracts, pulling the edge of the leaf back on itself to cover the leaf blotch (Fig. 2). The larva remains in the folded leaf shelter, consuming the remaining mesophyll content of the leaf. After feeding for 6 to 10 days and exhausting most of the tissue within this chamber, the larva exits via a 1 mm round hole.

Larva—leaf tip roller stage. The larva migrates down the shoot 2 to 5 cm, where it selects the next feeding site – the tip of an older, mature leaf. On the underside of the leaf, the larva spins silken threads from the leaf tip back to a point approximately 1 cm. When enough threads have been attached, the contracting silk pulls the tip back upon itself. Once folding begins, the larva attaches new threads to the top of the rolled tip and stretches them back another 1 cm (Fig. 3). As the tips contract, the silk pulls the leaf further over into an almost complete roll. The larva continues this process of webbing the leaf and letting the contracting silk roll the leaf tip back on itself until it has completed 1 to 2-1/2 revolutions. The larva then enters the rolled-up leaf and spins silk across the 2 open ends of the cylinder. The silk contracts, closing the outer ends and forming a small chamber, 0.5 cm in diameter and 1 to 1.5 cm long, where the larva completes feeding (Fig. 4). When development is complete, the larva leaves the frass-filled chamber by cutting a 1.5 mm exit hole in the wall of the leaf cylinder. The larval stage from egg hatch to pupation requires approximately 40 days.

Pupa. The cocoon is spun 12.5 to 15 cm back from the shoot tip. The last instar larva finds a slight concavity in the underside of the leaf, often along the leaf edge, and lines it

lightly with silk. A thick sheet of silk is then spun over the top of the body to form a flat cocoon, 10 mm long x 4 mm wide x 1.5 mm thick. The exposed surface of the cocoon is opaque, white silk. The pupal stage lasts approximately 15 days. The pupa anterior is sharp, while the posterior tip contains numerous spines. Anchoring with these spines and bending the abdomen to obtain a push forward, the pupa forces the anterior end through the wall of the cocoon until the body is about halfway out. An adult then emerges, leaving the empty pupal case protruding from the cocoon (Fig. 5).

Feeding behavior. To determine if *C.* sp. nr. *schinella* was capable of feeding on any Hawaiian plants other than *M. faya*, host range testing was performed in quarantine on 84 species of native, ornamental, agricultural, and forest plants.

Of the 84 plant species tested, egg laying, followed by normal larval development leading to pupae and adults, was observed on only one species, the very closely related *M. cerifera* L. Of the 83 other species of plants tested, the females oviposited on many of them when no *M. faya* foliage was present, but the resulting larvae either could not penetrate the leaf cuticle, or if they could mine into the leaf, could not utilize it as a food source and died without completing development.

It was concluded from these feeding studies that if *C.* sp. nr. *schinella* was released in Hawaii and became established, it would pose no threat to plants other than the target weed, *M. faya*, and the very closely related weed species, *M. cerifera*. These host test results were compiled into a petition submitted to the HDOA Plant Quarantine Branch requesting permission to release this agent as a biological control agent for *M. faya* in Hawaii on April 20, 1990 (Markin 1990). After extensive reviews by members of several advisory boards, the permit (No. 03-91-H-5106) to release this agent was granted on March 12, 1991.

Field release. The first release of *C.* sp. nr. *schinella* consisting of 50 adults was made in the Volcanoes Golf Course subdivision near the Volcano Village and Hawaii Volcanoes National Park on the Island of Hawaii on July 24, 1991. Over 3 subsequent months, 3 additional releases were made at this site and 2 other localities in the subdivision. By October 21, a total of 725 adults and pupae had been released. In December 1991, live larvae were found at all release sites, indicating that establishment had occurred.

By the summer of 1994, the last year of the *M. faya* project, monitoring indicated the moth was well established in the Volcanoes Golf Course subdivision. In Hawaii Volcanoes National Park, it could be found around Kilauea Crater and in a southerly direction for at least 5 km out Chain of Crater's Road. In a northeast direction along Highway 11 towards Hilo, no evidence of the moth was found beyond the park boundary near Volcano Village. The *M. faya* project lost its funding and support in 1993, and by 1995 all personnel had been reassigned or transferred. However, during periodic visits (up to 1999) to the park and golf course area, *C.* sp. nr. *schinella* could still be found, but at very low population levels. Usually no more than 15 active feeding sites (mines, blotches, or leaf tip rolls) could be found in 15 minutes of visual search at any one location, about the same as 2 years after its release.

Parasitism. An effort was made to determine if any parasitoids had begun to utilize *C.* sp. nr. *schinella* as a host during 1993. All tip rolls believed to contain larvae were collected and placed in separate petri dishes. Several additional fresh leaves were added as a food source or pupation site, and the dishes were kept in a closed plastic sack to maintain high humidity. From the 43 tip rolls collected, 27 adults emerged and 15 larvae died (either in the tip roll or as pupae), most from a fungus. No parasitoids emerged from any of these field-collected larvae. From 9 live pupae collected in the field, 5 adults emerged, as well as 3 small, banded-winged parasitoids (*Glyptapanteles* sp. Hymenoptera: Braconidae). No effort was made to search for *C.* sp. nr. *schinella* eggs, but it was known from laboratory rearing that its eggs were attacked by 2 locally abundant egg parasitoids, probably *Trichogramma perkinsi* Girault and *T. chilonis* Ishii.

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