



Ecology, host specificity and impact of *Atomacera petroa* Smith (Hymenoptera: Argidae) on *Miconia calvescens* DC (Melastomataceae)

Francisco R. Badenes-Perez^{a,*}, M. Tracy Johnson^b

^a Pacific Cooperative Studies Unit, University of Hawaii at Manoa, Honolulu, HI 96822, USA

^b Institute of Pacific Islands Forestry, USDA Forest Service, Pacific Southwest Research Station, Volcano, HI 96785, USA

Received 16 March 2007; accepted 15 May 2007

Abstract

Miconia calvescens DC (Melastomataceae) is an invasive tree considered to be the greatest threat to natural ecosystems of Hawaii and other Pacific islands. The potential of the sawfly *Atomacera petroa* Smith (Hymenoptera: Argidae) as a biological control agent of *M. calvescens* was evaluated in field and laboratory studies in its native range in Brazil. At two field sites, 31.1% and 15.3% of the *M. calvescens* leaves sampled presented rasping damage by *A. petroa* larvae, affecting 2.0–66.7% (16.8% on average) of the area of each attacked leaf. Damage by *A. petroa* was significantly more frequent among older leaves (81.2% affected) than younger leaves (18.8% affected), and percentage of leaves damaged declined significantly with increasing stem diameter. Damage by individual *A. petroa* larvae feeding as first through sixth instars ranged from 304 to 924 mm² (663 mm² on average) of *M. calvescens* leaf material in the field. In the laboratory, *A. petroa* developed through the final three larval instars in 2.1, 2.5 and 3.1 d on average, respectively, pupated for 5–10 d, and survived as adults for 5–8 d. No feeding damage by *A. petroa* was observed on plant species associated with *M. calvescens* at field sites, including three other species of Melastomataceae, or on test plants exposed to *A. petroa* larvae in the laboratory, indicating that *A. petroa* has a narrow host range. Host specificity, foliar impact, and the likely absence of specialized natural enemies in Hawaii appear to justify further study of *A. petroa* as a biological control agent of *M. calvescens*.

© 2007 Elsevier Inc. All rights reserved.

Keywords: *Miconia calvescens*; *Atomacera petroa*; Sawfly; Weed management; Leaf area; Host specificity

1. Introduction

The velvet tree, *Miconia calvescens* DC (Melastomataceae), is a small tree native to Central and South America that is considered a serious threat to natural ecosystems in Hawaii and other Pacific islands because of its ability to invade intact native forests (Medeiros et al., 1997; Meyer, 1998). *M. calvescens* can outcompete the native vegetation of these islands and has displaced over 65% of the native forest in Tahiti since its introduction in 1937 (Meyer and Florence, 1996). Herbicides and mechanical removal are

the main methods used to contain the spread of *M. calvescens*, but control is difficult and costly, especially in remote areas. Biological control is considered an essential tool for long-term management of *M. calvescens* (Smith, 2002).

Argidae (Hymenoptera) is one of the most diverse families of sawflies in the neotropics, with 30 genera and approximately 300 species described (Smith, 1969, 2006). The subfamily Atomacerinae includes only the genus *Atomacera* and is restricted to the western hemisphere, mainly the eastern part of the Americas, from southeastern Canada to northern Argentina (Smith, 1992, 2006). Most larvae of Argidae feed externally on foliage, and several species are economically important defoliators (Cahoon and Stevenson, 1986; Smith and Middlekauff, 1987; Boyd and Cheatham, 2004). Two species of Argidae, *Schizocerca pilicornis* (Holmgren) (Gorske et al., 1977; Norris, 1997) and *Arge humeralis* (Beauvois) (Regas-Williams and

* Corresponding author. Present address: Department of Entomology, Max Planck Institute for Chemical Ecology, Hans-Knoell-Str. 8, D-07745 Jena, Germany. Fax: +49 03641 57 1502.

E-mail address: fbadenes-perez@ice.mpg.de (F.R. Badenes-Perez).

Habeck, 1979) have been considered for biological control of purslane and poison ivy, respectively.

Larvae of *Atomacera* spp. have been found feeding on plant species in the families Convolvulaceae, Fabaceae, Melastomataceae and Malvaceae (Lindquist and Trinnell, 1965; Boyd and Cheatham, 2004; Smith, 2006). Larvae of the sawfly *Atomacera petroa* Smith rasp the upper surface of *M. calvescens* foliage causing abundant scars and reducing photosynthetic tissue (Picanço et al., 2005; Smith, 2006). The original description of *A. petroa* only included morphological descriptions of the adults (Smith, 1992). Here, we study the biology, host specificity and impact of *A. petroa* under laboratory conditions and in the natural habitat of the insect in Brazil to evaluate its potential as a biological control agent of *M. calvescens*.

2. Materials and methods

This study was conducted at two field sites with native populations of *M. calvescens*, Viçosa and Dionisio, in the state of Minas Gerais, Brazil. Both areas were in secondary Atlantic forest heavily disturbed by adjacent agricultural activity and eucalyptus plantations. The Viçosa site, at 20°45'14''S and 42°52'53''W and 645 m above sea level, and the Dionisio site, at 19°50'34''S and 42°46'36''W and 345 m above sea level, lay approximately 150 km apart.

Laboratory studies were conducted on the campus of the Universidade Federal de Viçosa in a room exposed to ambient daylight, temperature and humidity. During the period of this study, from April to September 2006, the laboratory experienced a photoperiod of approximately 11–12 h:13–12 h light:dark, 22 ± 8 °C and 85 ± 10% RH. Climatic data for Viçosa were obtained from the Department of Agricultural Sciences of the Universidade Federal de Viçosa. Climatic data for Dionisio were provided by the “Estação Meteorológica de Ponte Alta” belonging to CAF Santa Bárbara Ltda.

2.1. Biology of *A. petroa*

A total of 20 *M. calvescens* plants were randomly selected and examined for presence of eggs, larvae, pupae and adults of *A. petroa* every four weeks from April to September 2006 in each of two locations (Viçosa and Dionisio). A minimum of one-third of the area of leaves and stems of each plant was examined if it was not possible to inspect the whole plant because of its location and/or large size. A correction factor was applied to calculate insect density per plant according to the approximate proportion of each plant sampled (e.g., if only 50% of a plant could be inspected, the total number of insects for the plant was determined as those in the 50% inspected multiplied by two).

Although larvae were easily collected in the field by removing the entire leaf where they were feeding, they were very sensitive to manipulation, and detaching them from the leaf resulted in their death within a few days.

Larvae were transferred successfully to rearing containers in the laboratory by carefully cutting the *M. calvescens* leaf approximately 2 mm around each larva without detaching it from the leaf surface. To study the life cycle of *A. petroa* on *M. calvescens*, 25 field-collected 3rd instars were placed individually in plastic food storage containers (30 × 15 × 10 cm) with one *M. calvescens* leaf (approximately 30 × 15 cm) with the adaxial side facing upwards. Observations were made every 24 h and larvae were transferred to a fresh leaf every 48 h until they pupated. Pupae were held in the same containers and were examined every 48 h. Emerging adults were offered a food source of 10% sugar solution in a 50 ml Erlenmeyer flask plugged with cotton. To study pupating behavior, five 6th instar larvae were placed on the leaves of an 80-cm tall 3-year-old plant grown in a 15 cm pot that was placed in a cylindrical plastic garbage can (1.0 m height × 0.5 m diameter). The container was sealed at the top with cheese cloth that had a mesh small enough (<0.5 mm) to prevent entrance of natural enemies. Observations were made 48 h later.

2.2. Host specificity of *A. petroa*

Plant species growing near *A. petroa*-infested *M. calvescens* were examined for *A. petroa* larvae and feeding damage in June 2006 (measurements taken as presence/absence). Inspected plants were located within a 10 m radius of each of five randomly selected *M. calvescens* plants at each field site. Plant species occurring in association with the native *M. calvescens* (monocolored) included outplanted *M. calvescens* from Hawaii (bicolored type with purple abaxial side of leaves), *Miconia prasina* (Sw.) DC, *Clidemia hirta* (L.) D. Don, and *Tibouchina granulosa* Cogn. (Melastomataceae); *Ricinus* sp. (Euphorbiaceae); *Desmodium* sp. (Fabaceae); *Ficus* sp. (Moraceae); *Musa paradisiaca* L. (Musaceae); *Eucalyptus* sp. and *Psidium guajava* L. (Myrtaceae); *Piper* sp. (Piperaceae); *Rubus* sp. (Rosaceae); *Coffea arabica* L. (Rubiaceae); and *Citrus* sp. (Rutaceae). At least three plants of each species were examined.

No-choice and two-choice experiments were conducted in the laboratory to compare survival of *A. petroa* larvae on a control of local *M. calvescens* vs. bicolored *M. calvescens* from Hawaii as well as lettuce, *Lactuca sativa* L. (Asteraceae), collards, *Brassica oleracea* L. var. *acephala* (Brassicaceae), and watercress, *Nasturtium officinale* Ait. F. (Brassicaceae). The latter three plant species were chosen because they are agricultural crops commonly grown in both Brazil and Hawaii and because they were readily available and allowed us to evaluate host range for two additional plant families, Asteraceae and Brassicaceae. Approximately, equal quantities of leaves (in terms of total leaf area) of each plant type were placed with the adaxial side facing upwards in plastic containers 30 × 15 × 10 cm. Field-collected larvae ranging from 3rd to 6th instars, five of each instar per replicate and treatment (i.e., a total of

20 larvae per replicate and treatment), were transferred to each experimental arena on cut leaf pieces. In the no-choice experiment, larvae were placed on test plant leaves. In the two-choice experiment, larvae were placed in the center of the experimental arena between a leaf of local *M. calvescens* and foliage of either *M. calvescens* from Hawaii, *L. sativa*, *B. oleracea* or *N. officinale*. Feeding damage and survival of larvae was assessed after 96 h. During the experiments, test leaves were maintained turgid by being kept in a closed container and being replaced by new ones after 48 h. All experiments were replicated three times.

2.3. Herbivory and impact of *A. petroa* on *M. calvescens*

Numbers of leaves damaged and not damaged by *A. petroa* larvae were counted on 20 *M. calvescens* plants randomly selected in May and September 2006 at each of the field sites. Whole plants were inspected, or when this was not possible because of the size or accessibility of the full plant, care was taken to examine at least one third of the total leaf area of the plant. To evaluate patterns in distribution of damage within plants, the number of fully expanded leaves was counted for each terminal branch examined in May 2006, and numbers of *A. petroa*-damaged leaves among the bottom (older) half and the top (younger) half of each branch were recorded (the normal pattern of leaf phenology is that the youngest/smallest leaves of a branch are the terminal buds at the top of the branch and the older/larger leaves are at the bottom of the branch). The basal diameter of each *M. calvescens* tree was recorded to assess abundance of *A. petroa* damage relative to the age of tree.

From all the plants sampled in the field in May, a total of 60 leaves with *A. petroa* damage were randomly selected in each field site and returned to the laboratory. Each leaf was pressed flat, and the adaxial surface was photographed with a digital camera. The area of the leaf affected by *A. petroa* was determined using WinFOLIA® leaf area analysis software (Regent Instruments Inc., 2003). Larvae of *A. petroa* feed on the adaxial side of *M. calvescens* leaves while moving backwards, consuming all leaf tissue except the lower epidermis and leaving a characteristic track history of feeding on the leaf. To separate the leaf damage caused by each instar in the field, 10 leaves presenting damage by the six instars of one larva of *A. petroa* were randomly selected in May 2006 at the field site in Dionisio. Damage by each instar was distinguished by the width of the injury tracks left on the leaf, which is correlated with larval cephalic capsule size. The area of the leaf affected by each instar of *A. petroa* was determined with the help of WinFOLIA® (Regent Instruments Inc., 2003). Feeding behavior of individual *A. petroa* larvae in the field was examined by collecting 10 leaves from plants at Dionisio in August 2006, with each leaf presenting damage by the six instars of a single larva of *A. petroa*. For each size class of feeding tracks (corresponding to each instar), five tracks were randomly selected for measurement of width and length. The

number of injury tracks produced by each instar was counted for each leaf. In addition to measurements of damage occurring in the field, leaf damage by the 25 larvae used to study the life cycle of *A. petroa* in the laboratory also was quantified using WinFOLIA® (Regent Instruments Inc., 2003). Data were recorded as leaf area damaged by each larva for each 48 h interval from 3rd instar to pupation.

2.4. Statistical analysis

Insect densities through time were evaluated using analysis of variance with PROC GLM procedure of SAS® (SAS Institute Inc., 2004). Relationships between leaf area damaged and larval development and between plant age and percentage of leaves with *A. petroa* damage were examined using stepwise multiple regression analyses with PROC REG procedure of SAS® (SAS Institute Inc., 2004). In all cases, when an *F* test indicated a significant effect at $P \leq 0.05$, means were separated by Fisher's protected least significant difference (SAS Institute Inc., 2004). Data for the distribution of *A. petroa* damage on leaves within a branch (top vs. bottom half) were analyzed using a paired *t* test. A square root transformation was used to normalize data on the distribution of *A. petroa* damage within a branch/plant. Although tests of significance for these analyses were based on the transformed data, only untransformed data are presented.

3. Results

3.1. Biology of *A. petroa*

Densities of *A. petroa* varied significantly through time at both Dionisio ($F = 60.30$, $df = 5$, 114 , $P < 0.001$) and Viçosa ($F = 60.30$, $df = 5$, 114 , $P < 0.001$) (Fig. 1). In Dionisio, larval populations peaked in June and July and disappeared in August when temperatures were lowest and conditions were dry (Fig. 2). In Viçosa, *A. petroa* lar-

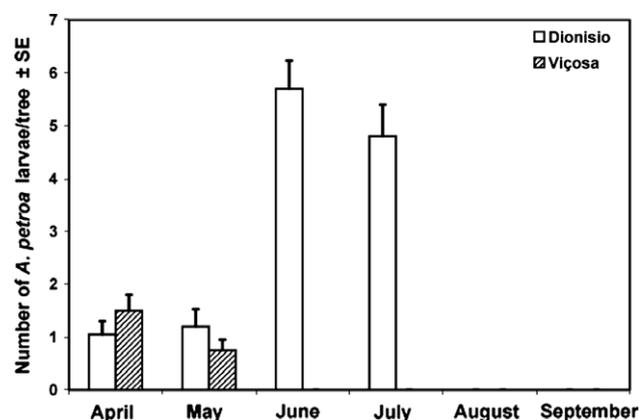


Fig. 1. Seasonal abundance of *A. petroa* in the natural habitat in Dionisio and Viçosa April through September 2006.

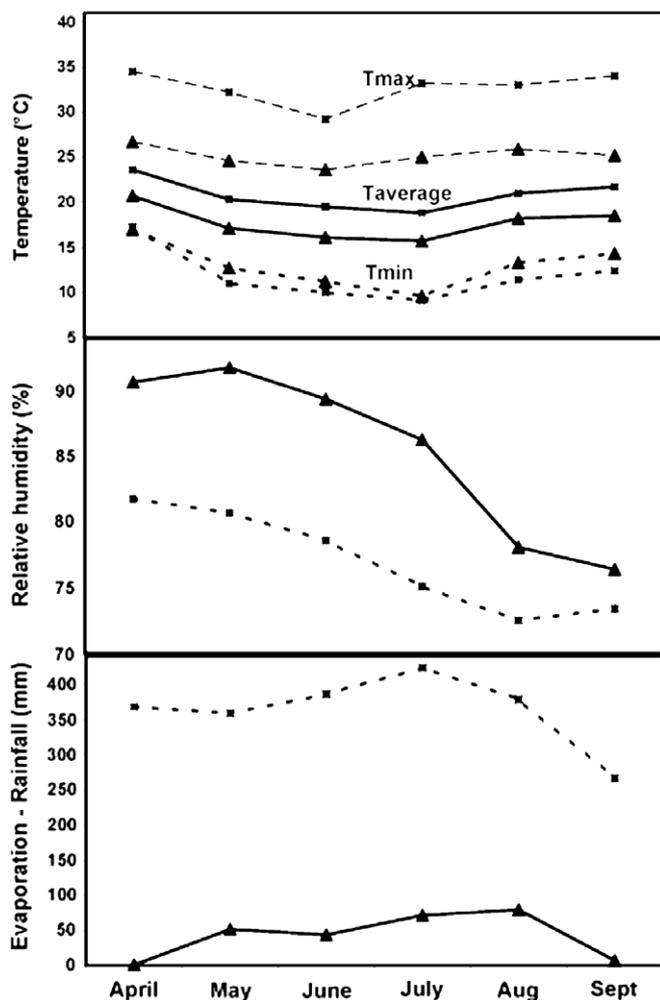


Fig. 2. Monthly temperatures (maximum, minimum and average), relative humidity and net evaporation (evaporation–rainfall) for field sites in Dionisio (▲) and Viçosa (■) during this study (April–September, 2006). Net evaporation is an estimate of the real loss of moisture from the soil, as it takes into account both gross evaporation and rainfall.

vae disappeared after April and May, corresponding with the arrival of the coldest winter months (Fig. 2). The differences in population densities between Dionisio and Viçosa could not be accounted for. No parasitoids or other natural enemies were observed attacking *A. petroa* in the field or among field-collected larvae taken to the laboratory.

When present, larvae in different instars were found, indicating overlapping generations. Up to six larvae of various instars were found on one leaf, although typically each leaf had only one larva. Inspections of *M. calvescens* leaves and stems with recent damage from late-instars of *A. petroa* yielded no pupae, indicating that larvae descend from plants to pupate in the soil or surface litter. In the laboratory, late instars placed on a large potted plant descended from the plant but drowned in water at the bottom of the container before they could pupate. Adults were only seen in the field once at midday. No eggs were found in the field or on leaves collected and examined in the laboratory.

In the laboratory, observations could only be made starting from the 3rd larval instar, as 1st and 2nd instars died soon after collection from the field and transfer to plastic containers. Older larvae moved off the leaf cuttings and started feeding on whole *M. calvescens* leaves within a few minutes of transfer. Based on head capsule measurements, most *A. petroa* larvae pupated after six instars (two laboratory-reared larvae developed through seven instars). In the laboratory, larval development (mean \pm SEM) averaged 2.1 ± 0.1 d for the 4th stadium, 2.5 ± 0.2 d for the 5th stadium, and 3.1 ± 0.2 d for the 6th stadium ($n = 25$). *A. petroa* pupated between the abaxial surface of the *M. calvescens* leaf and the surface of the plastic container. Pupation occurred in a cocoon that was light brown in colour and had a rectangular–prismatic shape (approximately $3.8 \times 1.5 \times 1.3$ mm). Adults emerged from the pupal case after five to ten days and lived five to eight days in May 2006 ($n = 10$). Adults did not emerge from 15 pupae experiencing low ambient temperatures between June and August, but did begin emerging in September when temperatures increased, indicating that the pupa probably is the overwintering stage.

3.2. Host specificity

In the field, *A. petroa* was only observed feeding on *M. calvescens*. Larvae were observed on both types of *M. calvescens* at one of the field sites (Viçosa), where plants of *M. calvescens* from Hawaii (bicolored type from Hawaii with purple abaxial side of leaves) had been planted between local *M. calvescens* plants (monocolored type from Brazil with green leaves). There was no apparent difference in the levels of abundance, or the extent of feeding damage caused by *A. petroa* on *M. calvescens* plants from Brazil and Hawaii (Badenes-Perez, personal observation). No *A. petroa* larvae were observed on any other plant species, including other Melastomataceae (*M. prasina*, *C. hirta* and *T. granulosa*) growing in the vicinity of *M. calvescens* plants attacked by *A. petroa*.

In no-choice experiments in the laboratory, *A. petroa* larvae exposed to plants other than *M. calvescens* moved off the plant leaf within a few minutes and began wandering around the plastic container. Larvae, which are usually bright green from food in their guts, became progressively clearer as a result of the lack of feeding on non-hosts. Except for two 6th instar larvae that pupated without feeding, all larvae died within 96 h in treatments without *M. calvescens*. Larvae were found feeding and healthy (100% survival) after 96 h in no-choice treatments with *M. calvescens* of either the Brazilian or the Hawaiian type. In choice experiments, only larvae that reached *M. calvescens* were alive after 96 h and survival rates were 100%, 88.3%, 85.0% and 86.7% on the treatments with Hawaiian *M. calvescens*, *L. sativa*, *B. oleracea* and *N. officinale*, respectively. No feeding damage was found on any of the plants tested other than *M. calvescens*.

3.3. Herbivory and impact of *A. petroa* on *M. calvescens*

Among randomly sampled trees, the mean percentage of leaves (\pm SEM) that presented damage by *A. petroa* was $26.5 \pm 3.4\%$ in May and $35.8 \pm 4.8\%$ in September at Dionisio and $24.1 \pm 4.6\%$ in May and $6.5 \pm 1.8\%$ in September at Viçosa. Among leaves damaged by *A. petroa* in May 2006, the total leaf area affected ranged from 3.3% to 50.0% (average of 17.3%) and from 2.0% to 66.7% (average of 16.2%) at Dionisio and Viçosa, respectively. Taking into account the average percentage of leaves with *A. petroa* damage per branch and the average leaf area damaged, the total damage per tree was estimated to range from 4.6% to 6.2% at Dionisio and from 3.9 to 1.1% at Viçosa for May and September, respectively. Leaves with various levels of damage from *A. petroa* persisted without abscission for several months after larvae were no longer present in the field.

Damage to leaves in the field confirmed laboratory observations that *A. petroa* has six larval instars (Table 1). An exponential function best described leaf area damage for the six instars ($y = -81 + 72x + 0.29e^x$, $n = 60$, $r^2 = 0.92$, $F = 156.64$, $P < 0.0001$) (Fig. 3). The size of the leaves where *A. petroa* damage was found ranged from 118 to 929 mm². In the laboratory, an exponential function also best described cumulative leaf area damaged by 3rd through 6th instars ($y = -353 + 143x + 1.91e^x$, $n = 100$, $r^2 = 0.91$, $F = 464.31$, $P < 0.0001$) (Fig. 3).

The percentage of leaves damaged by *A. petroa* decreased with increasing stem diameter at both Dionisio ($y = 7.8 - 0.8x$, $n = 20$, $r^2 = 0.30$, $F = 6.74$, $P = 0.012$) and Viçosa ($y = 8.1 - 1.5x$, $n = 20$, $r^2 = 0.50$, $F = 18.17$, $P < 0.001$), indicating that damage by *A. petroa* is relatively higher on younger plants than on older ones for the range of ages sampled (Fig. 4). Within a branch, of all leaves damaged by *A. petroa*, more were located on the bottom half than on the top half at both Dionisio (81.9% vs. 18.1% on average, respectively; $t = 5.47$, $df = 34$, $P < 0.001$) and Viçosa (80.6% vs. 19.4% on average, respectively; $t = 5.61$, $df = 28$, $P < 0.001$). This bias toward older leaves is consistent with the lack of *A. petroa* damage on leaves smaller than 118 mm².

4. Discussion

Larvae of *A. petroa* collected from the field could be reared in the laboratory as 3rd to 6th instars on detached

Table 1
Dimensions (mean \pm SD) of feeding tracks made by individual *A. petroa* larvae on separate *M. calvescens* leaves in the field ($n = 10$)

Instar	Width (mm)	Length (mm)	No of tracks per larva
1st	0.44 \pm 0.03	2.0 \pm 1.3	9.6 \pm 1.5
2nd	0.72 \pm 0.04	3.3 \pm 1.2	11.2 \pm 2.4
3rd	0.97 \pm 0.07	5.2 \pm 1.7	11.6 \pm 1.8
4th	1.13 \pm 0.05	6.7 \pm 4.6	12.0 \pm 1.9
5th	1.37 \pm 0.07	11.1 \pm 5.1	14.2 \pm 1.9
6th	1.51 \pm 0.10	9.5 \pm 4.0	14.2 \pm 1.5

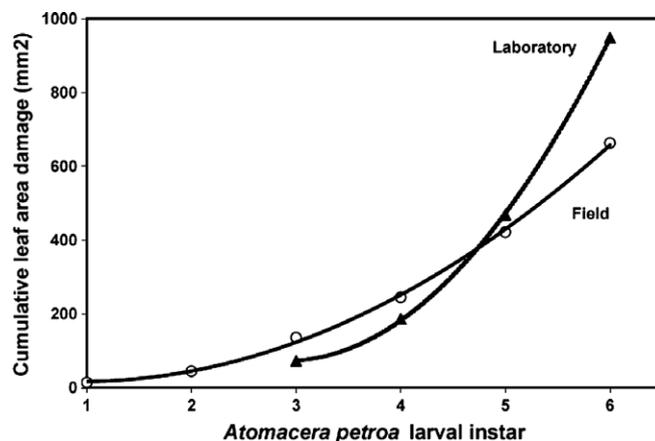


Fig. 3. Cumulative leaf area damage by individual larvae of *A. petroa* in the field ($n = 60$) and in the laboratory ($n = 100$).

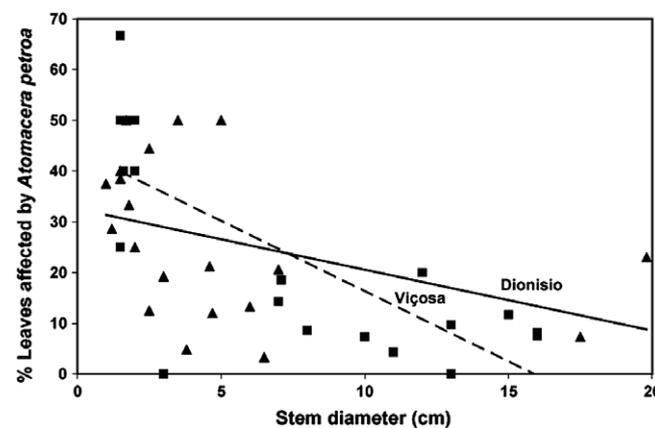


Fig. 4. Percentage of leaves damaged by *A. petroa* in relation to stem basal diameter of plants sampled in Dionisio (\blacktriangle) and Viçosa (\blacksquare) in May 2006.

M. calvescens leaves in plastic containers. Larvae pupated successfully in these containers, following an apparent natural behavior to descend from the plant to pupate in leaf litter, as do other *Atomacera* spp. such as *A. debilis* and *A. decepta* (Weiss and Lott, 1923; Lindquist and Trinnell, 1965; Tippins, 1965). Unfortunately, asynchronous emergence of our few and relatively short-lived adults did not permit observation of mating and oviposition. Eggs of *A. petroa* were never seen, but most likely are inserted singly into tissue at leaf margins or on the adaxial side of leaves, where larvae from 1st to 6th instar were always found feeding, typically solitarily. Most adults of female Symphyta insert their eggs on the leaves of their host plants, using their saw-like ovipositor to cut vegetable tissue (Smith, 2006). Further research is needed to investigate conditions for mating and oviposition in order to determine how *A. petroa* might be successfully reared through its entire life cycle in quarantine.

Miconia calvescens is the only known host plant for *A. petroa*. A similar *Atomacera* species has been found feeding on *M. calvescens* and *Miconia astroplocama* Donn. Sm. in Costa Rica (Johnson, personal observation). These obser-

vations together with preliminary host specificity testing reported here suggest that *A. petroa* is restricted to a few *Miconia* spp. Host ranges of other Atomacerae are poorly known in general, but two well studied North American species are restricted either to a single plant genus (Boyd and Cheatham, 2004) or to a few closely related genera in the same family (Smith, 1969). Although more extensive host specificity tests in quarantine will be required if *A. petroa* is selected for further evaluation as a potential biocontrol agent, its host range appears likely to be suitably narrow for Hawaii, where there are no native Melastomataceae (Smith, 2002).

Damage by *A. petroa* in its natural habitat was pervasive but low, on average affecting no more than 6% of the overall leaf area of *M. calvescens*. The levels of damage caused by *A. petroa* observed in the field were consistent with seasonal abundance of larvae taking into account that even heavily damaged leaves remained attached to trees for several months (*A. petroa* feeding did not appear to accelerate leaf drop). Damage by *A. petroa* larvae was more common in trees with smaller basal diameter (younger trees) and on leaves located in the bottom part of a branch (older leaves of the branch). Preference for older foliage also has been shown to occur in other sawfly species, such as most pine-feeding sawflies (Haack and Mattson, 1993). The defoliating effect of *A. petroa* could be complemented with the introduction of other natural enemies of *M. calvescens* that feed on other parts of the plant. For example, *Diclidophlebia* spp. in Brazil and Costa Rica (Homoptera: Psyllidae) attack mainly younger leaves, growing tips and inflorescences of *M. calvescens* (Burckhardt et al., 2005; Picanço et al., 2005; Morais, 2007) and were often observed simultaneously in trees affected by *A. petroa* (Badenes-Perez, personal observation).

Our assessment of herbivory by *A. petroa* indicated that larvae kept in the laboratory fed more vigorously than those in the field. This may have been caused by lack of disturbance from biotic (e.g., natural enemies) or abiotic factors (e.g., heavy rain), which could reduce feeding intensity by *A. petroa* in the field. Leaves presented to *A. petroa* in the laboratory were free of damage, whereas leaves where *A. petroa* larvae fed in the field often were previously damaged by other *A. petroa* larvae, requiring more movement to feed within the leaf. Alternatively, larvae in the laboratory may have needed to consume more leaf material because food quality, in terms of nutrients and water, was lower on detached leaves than on leaves still attached to the plant.

The impact of a herbivore on a host plant depends on the population dynamics of the herbivore, which in turn depend on a variety of biotic and abiotic factors. Although *A. petroa* larvae are not gregarious, one of the general characteristics shared by sawflies species causing outbreaks (Haack and Mattson, 1993; Larsson et al., 1993), their populations are likely to grow to higher densities in the absence of factors that limit them in their native habitat. Indirect evidence of mortality of *A. petroa* larvae in the field in Bra-

zil included occasional leaves bearing feeding tracks of early instars but without the larger tracks made by later instars. It is not clear what might have caused such mortality. There was no evidence of heavy rainfall having a significant detrimental effect on *A. petroa* larvae (Badenes-Perez, personal observation). Parasitoids and other natural enemies of *A. petroa* were not observed, in spite of collection and laboratory rearing of more than 100 larvae. In contrast, *Antiblemma* sp. larvae (Lepidoptera: Noctuidae) occupying the same ecological niche (*M. calvescens* leaves) at the Dionisio field site were heavily parasitized (Badenes-Perez, unpublished). Since members of the family Argidae do not exist in Hawaii and other Pacific islands where *M. calvescens* is an invasive weed, the probability of *A. petroa* encountering parasitism if introduced for biological control appears low. However, generalist predators such as vespid wasps and ants might be a significant source of mortality in Hawaii (Gambino et al., 1987; Reimer, 1994). The abiotic environment in Hawaii appears favorable for *A. petroa*. Moderate and consistent average temperatures (20–27 °C), relative humidity (70%) and rainfall (200–300 mm/month) in the areas of *M. calvescens* infestations in Hawaii (Jovic and Jovic, 1998) indicate that environmental factors limiting seasonal development of *A. petroa* in Brazil (extreme temperatures and low humidity) are less likely to impede population growth in Hawaii. High humidity seems to be essential for sawfly development in general, especially for the thin-integumented larvae and for eggs that depend on healthy plant tissue (Smith, 1993). The climatic suitability of Hawaii, combined with the likelihood that *A. petroa* is highly host-specific, suggests that this insect deserves further consideration as a potential agent for biological control of *M. calvescens*.

Acknowledgments

We thank Drs. Robert Barreto and Marcelo Picanço as well as people working in their laboratory groups at the Universidade Federal de Viçosa for assistance conducting this study. Funding was provided by the Hawaii Invasive Species Council and the US Forest Service International Programs.

References

- Boyd, D.W., Cheatham, C.L., 2004. Evaluation of twelve genotypes of *Hibiscus* for resistance to hibiscus sawfly, *Atomacera decepta* Rohwer (Hymenoptera: Argidae). *J. Environ. Hort.* 22, 170–172.
- Burckhardt, D., Hanson, P., Madrigal, L., 2005. *Diclidophlebia lucens*, n. sp. (Hemiptera: Psyllidae) from Costa Rica, a potential control agent of *Miconia calvescens* (Melastomataceae) in Hawaii. *Proc. Entomol. Soc. Wash.* 107, 741–749.
- Cahoon, D.R., Stevenson, J.C., 1986. Production, predation, and decomposition in a low-salinity *Hibiscus* marsh. *Ecology* 67, 1341–1350.
- Gambino, P., Medeiros, A.C., Loope, L.L., 1987. Introduced vespids *Paravespula pennsylvanica* prey on Maui's arthropod fauna. *J. Trop. Ecol.* 3, 169–170.
- Gorske, S.F., Hopen, H.J., Randell, R., 1977. Bionomics of the purslane sawfly, *Schizocerella pilicornis*. *Ann. Entomol. Soc. Am.* 70, 104–106.

- Haack, R.A., Mattson, W.J., 1993. Life history patterns of North American tree-feeding sawflies. In: Wagner, M.R., Raffa, K.F. (Eds.), . Sawfly Life History Adaptations to Woody Plants. Academic Press, San Diego, CA, pp. 503–545.
- Jovic, S.P., Jovic, J.O. (Eds.), 1998. Atlas of Hawaii. University of Hawaii Press, Honolulu, HI.
- Larsson, S., Björkman, C., Kidd, N.A., 1993. Outbreaks in Diprionid sawflies: why some species and not others? In: Wagner, M.R., Raffa, K.F. (Eds.), Sawfly Life History Adaptations to Woody Plants. Academic Press, San Diego, CA, pp. 453–483.
- Lindquist, O.H., Trinnell, J.R., 1965. The tree foil sawfly, *Atomacera debilis* Say (Hymenoptera: Argidae), in Ontario. *Can. Entomol.* 97, 181–184.
- Medeiros, A.C., Loope, L.L., Conant, P., McElvaney, S., 1997. Status, ecology and management of the invasive plant *Miconia calvescens* DC (Melastomataceae) in the Hawaiian Islands. *Bishop Mus. Occ. Pap.* 48, 23–36.
- Meyer, J.-Y., 1998. Observations on the reproductive biology of *Miconia calvescens* DC (Melastomataceae), an alien invasive tree on the island of Tahiti (South Pacific Ocean). *Biotropica* 30, 609–624.
- Meyer, J.-Y., Florence, J., 1996. Tahiti's native flora endangered by the invasion of *Miconia calvescens* DC (Melastomataceae). *J. Biogeogr.* 23, 775–781.
- Morais, E.G.F., 2007. *Dichidophlebia smithi* (Hemiptera: Psyllidae) como agente de controle biológico da planta invasora *Miconia calvescens*. MSc Thesis. Universidade Federal de Viçosa, 68p.
- Norris, R.F., 1997. Impact of leaf mining on the growth of *Portulaca oleracea* (common purslane). *J. Appl. Ecol.* 34, 349–362.
- Picanço, M.C., Barreto, R.W., Fidelis, E.G., Semeao, A.A., Rosado, J.F., Moreno, S.C., de Barros, E.C., Silva, G.A., Johnson, M.T., 2005. Biological control of *Miconia calvescens* by phytophagous arthropods. Technical Report 134. Pacific Cooperative Studies Unit, University of Hawaii at Manoa, Honolulu, HI, pp. 31.
- Regas-Williams, K.A., Habeck, D.H., 1979. Life history of a poison ivy sawfly *Arge humeralis* (Hymenoptera: Argidae). *Fla. Entomol.* 62, 356–363.
- Regent Instruments Inc., 2003. WinFOLIA® 2003d. Quebec, Canada.
- Reimer, N.J., 1994. Distribution and impact of alien ants in vulnerable Hawaiian ecosystems. In: Williams, D.F. (Ed.), . Exotic Ants: Biology, Impact, and Control of Introduced Species. Westview Press, Boulder, CO, pp. 11–22.
- SAS Institute Inc., 2004. SAS/STAT® User's Guide. Version 9.1. SAS Institute Inc., Cary, NC.
- Smith, D.R., 1969. Key to genera of the nearctic Argidae (Hymenoptera) with revisions of the genera *Atomacera* Say and *Sterictiphora* Billberg. *T. Am. Entomol. Soc.* 95, 439–457.
- Smith, D.R., 1992. A synopsis of the sawflies (Hymenoptera: Symphyta) of America south of the United States: Argidae. *Mem. Am. Entomol. Soc.* 39, 1–201.
- Smith, D.R., 1993. Systematics, life history, and distribution of sawflies. In: Wagner, M.R., Raffa, K.F. (Eds.), . Sawfly Life History Adaptations to Woody Plants. Academic Press, San Diego, CA, pp. 3–32.
- Smith, C.W., 2002. Forest pest biological control in Hawaii, Technical Report 129. In: Smith, C.W., Denslow, J.S., Hight, S. (Eds.), . Workshop on Biological Control of Invasive Plants in Native Hawaiian Ecosystems. Pacific Cooperative Studies Unit. University of Hawaii at Manoa, Honolulu, HI, pp. 91–102.
- Smith, D.R., 2006. Los Sinfitos. In: Hanson, P.E., Gauld, I.D. (Eds.), Hymenoptera de la Region Neotropical. *Memoirs of the American Entomological Institute* 77, 1997, Gainesville, FL, pp. 166–201.
- Smith, D.R., Middlekauff, W.W., 1987. Argidae (Tenthredinoidea). In: Stehr, F. (Ed.), . Immature Insects. Kendall/Hunt Publishing, Dubuque, IA, pp. 625–627.
- Tippins, H.H., 1965. The sawfly *Atomacera decepta*, a pest of *Hibiscus*. *J. Econ. Entomol.* 58, 161.
- Weiss, H.B., Lott, R.B., 1923. Notes on the desmodium sawfly *Atomacera desmodii* Dyar. *Entomol. News* 34, 167.