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July 26, 2010

Katherine Kealoha, Esq.
Director
Office of Environmental Quality Control
235 South Beretania Street, Suite 702
Honolulu, Hawaii 96813

Dear Ms. Kealoha:

Subject: Finding of No Significant Impact (FONSI) for "Field Release of *Secusio extensa* (Butler) (Lepidoptera: Arctiidae), for Biological Control of Fireweed, *Senecio madagascariensis* Poiret (Asterales: Asteraceae), in Hawaii"

The Hawaii Department of Agriculture has reviewed the draft EA. The draft EA was published in the Environmental Notice on April 23, 2008. A 30-day public comment period began on April 23, 2008, but no comments were received. The agency has determined that this project will not have significant environmental effects and has issued a FONSI.

We have enclosed a completed OEQC Publication Form and four copies of the final EA. Please call Dr. Neil Reimer at 973-9522, should you have any questions.

Sincerely,

A handwritten signature in black ink, appearing to read "Sandra Lee Kunimoto".

Sandra Lee Kunimoto
Chairperson, Board of Agriculture

Enclosures

Field Release of *Secusio extensa* (Butler) (Lepidoptera: Arctiidae), for Biological Control of Fireweed, *Senecio madagascariensis* Poiret (Asterales: Asteraceae), in Hawaii

**Final Environmental Assessment
July 2010**

**Proposing Agency contact:
Dr. Neil Reimer
Plant Pest Control Branch
Hawaii Department of Agriculture
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**Determining Agency:
Hawaii Department of Agriculture
Sandra Lee Kunimoto, Chair
1428 S. King St.
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Phone: (808) 973-9550**

I. Project Description, Purpose, and Need

A. Description of proposed action:

The Hawaii Department of Agriculture (HDOA) proposes to release the moth *Secusio extensa* (Butler) (Lepidoptera: Arctiidae) into Hawaii as a natural enemy to control Madagascar fireweed, *Senecio madagascariensis* Poiret. This plant is a highly invasive and poisonous weed in pastures, rangelands, and wayside areas on most of the major islands, but mainly the islands of Hawaii and Maui. The objective of this project is for the released natural enemy to reduce the fireweed populations to low levels so that they are no longer a significant problem to livestock and the environment. The release of this natural enemy is expected to result in long-term control of this invasive and toxic weed.

B. Background information on the pest to be controlled:

Classification of target (host) organism

The pest species

According to Wagner, et al. (1990), *Senecio madagascariensis* Poiret belongs to the family Asteraceae, one of the most successful families of flowering plants. In Hawaii, this family is represented by 76 genera and 181 species distributed in 11 of the 13 tribes. There are 91 native species (90 endemic and 1 indigenous) in 12 genera. A total of 90 species in 67 genera have become naturalized. Many of these are common weeds but some have proven to be highly invasive. There are 3 species in the genus *Senecio*, all immigrants that have become naturalized, including *S. madagascariensis*.

S. madagascariensis is commonly known as fireweed, Madagascar fireweed, Madagascar ragwort, and common groundsel. It is a low (10 to 50 cm), upright, branched herb with variable growth habit and leaf structure. In coastal areas of Australia, it is usually observed as a low, heavily-branched, short-lived perennial bush. Generally, the leaves are bright green, alternate, and narrow with serrated, entire, or lobed margins. The broader leaves are 2 to 6 cm long, occasionally 8 to 10 cm on mature plants. The flowers are small (1 to 2 cm in diameter), yellow, and daisy-like, usually with 13 petals, and can number from 2 to 200 per plant. The seeds are small (1 to 3 mm in length), light, slender, and cylindrical in shape with a downy surface, and attached to a pappus of fine, silky, white, feathery hairs. The plant has a shallow, branched tap root with numerous fibrous roots, growing from 10 to 20 cm deep. (Motooka, et al. 2004).

Madagascar fireweed has been spreading widely in the Hawaiian Islands since its first appearance around 1980. The plant competes very successfully in useful pastures and is currently invading more than 400,000 acres of valuable rangelands on the Island of Hawaii and Maui. Infestations on Oahu, Molokai, and Kauai have been contained by mechanical means (personal communication, Nilton Matayoshi and Becky Azama, HDOA). Infestations are so widespread on the islands of Hawaii and Maui that chemical and mechanical control is not economically practical. Estimated chemical control of fireweed on the Big Island of Hawaii alone may exceed eleven million dollars per year for three herbicide treatments of 350,000 acres. Thus, biological control is believed to be the only effective, practical, long-term means of

suppressing and limiting further dispersal of this highly invasive weed in pastures, rangelands, and wayside and natural areas.

A comparison of fireweed in Hawaii with what is found in Madagascar and South Africa, the two main regions where fireweed is believed to be endemic, clearly illustrates the potential of herbivores in those native fireweed habitats to suppress populations of this weed. Under favorable conditions in Hawaii, fireweed readily disperses throughout overgrazed pastures and other disturbed sites. In Madagascar and South Africa, under similar growing conditions, only occasional plants are found.

Life history of the target organism

Fireweed is highly adaptable to changes in the environment. In Australia, the plant behaves as a short-lived perennial under favorable conditions, but, under arid conditions, it behaves as an annual. In the field, various stages of development from seedlings to flowering plants can be observed throughout most of the year. Germination of the seeds depends on rainfall but is also stimulated by light and warm temperatures. Flowers are produced 6 to 10 weeks after seedlings emerge. The seeds can germinate immediately after they are released from the flower head. Thus, the plant may produce 6 to 8 generations per year. The light, fluffy seeds are readily spread by wind, which is considered to be the major factor for dispersal over large areas and long distances. They can also be spread in hay and grain products, on clothing and vehicles, and by livestock, birds, and other animals. Fireweed plants can produce large quantities of seed over a long period. Each flower produces between 100 and 150 seeds. Thus, a single large plant has the ability to produce approximately 25,000 or more seeds with high viability. Fireweed can also grow vegetatively. Stems root at the nodes when in contact with moist soil. Fireweed has the ability to grow on a wide range of soil types from fertile clay soils to sandy soils low in fertility, but the optimum soil is one that is well-drained and lighter in texture. (Allan, et al. 2001).

Pest status of Madagascar fireweed

In Hawaii, fireweed has been declared a noxious weed under Chapter 68, Hawaii Administrative Rules (HAR) and a pest for control or eradication in Chapter 69A, HAR. Its seed is a prohibited noxious weed seed in Chapter 67, HAR.

Fireweed is an invasive plant that quickly infests heavily grazed or neglected pastures, cultivated land, and other disturbed sites. It is a strong competitor against pasture forage plants for light, moisture, and soil nutrients, particularly phosphorus and nitrogen (Allan, et al. 2001). Fireweed is an opportunistic weed with the ability to invade a wide range of habitats in a short period of time. In Australia, *S. madagascariensis* has had a significant impact on agriculture as a result of its invasiveness, competitiveness with pasture forage, and toxicity to livestock. In combination with its high seed production, ease of distribution, adaptability and variability in the field, germination, growth, and flowering during much of the year, alkaloid content, and the absence of effective natural enemies in its new range of distribution, fireweed readily achieves its invasive potential. Fireweed plants produce large numbers of viable wind-blown seeds which form dense infestations. The seedlings develop rapidly and produce flowers as early as six weeks after emergence. The avoidance of the weed by cattle greatly favors its growth and competitiveness, and reduces pasture yield and grazing area (Sindell, 1996).

Fireweed, like many other *Senecio* species, contains a pyrrolizidine alkaloids (senecionine and other related chemotypes) (McBarron, 1976), which is toxic to livestock. When ingested, it accumulates in and damages the liver resulting in the reduction of growth of these animals and, in severe cases, death. The disease is progressive, with symptoms and mortality occurring weeks or months after consumption of the plants (Bull, 1955).

C. Background information on the natural enemy to be released

Secusio extensa (Butler) (Lepidoptera: Arctiidae) Life History

S. extensa eggs are dome-shaped, 0.8 mm in diameter, 0.75 mm in height, and smooth with no reticulations. They are creamy to white when freshly deposited and turn black one day before hatching. Usually, the eggs are laid singly or in batches of up to 62 eggs with unmated females more apt to lay eggs singly or in smaller batches of up to 35 eggs. The eggs of this moth, in the field, are usually laid on the underside of leaves. The upper side of leaves, stems, and, occasionally, flower heads may be used as oviposition substrates. In the laboratory, females lay eggs on the sides of plastic rearing containers and cage surfaces and frequently deposit fresh eggs onto previously laid batches. Unlike other Lepidoptera, the presence of a host plant in a rearing container is not necessary for oviposition. Mean egg duration is 5.7 days at ambient temperature. The egg hatching rate was estimated from random samples taken from every generation. Mean egg hatch for the first 21 generations (all reared on fireweed under quarantine conditions) from a total of 8,312 eggs was $77.3 \pm 5.3\%$ and ranged from 36.2% to 98.3%, depending on the mating rates among cohorts.

The larval stage consists of five instars. Young larvae (first and second instars) feed gregariously on the lower surface of leaves and disperse as they mature. The head of the larva is smooth with only primary setae and six ocelli. The head is covered dorsally by long thoracic setae. Like on most arctiids, the body of the larva is densely covered with dark, plumose setae. The larvae crawl rapidly and feed at night. Feeding on fireweed, first instar increase in size to a length of 2.8 mm with a head capsule width of 0.4 mm during a period of 4.3 days. The head capsules of first instar are dark brown, yellow in the next three instars, and light brown in the fifth. When the host plant is not found, first instar may feed on other eggs in the rearing container. However, larval cannibalism has never been observed among the five instars. If the natural host (fireweed) is not available, first instar perish within 48 hours without any sign of feeding on each other. First instar are capable of producing silken thread when brushed away from the host. The other succeeding instar do not and, thus, prefer to curl and drop from the plant when disturbed. Second instar increase in size to 5.8 mm long with a 0.6 mm wide head capsule that is yellow during a period of three days. Third instar grow to 9.9 mm long with a 0.8 mm wide head capsule during a period of 3.9 days. Fourth instar enlarge to 13.9 mm long with a 1.4 mm wide head capsule during a period of 4.3 days. Fifth (final) instar increase in size to 26.4 mm in length with a head capsule width of 2.2 mm during a period of 7.3 days. This duration is highly variable, depending on the quality of the host plant.

Larval feeding, as observed from the damage done to fireweed host plants, increases

significantly with each instar during the larval stage spanning just over three weeks. Voracious feeding by fifth instar is the most damaging to the plant as they devour the leaves and may even strip the outer layers (epidermis and cortex) of the stems. They apparently do not have a liking for the fireweed inflorescence because, most of the time, these are left intact. Fifty *S. extensa* larvae (fifth instar) are able to completely defoliate four full-grown fireweed plants in one-gallon plastic pots confined in a cage. These plants never recover from the defoliation and they all die. The fifth instar spins a light silken cocoon sprinkled with larval setae. Mature larvae usually pupate between layers of newspapers at the bottom of the rearing cage. Unlike other arctiids, no pupae are formed on the walls of the cages or on the plants. The prepupa loses most of the long setae, become about one cm shorter than the average mature larva, and remains as a prepupa for a day before developing into a pupa.

The pupa is oblong, about half the length of a mature larva, stout, and brown with dark stripes. The forewing has eight dark longitudinal bands. All abdominal segments have dark stripes. The male antenna has a dark stripe on the outer margin extending for more than half its length. It extends to less than half the antennal length in the female pupa. The pupa has seven pairs of spiracles on abdominal segments two to eight. The ninth abdominal segment of the male is complete, bearing a genital slit between two slightly elevated kidney-shaped pads. The eighth abdominal segment of the female is divided by the ninth with a genital opening in the middle. The male pupa is slightly smaller in length and width than the female pupa. The duration of the pupal stage is 11.3 days for both sexes. The whole life span of *S. extensa* is 41.1 days, producing up to nine generations per year when the larvae are fed fireweed under conditions that exist in the HDOA Insect Containment Facility.

The adults are medium-sized, beige-colored moths with various shades of brown mottling on the forewings, including many small, dark brown spots on the proximal portion of the forewings and, also, on the pronotum. There are larger dark brown spots aligned on the mid-dorsum of the beige thorax and on the yellow-orange, somewhat elongate, yet truncated abdomen. The wings of the adults, when at rest, are held roof-like over their bodies. The adults are nocturnal.

Natural geographic range of *Secusio extensa*

Caterpillars of the fireweed moth, *S. extensa*, were collected from the southern region of Toleara Province, Island of Madagascar, in October 1999. Young and mature larvae were collected from fireweed infested plants at three localities along the sand dunes of the Indian Ocean. Collection sites were at Saint Luce, Evatra, and Fort Dauphin. Elevations of the three sites ranged from 6 to 79 meters and day temperature ranged from 24 to 34 degrees C. Larvae were reared to the pupal stage on field collected fireweed cuttings immersed in water. The initial cohort produced from this collection consisted of 606 pupae, which resulted in the emergence of 398 adults (34% pupal mortality) with a sex ratio of 51.7% females. A laboratory colony was established on potted plants or cuttings of fireweed for studies on bionomics and host range. *S. extensa* is considered to be the most damaging insect to fireweed during the summer season in Madagascar. Heavy feeding caused rapid destruction of the plants during this time of the year. An average of eight larvae was observed feeding on each plant in the native region.

Identification of *S. extensa* is credited to Dr. John Rawlins, Associate Curator at the Carnegie Museum of Natural History, Section of Invertebrate Zoology, Pittsburgh, PA. There is no

published information on the life history of this moth. The genus contains a number of other species of which *Secusio pustularia* Walker and *S. pulverata* from mainland Africa are closely related (Mlawula Nature Reserve Fauna 2005). The larvae are very close to members of the subfamily Nyctemerinae, many of which are obligate feeders on species of the tribe Senecioneae (*Emilia*, *Senecio*, and other genera) (DaCosta and Weller 2005).

There are mixed taxonomic opinions on the genus identity of this moth. Butler first described *S. extensa* under the genus *Sommeria* from specimens collected in Madagascar at Betsileo. *S. extensa* was later placed in the genus *Diota* and subsequently changed to *Galtara*. The type species is *Galtara extensa* Butler, the only species in this genus from Madagascar. *Galtara purata* Walker, 1860, is the type for genus *Galtara*, and *Secusio strigata* Walker, 1854, is the type for genus *Secusio*. If *G. purata* and *S. strigata* are congener, then the senior valid generic name would be *Secusio*. Until this problem is solved, Systematist J. Rawlins prefers to place it under the senior name *Secusio* (J. Rawlins, Carnegie Museum, personal communication with M. Ramadan). Nonetheless, ever since this species was described by Butler in 1880, there have been no records for both names (*G. extensa* or *S. extensa*) anywhere in the world to indicate that this insect is a pest on any crop or that it has a preference for any plant other than herbs and weed members of the tribe Senecioneae.

The other mottled beige arctiid species in mainland Africa is *Diota rostrata* and this too has been found only on Senecioneae. USDA is now considering it for use in California for biocontrol of *Delairea odorata*, formerly *Senecio mikanioides*. *Secusio pustularia* Walker is another related species commonly found in Mlawula, Swaziland. There are no records to indicate that it is a pest of any African crop or other plants of value.

While other species of the genus *Secusio* (*S. pulverata*, *S. pustularia* Walker, *S. strigata*, *Secusio* spp.) are common on the African continent (Swaziland, Rwanda, and South Africa), *S. extensa* is not recorded in any survey. It is only found in Madagascar in habitats where populations of *S. madagascariensis* are present. Two field surveys were conducted by HDOA Exploratory Entomologist in Madagascar during the summer (October 1999) and the rainy seasons (April 2005). During these seasons, examination of all plants around and in between fireweed populations infested with *S. extensa* indicated that this insect was found only on *S. madagascariensis*. Plants examined included those in the families Asteraceae and Rubiaceae, and also sweet potato, cassava, cucurbits, rice, pineapple, tomato, and various grasses. Close examination of four common herbs of Asteraceae (*Emilia tranvaalensis*, *Tridax procumbens*, *Sonchus oleraceus*, and *Bidens pilosa*) present at the survey sites in Madagascar showed that the plants were not attacked by *S. extensa* larvae.

Host range of *S. extensa*

Appendix 1 (pp. 24-27) lists the known host range of *S. extensa*, as determined by exposures of test plants to adults for oviposition and to larvae for feeding tests during host specificity studies in cages in quarantine. Studies included both no-choice and choice host testing. Host specificity tests were conducted on 71 endemic and naturalized species (52 genera) in 12 tribes of Asteraceae and 17 species of non-Asteraceae including six native shrubs and trees considered key components of Hawaiian ecosystems.

Recorded Host Range

No information on non-target hosts of this moth could be found in the literature. The only information found in literature on *Secusio extensa* was taxonomic. There was no available information on the biology and habits of this moth species.

Parasites/hyperparasites

Parasitoids of *S. extensa* were not found during field explorations in East Africa, as well as during the unpacking and processing of the collected materials and propagation and colonization of the species in the HDOA Insect Containment Facility in Honolulu.

Status as hyperparasite

Not applicable.

Locations of rearing facilities and release sites

The HDOA Insect Quarantine Facility is located at 1428 South King Street, Honolulu, Hawaii. If *S. extensa* is approved for release from quarantine as a biocontrol agent, mass propagation of the moth will be done in the HDOA Insect Rearing Facility at the same location. *S. extensa* will be shipped to the other Hawaiian islands for release where needed.

Number/quantity to be released

Releases will continue to be made until the insect becomes established. Numbers released per month are expected to be on the order of hundreds of larvae and adult moths.

Timing of release

No particular timing of releases is made. Areas of high fireweed populations on the Big Island and Maui will have preference for inoculative releases of *S. extensa*.

II. Alternatives to the Proposed Action

The actions being considered in this EA are (1) No Action (not issuing a permit) or (2) issuing a permit for release of *S. extensa*. The no action alternative is equivalent to an acceptance of the types and intensities of current impacts associated with infestations of fireweed. The issuance of a permit would result in releases of *S. extensa* that would, if successful, remove the undesirable influence of fireweed on the environment, and those of alternative control practices on fireweed in the absence of *S. extensa*.

III. Environmental Impacts of the Proposed Action and Alternatives

Expected environmental impacts of the proposed release

Field observations in Madagascar of *Secusio extensa* and quarantine studies in Hawaii strongly indicate that the proposed release of this fireweed biocontrol agent will not have any undesirable, negative, non-target effects on the natural environment of the Hawaiian Islands. Environmental impacts associated with the no action alternative of not issuing permits for release are those resulting from damage to the environment and the cattle industry caused by fireweed infestations and those caused by other methods employed to control fireweed infestations (both types of impacts are now occurring). The proposed release and establishment of *S. extensa* is intended to reduce these impacts. In the absence of effective natural enemies of fireweed, possible negative environmental impacts caused by repeated use of herbicides to control fireweed infestations add to the existing negative impacts caused by the displacement of desirable plants by fireweed. Use of chemical herbicides to control fireweed would be reduced if the proposed biological control agent becomes permanently established in the environment and is able to sufficiently impact population densities of fireweed. The suppression of fireweed to very low densities will greatly reduce the incidence of fireweed poisoning of cattle. The probability of establishment and degree of control can only be determined after the proposed releases are made.

Potential impacts on human environment

There will be no impact of the release of this moth on the human environment in Hawaii. No negative impacts on human activities are anticipated. A positive impact would be the reduction of fireweed in pastures and rangelands, thus reducing the opportunities for cattle and other grazing animals to be poisoned from the ingestion of fireweed plants or plant parts and, thereby, greatly reduce opportunities for the poison to taint beef for human consumption. No desirable animal is known to intentionally feed on any part of the fireweed plant, so the suppression of fireweed will not deplete the food source of any animal.

Literature search for other host records

As reported previously in this document, literature search for information on *Secusio extensa* disclosed that no information was available other than those regarding the taxonomy of this species. Also, there was nothing to indicate that *S. extensa* had ever been used for biological control anywhere else in the world. Thus, the only information presently available on host records is found in the research paper by Ramadan (Appendix 1) of his studies of the bionomics and host range of *S. extensa*.

Host specificity in country of origin

Field observations by the HDOA Exploratory Entomologist during his explorations for natural enemies of fireweed in Madagascar left no doubt that *Secusio extensa* larvae would restrict its feeding to *Senecio madagascariensis* (fireweed). *S. extensa* larvae were never found feeding on any other plants, including those in the family Asteraceae and, even more specifically, there was no evidence of feeding on *Emilia* spp., which is in the same tribe Senecioneae as fireweed, even though the larvae were readily observed on fireweed plants growing in close proximity.

Interactions with established biocontrol agents

S. extensa may interact with other natural enemies introduced to control fireweed in the future. However, no adverse impact on the other agents is anticipated from the presence of this new biocontrol agent in Hawaii. This moth will put a great deal of stress on fireweed plants by defoliating them. No insect has ever been purposely introduced into Hawaii to attack fireweed. A few generalist phytophagous insects have been reported but these have no significant impact on fireweed populations. *S. extensa* is not expected to have any significant interaction with these insects.

Potential impact on T&E species

Based on field observations in Madagascar and host specificity studies in quarantine in Hawaii, no negative impact on any threatened and endangered (T&E) species of plant or animal is anticipated. These studies demonstrated that only plants in the tribe Senecioneae serve as viable hosts for *S. extensa*. The larvae also completed development on *H. annuus* in the tribe Heliantheae in no-choice, tests but this was an inferior host resulting in small larvae and adults, and progeny with low fecundity and poor mating success. (see Appendix 1)

There are 33 species of plants in the family Asteracea on the T&E species list as designated under the US Endangered Species Act. These 33 species belong to 8 genera. HDOA conducted host specificity studies with 6 T&E species and test plants in 7 of the 8 genera containing T&E species. No feeding or development by *S. extensa* was observed in any of these tests. One genus, *Hesperomannia*, was not tested due to the rarity of this species and the negative impact collecting this species in the wild would have on the existing population. Based on studies with other plants of the same tribe (Vernonieae) it is not expected that *S. extensa* can develop on this plant

None of the organisms on the list of T&E animals and insects have the potential to feed on fireweed and therefore would not be impacted by its control.

Impact to related non-target potential hosts

Field observations in Madagascar and host specificity studies in quarantine in Hawaii have clearly shown that *S. extensa* will have no significant negative impact on non-target potential hosts in Hawaii, including plants in the same family (Asteraceae) and even those in the same tribe (Senecioneae).

Potential of *S. extensa* to act as a hyperparasite

Not applicable. There is no data that would suggest that *S. extensa* could possibly act as a hyperparasite. Although a predatory caterpillar has been discovered in Hawaii, there are no hyperparasitic Lepidoptera anywhere in the world.

Potential of *S. extensa* to attack non-targets

Extensive testing demonstrated that *Secusio extensa* is host specific to the tribe Senecioneae, which does not contain any native or economically important plant species in Hawaii. The one

exception was *Helianthus annuus* on which *S. extensa* did complete one generation, however the resulting progeny were smaller, had poorer mating success and were less fecund than larvae fed on plants in the Senecioneae, demonstrating that this is an inferior host that cannot sustain a population of the moth. A more complete explanation can be found in Table 1 and Appendix 1.

Field observations in Madagascar and host specificity tests in quarantine in Hawaii have confirmed that *S. extensa* will not survive on native non-target plant species and, thus, will not have any negative impact on the natural environment in Hawaii.

Larvae did not feed on any non-Asteraceae tested, including species with similar pyrrolizidine alkaloid chemistry, crops, and six ecologically prominent native species. (see Appendix 1)

IV. Environmental Assessment Process and Environmental Permits

A. Basis for Environmental Assessment

This Environmental Assessment was prepared in accordance with Chapter 343, Hawaii Revised Statutes (HRS) by the proposing agency. The EA was triggered because state funding was used by HDOA in the research conducted. As the release will impact a significant agricultural pest, the Hawaii Department of Agriculture is acting as the approving agency in accordance with Chapter 343.

A draft environmental assessment (EA) was prepared by the proposing agency and posted in The Environmental Notice of the Office of Environmental Quality Control on April 23, 2008. No comments on the draft EA were received by the Proposing Agency or the Determining Agency during the 30 day comment period.

B. Environmental Permits

The proposed action requires permits from United States Department of Agriculture Plant Protection and Quarantine (USDA/PPQ) and the Hawaii Board of Agriculture (BOA).

Conditions for the importation of *S. extensa* into the HDOA Insect Containment Facility have been obtained from USDA/PPQ. USDA/PPQ and BOA permits with permit conditions for the release of *S. extensa* from the facility into the environment may be obtained once the federal EA is finalized and if a FONSI declared.

V. Listing of Agencies and Persons Consulted

A. Public Meetings

This proposed action, to release *Secusio extensa* for control of Madagascar fireweed, has gone through a public notification process through the Board of Agriculture permitting process. This

is in accordance with Chapter 92 (Public Agency Meetings and Records), HRS, commonly referred to as the Sunshine Law. As part of this process the public was notified and had the opportunity to attend, comment and testify on this proposed release at the Plants and Animals Committee meeting. No comments opposed to this action were presented at this public meeting.

B. List of Consulted Parties

Following is a list parties, agencies, and individuals that were consulted:

- Dr. John E. Rawlins, Invertebrate Zoology Section, Carnegie Museum of Natural History, Pittsburgh, Pennsylvania, made the species determination of specimens of *Secusio extensa*. According to Rawlins, he is not aware of anything that has been published on the life history of *S. extensa*. Having received specimens of larvae as well as adults, Rawlins stated that the larvae are very close to those of other nyctemerines, many of which are known to be obligate feeders on Senecioneae (*Emilia*, *Senecio*, and other genera).
- Hawaii Cattlemen's Association
- Hawaii Cattlemen's Council
- James Greenwell, Palani Ranch Co.
- United States Fish and Wildlife Service, Ecological Services, Dr. Patrick Leonard
- United States Department of Agriculture, Plant Protection and Quarantine
- Hawaii Invasive Species Council
- Coordinating Group on Alien Pest Species (CGAPS)
- Department of Business, Economic Development & Tourism, Small Business Regulatory Review Board
- Dr. Lorna Arita-Tsutsumi, entomologist, University of Hawaii, Hilo
- Dr. Peter Follet, entomologist, USDA Agricultural Research Service
- Dr. Frank Howarth, entomologist, Bishop Museum
- Dr. Arnold Hara, entomologist, University of Hawaii, Manoa
- Dr. Ronald Mau, entomologist, University of Hawaii, Manoa
- HDOA Plants and Animals Committee
 - Mr. Clyde Tamaru, University of Hawaii, Manoa
 - Mr. Rob Hauff, Department of Land and Natural Resources
 - Ms. Carol Okada, Department of Agriculture
 - Mr. Ken Redman, Honolulu Zoo
 - Mr. Ken Matsui, Petland
 - Dr. Sarah Park, Hawaii Department of Health
 - Dr. John McHugh, Hawaii Farm Bureau

Table 1.
Summary of Issues Raised During Consultation

Question or Concern	Response of Hawaii Department of Agriculture
<p>The data presented indicate a wider potential host range than described in the abstract and proposal; however, non-target impacts on native species will probably be limited to periods when moth populations are high – that is, if it successfully controls the target. During high populations dispersing moths will be faced with no-choice tests in nature. There is also a possibility of a significant host shift to a non-target. However, the risk may be small compared to the damage done by the target. No information is given on potential impacts of the adults.</p>	<p>Field observations by HDOA Exploratory Entomologist in Madagascar, where <i>Secusio extensa</i> was collected, showed them feeding only on fireweed, despite the presence of four common Asteraceae; <i>Emilia transvaalensis</i> (tribe Senecioneae), <i>Sonchus oleraceus</i> (tribe Lactuceae), and <i>Bidens pilosa</i> and <i>Tridax procumbens</i> (tribe Heliantheae).</p> <p>Oviposition alone is not a criteria for host determination. Even if <i>S. extensa</i> eggs are laid on other plants, the larvae must feed and successfully develop over many generations, otherwise it will die out.</p> <p><u>Conclusion:</u> <i>Secusio extensa</i> was not observed to attack any other Asteraceae in the fireweed habitat in its Madagascar homeland and will unlikely host-shift to related plant species in Hawaii.</p>
<p>A major lacuna (missing part) in the study is the potential impacts on native predators, especially the endangered Hawaiian Hoary Bat. All stages are reported to be toxic to a wide range of organisms. Although I agree most native birds may not come in contact with the active stages (except the elepaio?), bats are generalists nocturnal predators of flying insects, and moths are suitable prey. It is also possible that native spiders and other predators could be adversely affected. <i>Secusio</i> will need to attain high population densities to control the weed and therefore may come in contact with native predators in high numbers.</p>	<p>The pyrrolizidine alkaloids (PA) found in fireweed are acquired by the <i>S. extensa</i> larvae after feeding on the plant, then presumably sequestered into non-toxic metabolites transformed and stored to use as a deterrent to predators and courtship pheromones. As shown in other studies, insects and vertebrates find alkaloid-laden insects distasteful. Similarly, <i>S. extensa</i> will be unpalatable to native Hawaiian spiders, bats, and birds, and there should be no impact on them. Native Hawaiian birds are day feeders and should not interact with the nocturnal larvae and adults. Also, there is no documented evidence to show that other insects feeding on poisonous plants have been detrimental to native predators in Hawaii.</p>
<p>What do the adults feed on? Are they pollinators of weeds?</p>	<p>The adults are nectar feeders. Moths with their specialized mouthparts for taking nectar, won't be a major pollinator of weeds in Hawaii which are primarily wind pollinated. There are already many insects that visit flowers in Hawaii that are specialized as pollinators, such as bees, wasps, beetles, and flies.</p>
<p>Concern about poor track record of biocontrol in Hawaii, i.e, mongoose</p>	<p>The mongoose was never an officially sanctioned biocontrol project in Hawaii. HDOA conducts science-based studies on host specificity and biocontrol releases have been regulated since the mid 1970's. There have been over 50 biocontrol releases since then that have successfully controlled the target pest and none have attacked non targets.</p>
<p>The natural enemy is not truly host-specific, since it feeds on a wide range of plants in the tribe Senecioeae, as well as a few species in related tribes. The data presented suggest feeding on non-target species will be minor, but over time the agent may adapt to related hosts</p>	<p>In no-choice host range tests, the biological control agent <i>Secusio extensa</i> completed development on fireweed (the target host) and five other test species in the tribe Senecioneae. Of the five test species, <i>S. extensa</i> larvae had a high feeding rate and a high percentage survivorship for the plant species <i>Delairea odorata</i>, <i>Senecio vulgaris</i>, and <i>Crassocephalum crepidioides</i>. This data was significant enough to designate these as "permissible" or potential hosts. <i>Secusio extensa</i> larvae had low feeding rates and a low percentage of survivorship on <i>Emilia fosbergii</i> and <i>Erechtites hieracifolia</i>, designating them as "inferior" or unlikely hosts. All five plant species are exotics that have become naturalized in Hawaii.</p>

	<p>For the tribe Heliantheae, <i>S. extensa</i> completed development on only one test species, the sunflower plant, <i>Helianthus annuus</i>. The feeding rate and percentage survivorship of <i>Secusio extensa</i> larvae on sunflower was significantly lower than on its natural host, fireweed. Sunflower was therefore designated an “inferior” host.</p> <p>To further define the host potential of sunflower, larval feeding choice tests were conducted by placing first-instar <i>Secusio extensa</i> larvae inside a cage and allowing the wandering larvae to choose between the test and normal host plant. The larvae consistently fed only on fireweed and developed to the fifth-instar while sunflower leaves sustained only superficial damage. In one replicate, larvae had completely devoured the fireweed plant, but remained to feed on the stems rather than move to the sunflower plant that was touching it. In other replicates, where larvae were placed on the sunflower plant to start, the larvae moved off to feed on the fireweed. These tests show the preference to feed on its natural host in the presence of sunflower plants.</p> <p>Ovipositional choice tests were also conducted with sunflower to determine preference as an egg-laying site for <i>Secusio extensa</i>. No eggs were deposited on sunflower as there was clearly no interest by <i>S. extensa</i> females to oviposit on them, compared with its natural host, fireweed, for which a mean of 75 eggs was found on the plants.</p> <p>Although six test plant species (five in the tribe Senecioneae and one in the tribe Heliantheae) supported development of <i>Secusio extensa</i> to the adult stage, there were lower rates of male mating success among them as compared to the natural host plant. The production of mating volatile components in arctiid moths is contingent on larval access to their natural host plants containing pyrrolizidine alkaloid (PA) precursors. Rates of unmated females among pairs of <i>S. extensa</i> reared from <i>Crassocephalum crepidioides</i>, <i>Helianthus annuus</i>, <i>Emilia fosbergii</i>, <i>Senecio vulgaris</i>, and <i>Delairea (=Senecio) odorata</i>, were 1.5 - 3.3 folds higher than rates of unmated females reared from the natural host, <i>S. madagascariensis</i>. This is an indication of lower quality males reared on plants with a smaller amount or different chemotypes of PAs than the senecionine of the natural host. Colonies of <i>S. extensa</i> reared exclusively for three generations on <i>C. crepidioides</i> were in decline under laboratory conditions. Therefore, it is probable that the continuous rearing of the moth on these plants would not allow the moth to sustain a perpetuating population in the field for the lack of PAs.</p> <p><u>Conclusion:</u> <i>Secusio extensa</i> shows host specificity to the tribe Senecioneae, which does not contain any native or economically important plant species in Hawaii.</p>
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VI. Findings and Reasons

Chapter 11-200-12, HRS, outlines those factors agencies must consider when determining whether an action has potential for a significant effect.

1) *Involves an irrevocable commitment to loss or destruction of any natural or cultural resources.*

The fireweed is not a natural or cultural resource. In fact, fireweed is detrimental due to it's

competitive nature and toxicity to natural and cultural resources such as native plants. Control of fireweed will be beneficial to natural and cultural resources.

2) Curtails the range of beneficial uses of the environment.

The proposed action will not curtail beneficial uses of the environment. In fact, it will cause a decline in the population of fireweed which is toxic to livestock and competitive with other plants.

3) Conflicts with the state's long-term environmental policies or goals and guidelines as expressed in Chapter 344, HRS, and any revisions thereof and amendments thereto, court decisions, or executive orders.

The proposed action does not conflict with the state's environmental policies or goals and guidelines as expressed in Chapter 344, HRS. The proposed action is in harmony with these guidelines as it will protect native flora and plant feeding animals from this weed.

4) Substantially affects the economic or social welfare of the community or state.

The proposed action will have a positive effect on the economic welfare of the state. Fireweed occupies an estimated 400,000 acres and is toxic to livestock. Poisoning often occurs when small plants intermixed with desirable forage are ingested by livestock while grazing. Chemical control of fireweed on the Big Island is estimated to exceed eleven million dollars annually. This expense will not be needed with a successful biocontrol agent suppressing the weed population.

5) Substantially affects public health

The proposed action will have no negative effect on public health.

6) Involves substantial secondary impacts, such as population changes or effects on public facilities.

No secondary impacts on population changes or public facilities are expected from the control of this weed.

7) Involves a substantial degradation of environmental quality.

No substantial degradation of environmental quality is expected from the release of this natural enemy. In fact, environmental quality should improve due to decreases in this weed.

8) Is individually limited but cumulatively has considerable effect upon environment or involves a commitment for larger actions

The proposed action is limited to controlling a significant pest to livestock. No cumulative negative effect on the environment is anticipated

9) Substantially affects a rare, threatened or endangered species, or its habitat.

The proposed action is not anticipated to substantially affect rare, threatened or endangered species or their habitat. The natural enemy is host specific to the weeds in the tribe Senecioneae in Hawaii. No native, rare, threatened or endangered plants are closely related to its host.

Studies by HDOA demonstrated that the natural enemy will not attack native, endemic, rare, endangered, or threatened plant species in Hawaii. Also, no threatened or endangered species

feed on fireweed.

10) Detrimentially affects air or water quality or ambient noise levels.

The proposed action, to release *S. extensa*, is not anticipated to affect air or water quality or ambient noise levels. Reductions in fireweed populations may have a positive local impact on water quality with the decrease in the use of herbicides.

11) Affects or is likely to suffer damage by being located in an environmentally sensitive area such as a flood plain, tsunami zone, beach, erosion-prone area, geologically hazardous land, estuary, fresh water, or coastal water.

The proposed action is not anticipated to have any impact on the environmentally sensitive areas.

12) Substantially affects scenic vistas and view planes identified in county or state plans or studies.

The proposed action is not anticipated to affect scenic vistas or view planes.

13) Requires substantial energy consumption.

No substantial energy consumption will be required for this proposed action.

Issues of Uncertainty

Uncertainty regarding the consequence of a subject action requires evaluation as part of an EA. In the case of the proposed project, questions regarding uncertainty were expressed during the consultations.

One concern related to the uncertainty that *S. extensa* may attack non-target plants. The commenters were satisfied with the evidence in Appendix 1 in which host specificity studies were conducted on related plants that are known to occur in Hawaii and only other related weeds served as potential hosts for this natural enemy. *Secusio extensa* was able to complete its life cycle on *Helianthus annuus* in no-choice but not choice tests, however, the resulting progeny were smaller, less fecund, and had poorer mating success demonstrating that this is an inferior host and populations of *Secusio* will not survive well on this host under natural conditions.

In summary, there is no action that has consequences that are completely predictable, and thus there is uncertainty associated with any proposed action, including this one. Uncertainty must be weighed against potential benefits of an action and adverse impacts that are likely to occur if an action is not undertaken. In this case, there is a consensus among ranchers and biologists in Hawaii that fireweed is deleterious to agriculture and the native flora. The uncertainty associated with biocontrol of fireweed appears to be low, due to the rigorous testing of this biocontrol agent and the general success of biocontrol projects in Hawaii. Balanced against the certainty of the damage posed by fireweed, the levels of uncertainty associated with the proposed action appear acceptable.

VII. Final Determination

The Hawaii Department of Agriculture has reviewed the draft EA. The draft EA was published

in the Environmental Notice on April 23, 2008. A 30-day public comment period began on April 23, 2008 but no comments were received. The agency has determined that this project will not have significant environmental effects and has issued a FONSI.

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VII. Appendices

Appendix 1 - Ramadan, M. M. 2006. Bionomics and Host Range of *Secusio extensa* (Butler) (Lepidoptera: Arctiidae), a Potential Biocontrol Agent of *Senecio madagascariensis* Poiret (Asteraceae). Report of the Hawaii Department of Agriculture, Plant Pest Control Branch.

**Bionomics and Host Range of *Secusio extensa* (Lepidoptera: Arctiidae), a
Potential Biocontrol Agent of
Senecio madagascariensis Poiret (Asteraceae)**

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Table of Contents

Abstract.....	3
Introduction.....	4
Materials and Methods.....	7
Origin of population.....	7
Identity and description.....	7
The test plants	8
Insect rearing and colony maintenance	11
Biology and life history studies.....	12
General host-range protocols	13
Larval Feeding Tests.....	13
No-Choice Tests.....	13
Estimation of feeding rates	13
Choice Tests.....	14
Tests on species recommended by U.S. Fish and Wildlife Service	14
Tests with non-Asteraceae plants and species containing pyrrolizidine alkaloids.....	15
Oviposition Choice Tests with <i>Helianthus annuus</i>	15
Oviposition Choice Tests with <i>C. crepidioides</i> , <i>S. vulgaris</i> , and <i>B. pilosa</i>	16
Data analysis	16
Results.....	17
Reproductive biology	17
Immature stages and development	18
Larval feeding no-choice tests	22
Larval feeding choice tests with sunflower.....	31
Oviposition choice tests with sunflower	35
Oviposition Choice Tests with <i>C. crepidioides</i> , <i>S. vulgaris</i> , and <i>B. pilosa</i>	35
Discussion.....	38
Acknowledgments.....	44
References.....	45

Abstract

The Madagascan fireweed, *Senecio madagascariensis* Poiret (family Asteraceae, tribe Senecioneae), has naturalized on the Hawaiian islands and is now one of the most invasive weeds infesting more than 400,000 acres of rangelands on the islands of Hawaii and Maui. Fireweed is also toxic, containing hepatoxins that affect grazing animals, primarily cattle and horses. The disease is progressive with no specific treatment. Prevention is ultimately the best approach

The biology and host range of the arctiid moth *Secusio extensa* (Butler) (Lepidoptera: Arctiidae), a potential biological control agent of fireweed, were determined in the Hawaii Department of Agriculture Insect Containment Facility. Colonies of this moth were introduced from three localities in southeastern Madagascar in 1999 and maintained for host range testing at $28 \pm 2^{\circ}\text{C}$ and RH 60 -80%. Host specificity tests were conducted on 71 endemic and naturalized species (52 genera) in 13 tribes of the family Asteraceae.

Host specificity tests indicated that plant species of the tribe *Senecioneae* were suitable for larval development with limited survival on *Emilia* and *Erechtites*. When tested on plants in the *Senecioneae* tribe, first instars completed development to adults on *Delairea odorata* (66.1%), *Senecio vulgaris* (57.1%), and *Crassocephalum crepidioides* (41.2%). *D. odorata* (Cape ivy), a declared noxious weed in mamane forests on the islands of Hawaii and Maui, was favorably consumed. Not more than 2.0% of the larvae developed to adults on *Emilia fosbergii* and *Erechtites hieracifolia*. Limited development (11.6%) to the adult stage was also observed on *Helianthus annuus* (sunflower), only during starvation no-choice trials in comparison to 78.3% adult development on the natural host, *S. madagascariensis*. *Helianthus. annuus* was entirely rejected as a potential host in choice larval-feeding and adult oviposition trials involving the primary host *S. madagascariensis* as control.

Furthermore, the larvae did not commence development on six native species of forest trees and shrubs recommended for testing by the U. S. Fish and Wildlife Service. These plants, major components of Hawaiian native ecosystems, are (*Dodonaea viscosa* Jacq. [Sapindaceae], *Cibotium glaucum* (Sm.) Hook.& Arn. [Dicksoniaceae], *Acacia koa* A. Gray [Fabaceae], *Sophora chrysophylla* (Salisb.) Seem. [Fabaceae], *Myoporum sandwicense* A.Gray [Myoporaceae], and *Metrosideros polymorpha* Gaud. [Myrtaceae]).

Results clearly show that *S. extensa* is strongly restricted to its natural host *S. madagascariensis*. Some larvae developed partially on other members of the tribe *Senecioneae*, which are also declared noxious weeds in the State of Hawaii. There are no native (endemic or indigenous) species in the tribe *Senecioneae* in the Hawaiian Islands.

Introduction

Fireweed is native to the southeastern region of Africa, where it is known to occur from coastal sites to 1,500 m above sea level. It is widely distributed in southern Africa from Madagascar and the Mascarene Islands through coastal Mozambique to Kwazulu-Natal and the Eastern and Western Cape provinces of South Africa (Sindel et al. 1998). In Madagascar, fireweed is present as occasional and isolated small populations restricted to the low altitude southeast and the semi-arid southwest part of the island (Marohasy 1989). In its native region, fireweed is not perceived as an invasive species and is only common on vacant lands, sand dunes, lands cleared for agriculture, and wayside areas (M. Ramadan, personal observations).

Fireweed has a variable growth habit and leaf shape dependant on the type of soil and habitat, Figure1 (M. Ramadan, personal observations, DNR Pest Facts 1998). An Australian botanist identified specimens collected from Madagascar, and South Africa as *Senecio madagascariensis* based on chromosome count and DNA studies with very low variation from the weedy form of *S. madagascariensis* complex in Australia (Scott et al. 1998). DNA leaf analysis of the Hawaiian and South African, Kwazulu-Natal, fireweed populations showed that they are identical (Le Roux et al. 2006). However, the Hawaiian infestation is assumed to have been started from carpet grass seed shipments from Australia (Motooka et al. 2004).

Away from its natural enemies in native lands, this species is now a significant weed of agricultural grasslands in Australia, spreading throughout many parts of coastal New South Wales and southeastern Queensland, and Argentina, the southeastern part of Buenos Aires province (Sindel et al. 1998). Recently, also recognized as a noxious weed in Colombia, Venezuela, Uruguay, and Japan (Satoru, K. et al.1999, also website: <http://www.museum.comet.go.jp/ogawa/narutosawagiku/default.htm>). Efforts to control well-established Australian populations of fireweed using mechanical, chemical herbicides, and extant herbivores have failed and efforts to introduce specific biocontrol agents were halted by the lack of funds (Marohasy 1989, MacFadyen and Sparks 1996).

Fireweed has been spreading widely in the Hawaiian Islands since its first appearance around 1980. The plant competes successfully in useful pastures and is currently invading more than 400,000 acres of valuable rangelands on the Island of Hawaii and Maui. Infestations on Oahu and Kauai have been contained by mechanical means (personal communication, Nilton Matayoshi, HDOA). Infestations are so widespread on Hawaii and Maui that chemical and mechanical control is not economically practical. Estimated chemical control of fireweed on the Big Island of Hawaii alone may exceed eleven million dollars per year for three herbicide treatments of 350,000 acres. Therefore, natural enemies that feed exclusively on fireweed should be effective in reducing the plant populations and the reliance on costly chemicals.

Fireweed is unpalatable and livestock generally avoid eating them, however, cattle will be forced to eat it when other feed is not available (Sindel and Michael 1988, Scott et al. 1998). As they

invade fields, they are often included as contaminants in feeds and grains that are readily eaten by most animals, particularly the young saplings (Sindel 1986). All parts of fireweed are known to contain pyrrolizidine alkaloids (PA) of the senecionine chemotype, which accumulate in the liver and are converted into toxic compounds responsible for liver damage. Poisoning often occurs when small plants intermixed with desirable forage are ingested accidentally by cattle and horses while grazing. Young animals are more vulnerable to PAs (Small et al. 1993). There is evidence that senecionine may accumulate in milk and cause symptoms in young animals consuming the milk. Contaminated hay or silage may also cause poisoning since the toxins are unaffected by drying (Dickinson et al. 1976). At Honokaa, Hawaii, 17 cattle have died, all associated with alkaloid poisoning (Pat Conant, HDOA, and report of veterinarian diagnostic report, Veterinary Associates, Inc. Kamuela, Hawaii, June 19, 2002).

Available clinical and experimental data suggest that a single episode of senecionine toxicity, and possibly a long-term low-level exposure, may lead to cirrhosis of the liver. Senecionine could also be a possible carcinogen in humans, since it has been demonstrated to induce cancer in experimental animals, the main target organ being the liver (Anonymous 2004, Deinzer et al. 1977). People drinking herbal teas and milk, or consuming honey contaminated with senecionine are at risk even if the quantities consumed are minor (Turner and Szczawinski, 1995). Therefore, animals grazing or resistant sheep used to control fireweed should not be offered for human consumption.

Only general herbivores (e.g. grasshoppers, weevils, thrips, aphids, scale insects, and mites) are feeding on fireweed in Hawaii, causing insignificant damage. The introduction of more adapted species and specific diseases appears to be the only sound and logical method to curb the increasing spread of this invasive toxic weed.

After exhausting all control measures in Australia, entomologists were convinced that biocontrol was the only long term solution for the fireweed problems (MacFadyen and Sparks 1996) Two Madagascan moths were tested but disqualified by Australian researchers for their attack on the native *Senecio lautus* as heavily as the fireweed (MacFadyen 1995). Since then, the Australian program has not received further funding for explorations in Africa.

The Hawaii Department of Agriculture initiated a survey in the native region of fireweed in South Africa and Madagascar for potential biocontrol agents during August and September of 1999. During this survey, eleven insects and two pathogens were shipped to the quarantine facility for evaluation and host range testing. A yellow rust fungus identified as *Puccinia lagenophorae* from fireweed in Australia, South Africa, and Madagascar was tested on 42 species in eight tribes of Asteraceae. The rust severely infected fireweed, but tests were discontinued when two Hawaiian endemic species were found to be susceptible (Killgore et al. 2001). The survey has resulted in the recognition of five insect flower-head feeders, three stem borers, a root feeder, and a Madagascan arctiid moth, whose larvae are voracious defoliators, as potential biocontrol agents. Host testing on seven potential biocontrol agents were terminated because of rearing problems or minimal impact on fireweed.

Because fireweed belongs to the family Asteraceae with half of the Hawaiian species being endemic and containing several endangered species, very specific insects are sought before permissions for release are granted. However, unlike Australia, there is no endemic or native species of the tribe *Senecioneae* in Hawaii and none of the naturalized species is economically important. Several potential candidates from the southern African and Madagascan biocontrol agents offer the possibility of a long-term solution of fireweed in the Hawaiian Islands.

This report contains results of detailed studies on the bionomics and host range of the Madagascan fireweed moth, *Secusio extensa* (Lepidoptera: Arctiidae). A cohort of this species was introduced to the Hawaii Department of Agriculture Insect Quarantine Facility in October 1999 and maintained for host range testing. Bionomics and host specificity of this promising candidate were determined to address its effect on the plant and its possible impact on non-target species. Governmental regulatory authorities require such information for release permits.



Figure 1: Healthy field collected fireweed, *Senecio madagascariensis*, Oahu 2004. Perennial branched herb with alternate dark green leaves and serrated margin (2-6 cm long). Flowers are daisy-like (1-2 cm diam.) with 13 petals, and 19-22 involucral bracts. Small cylindrical seed (2-3 mm long) with rows of fine hairs and silky pappus. One plant may produce up to 30,000 seeds (DNR Pest Facts 1998, Motooka et al 2004). Photos by Ron Heu, and Walter Nagamine, (Hawaii Dept. of Agriculture).

Materials and Methods

Origin of population:

Caterpillars of the fireweed moth, *Secusio extensa* (Butler), (Lepidoptera: Arctiidae), serious defoliators of fireweed (Figures 2, 3), were collected from the southern region of Toleara Province, Island of Madagascar on October 1999. Young and mature larvae were collected from fireweed infested plants at three localities along the sand dunes of the Indian Ocean, Saint Luce (24°.46' S, 47°. 10' E), Evatra (24°. 48' S, 47°. 05' E), and Fort Dauphin (25°.02' S, 46°.56' E). Elevations on the three sites ranged from 6 to 79 meters and day temperature ranged from 24 - 34 °C.

Larvae were reared to the pupal stage on field collected fireweed cuttings immersed in water. Initial cohort produced from this collection was 606 pupae, out of which 398 emerged to adults (34% pupal mortality) with a sex ratio of 51.7% females. A laboratory colony was established on potted saplings or cuttings of fireweed for studies on bionomics and host range.

S. extensa was considered to be the most damaging insect to fireweed during the summer season in Madagascar. Heavy feeding caused rapid destruction to the plant during this time of the year. An average of eight larvae was observed feeding on each plant in the native region. Colonies were continuously propagated on potted fireweed for about eight generations per year.

Identity and description:

Identification of the mottled beige-colored moth *Secusio extensa* (Butler), Figure 2 is credited to Dr. John Rawlins, Associate Curator, at the Carnegie Museum of Natural History, Section of Invertebrate Zoology, Pittsburg, PA. There is no published information on the life history of this moth. The genus contains a number of other species of which *Secusio pustularia* Walker and *S. pulverata* from mainland Africa are closely related (Anonymous 2005b). The larvae are very close to members of the subfamily *Nyctemerinae*, many of which are obligate feeders on species of the tribe *Senecioneae* (*Emilia*, *Senecio*, and other genera) (DaCosta and Weller 2005).

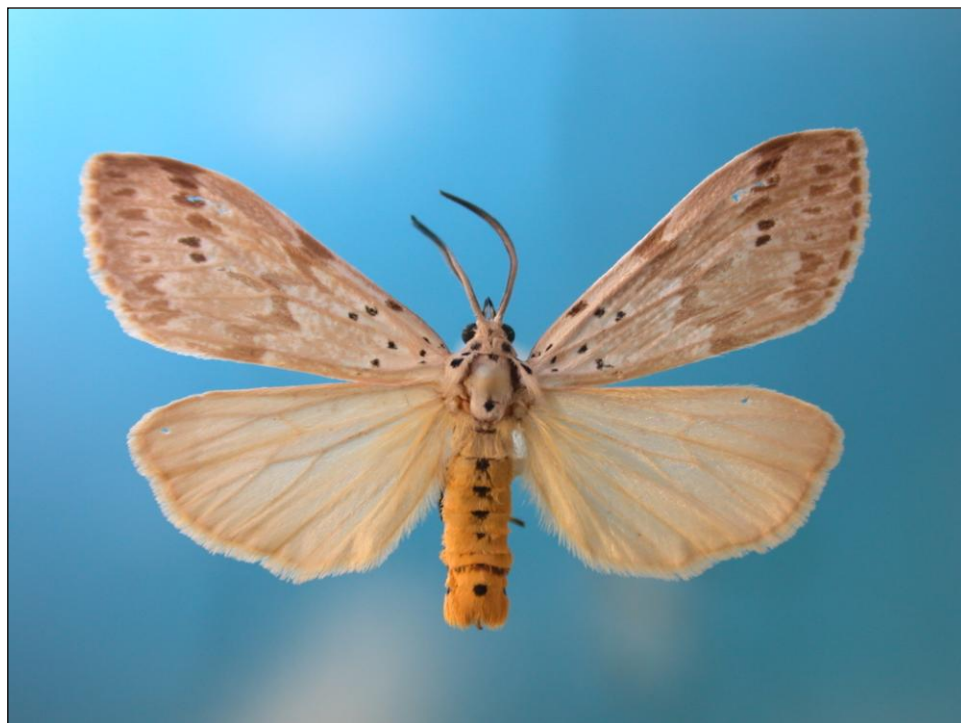


Figure 2: *Secusio extensa* male moth



Figure 3: *Secusio extensa* final instar

The test plants:

Asteraceae in Hawaii is represented by 76 genera and 181 species. About half of the species are endemic to Hawaii. Ninety species are naturalized; many of which are common weeds, but few have become serious problems (Wagner et al. 1999).

Members of the tribe *Senecioneae* are represented by six genera (*Crassocephalum*, *Delairea*, *Emilia*, *Erechtites*, *Petasites*, and *Senecio*). All escaped cultivation or became naturalized and none of the species is endemic to the Hawaiian Islands (Wagner et al. 1999). *Delairea odorata*, *Senecio vulgaris*, and *S. madagascariensis* are invasive weeds on the Big Island of Hawaii and Maui.

Seventy-one plant species were tested, representing all the thirteen tribes of Asteraceae, particularly the subfamily Asteroideae, and the closely related tribes of Helenieae, and Heliantheae, Judd et al. 2002 (Table 1). Six plant species recommended by Fish and Wild Life were also tested at the USDA Forest Service, Volcano National Park Quarantine Facility. All tests used potted saplings and control plants. Permits were obtained from Department of Land and Natural Resources for cuttings of endemic species.

Fireweed was propagated on Oahu from potted and field collected plants shipped to Oahu from the Big Island. Trial plants were propagated from seeds or field collected saplings. All plants were reared in outdoor cages and routinely disinfested from general insects (aphids, thrips, mites) by hand removal and spraying of water under pressure. No insecticides were used on plants.

Table 1. Plant list of Asteraceae used for host range experiments of *Secusio extensa* (sorted by species within subfamily and tribe). Plants tested against first instars mostly as potted plants or bouquets of cut foliage in starvation no choice experiments.*

Subfamily	Tribe	Species	Common name	Status
Asteroideae	Anthemideae	<i>Artemisia mauiensis</i>	Ahinahina	endemic
Asteroideae	Anthemideae	<i>Achillea filipendulina</i>	Fern leaf yarrow	naturalized
Asteroideae	Astereae	<i>Conyza bonariensis</i>	Hairy horseweed	naturalized
Asteroideae	Astereae	<i>Conyza canadensis</i>	Horseweed	naturalized
Asteroideae	Astereae	<i>Heterotheca grandiflora</i>	Telegraph weed	naturalized
Asteroideae	Astereae	<i>Erigeron</i> sp.	Pink jewel, Fleabane	naturalized
Asteroideae	Astereae	<i>Erigeron karvinskianus</i>	Daisy fleabane	naturalized
Asteroideae	Astereae	<i>Remya kauaiensis</i>		endemic
Asteroideae	Astereae	<i>Tetramolopium filiforme</i>		endemic
Asteroideae	Astereae	<i>Tetramolopium rockii</i>		endemic
Asteroideae	Calenduleae	<i>Calendula officinalis</i>	Pot marigold	naturalized
Asteroideae	Eupatorieae	<i>Ageratina adenophora</i>	Maui pamakani	naturalized
Asteroideae	Eupatorieae	<i>Ageratina reparia</i>	Hamakua pamakani	naturalized
Asteroideae	Eupatorieae	<i>Ageratum conyzoides</i>	Maile honohono	naturalized
Asteroideae	Eupatorieae	<i>Ageratum houstonianum</i>	Maile honohono	naturalized
Asteroideae	Gnaphalieae	<i>Gnaphalium purpureum</i>	Purple cudweed	naturalized
Asteroideae	Gnaphalieae	<i>Helichrysum bracteatum</i>	Strawflower	naturalized
Asteroideae	Helenieae	<i>Argyroxiphium</i> sp.	Silversword	endemic
Asteroideae	Helenieae	<i>Dubautia arborea</i>		endemic
Asteroideae	Helenieae	<i>Dubautia herbstobatae</i>		endemic
Asteroideae	Helenieae	<i>Dubautia laevigata</i>		endemic

Asteroideae	Helenieae	<i>Dubautia laxa</i>	Naenae pua melemele	endemic
Asteroideae	Helenieae	<i>Dubautia raillardiioides</i>	Naenae ula	endemic
Asteroideae	Helenieae	<i>Dubautia scabra</i>		endemic
Asteroideae	Helenieae	<i>Flaveria trinervia</i>	Clustered yellowtops	naturalized
Asteroideae	Helenieae	<i>Gaillardia grandiflora</i>	Blanket flower	naturalized
Asteroideae	Helenieae	<i>Tagetes erecta</i>	Marigold	hybrid cultivar
Asteroideae	Helenieae	<i>Wilkesia hobyi</i>	Dwarf iliau	endemic
Asteroideae	Heliantheae	<i>Bidens alba</i>	Spanish needles	naturalized
Asteroideae	Heliantheae	<i>Bidens amplexans</i>		endemic
Asteroideae	Heliantheae	<i>Bidens bipinnata</i>		endemic
Asteroideae	Heliantheae	<i>Bidens campylotheca</i>		endemic
Asteroideae	Heliantheae	<i>Bidens cosmoides</i>	Poola nui	endemic
Asteroideae	Heliantheae	<i>Bidens menziesii</i>		endemic
Asteroideae	Heliantheae	<i>Bidens pilosa</i>	Ki, , Hairy beggarticks	naturalized
Asteroideae	Heliantheae	<i>Bidens sp.</i>		endemic
Asteroideae	Heliantheae	<i>Eclipta prostrata</i>	False daisy	naturalized
Asteroideae	Heliantheae	<i>Gallinsoga quadriradiata</i>	Peruvian daisy	naturalized
Asteroideae	Heliantheae	<i>Helianthus annuus</i>	Common sunflower	naturalized
Asteroideae	Heliantheae	<i>Lipochaeta subchordata</i>		endemic
Asteroideae	Heliantheae	<i>Lipochaeta connata</i>		endemic
Asteroideae	Heliantheae	<i>Montanoa hibiscifolia</i>	Tree daisy	naturalized
Asteroideae	Heliantheae	<i>Parthenium hystreophorus</i>	False ragweed	naturalized
Asteroideae	Heliantheae	<i>Sigesbeckia orientalis</i>	Small yellow crown-beard	naturalized
Asteroideae	Heliantheae	<i>Synedrella nodiflora</i>	Nodeweed	naturalized
Asteroideae	Heliantheae	<i>Tithonia diversifolia</i>	Tree marigold	naturalized
Asteroideae	Heliantheae	<i>Tridax procumbens</i>	Coat buttons	naturalized
Asteroideae	Heliantheae	<i>Verbesina encelioides</i>	Golden crown-beard	naturalized
Asteroideae	Heliantheae	<i>Wedelia trilobata</i>	Creeping daisy	naturalized

Asteroideae	Heliantheae	<i>Xanthium strumarium</i>	Kikania, Cockleburr	naturalized
Asteroideae	Heliantheae	<i>Zinnia peruviana</i>	Pua pihi	naturalized
Asteroideae	Pluceae	<i>Pluchea indica</i>	Indian pluchea	naturalized
Asteroideae	Pluceae	<i>Pluchea chrolinensis</i>	Sourbush	naturalized
Asteroideae	Senecioneae	<i>Crassocephalum crepidioides</i>	Red flower ragleaf	naturalized
Asteroideae	Senecioneae	<i>Emilia fosbergii</i>	Pualele	naturalized
Asteroideae	Senecioneae	<i>Erechtites hieracifolia</i>	Fireweed	naturalized
Asteroideae	Senecioneae	<i>Farfugium japonicum</i> *	Leopard plant	ground cover plant
Asteroideae	Senecioneae	<i>Delairea odorata</i>	German ivy	naturalized
Asteroideae	Senecioneae	<i>Senecio confuses</i> *	Mexican flame vine	escaped cultivation
Asteroideae	Senecioneae	<i>Senecio madagascariensis</i>	Madagascan fireweed	naturalized
Asteroideae	Senecioneae	<i>Senecio vulgaris</i>	Common groundsel	naturalized
Cichorioideae	Arctoteae	<i>Gazania rigens</i> *	Gazania	naturalized
Cichorioideae	Cynareae	<i>Arctium lappa</i>	Gobo, Greater burdock	naturalized
Cichorioideae	Cynareae	<i>Centaurea melitensis</i>	Napa thistle	naturalized
Cichorioideae	Cynareae	<i>Cirsium vulgare</i>	Bull thistle	naturalized
Cichorioideae	Lactuceae	<i>Lactuca sativa</i>	Manoa lettuce	naturalized
Cichorioideae	Lactuceae	<i>Lactuca serriola</i>	Prickly lettuce	naturalized
Cichorioideae	Lactuceae	<i>Reichardai picroides</i>	Picridium	naturalized
Cichorioideae	Lactuceae	<i>Sonchus oleraceus</i>	Pualele	naturalized
Cichorioideae	Lactuceae	<i>Taraxacum officinale</i>	Common dandelion	naturalized
Cichorioideae	Lactuceae	<i>Youngia japonica</i>	Oriental hawkbear	naturalized
Cichorioideae	Vernonieae	<i>Elephantopus mollis</i>	Elephant foot	naturalized

*denote plants tested as bouquets of cut foliage. Systematic arrangements of species and tribe names adopted from Judd et al. 2002 and Wagner et al. 1999).

Insect rearing and colony maintenance:

S. extensa was reared continuously in the HDOA Insect Containment Facility at 22.0 ± 1.0 EC at night and 34.0 ± 2 EC during the day, 60-80% RH, and 13L: 11D photoperiod (fluorescent light and extra sunlight through window glass panels). To maintain the gene pool of the moth

population during lengthy host range studies, a random sample of 50 first instars from egg batches of at least three females per generation were used in the rearing protocol. Newly hatched larvae were placed on a potted fireweed flowering plant (.50 cm in height, 2-3 months old from seed) in a cage (80x50x50 cm). Newspaper was spread on the bottom of each cage for mature larvae to pupate. Host plants were added until all larvae pupated. Pupae were removed and placed into emergence cages (65 x45x45 cm) provided with water and streaks of honey.

After emergence, adult moths were paired in plastic rearing containers (1,900 ml) for mating and egg deposition. Moths were provided with honey streaks on the lid netting and a water container with a cotton wick. Eggs were collected daily in petri dishes and newly hatched larvae were used in host range tests and colony maintenance.

In case of a shortage of fireweed, supplementary feeding by potted or field-collected cuttings of *Crassocephalum crepidioides* was added to the cage mainly during the immense feeding periods of the final instar. However, larvae in control cages and cohorts used for fecundity tests were reared exclusively on the primary host, *S. madagascariensis*.

Biology and life history studies:

Development of immature stages was determined by rearing newly deposited batches of eggs (<10 h old) isolated in petri dishes and checked daily for hatching. First instars were placed in groups of 10 larvae per petri dish (15 diam. x 1.5 height cm) provided with fresh cuttings of fireweed made into bouquets immersed in small vials filled with water to prevent plant desiccation. Fireweed bouquets were changed daily and checked for larval exuviae, and instars were followed until pupation. Mature larvae were reared in plastic containers (1,900 ml) with organically covered and provided with fireweed until pupation. Experiments were repeated until adequate data were collected for estimation of life span and duration of immature stages.

Samples of 20 of each instar were immersed in boiling water for 10 minutes before being preserved in 75% alcohol for measurements and larval description. Diameter and height of fresh eggs, width of larval head capsules, and length of larvae, prepupae, and pupae of preserved specimens were measured using a dissecting microscope and a calibrated slide. The openings and features on the ventral last abdominal segments distinguished pupae of males and females. Terminology proposed by Peterson (1948) was adopted in diagnosing larval morphology and crochets arrangements.

Female fecundity and other reproductive attributes were obtained by determining daily oviposition of newly emerged pairs. Cohorts were reared from larvae fed on the primary host plant, *S. madagascariensis*. Adult pairs were held in plastic containers provided with water and streaks of honey and checked for daily oviposition and mortality. Eggs were counted daily and removed to petri dishes for estimation of egg hatching rate and mating status. Unhatched, collapsed eggs with no evidence of embryo development is an indication of unmated females. Dead females were dissected and the numbers of mature eggs remaining in the ovaries were

added to the numbers of deposited eggs to estimate the moth's potential fecundity. Reproductive parameters (longevity, fecundity, and oviposition periods) were then calculated for 20 pairs of mated *S. extensa* reared exclusively on fireweed.

General host-range protocols:

Plants subjected to host range testing were chosen following a strategy advocated by Wapshere (1974). Under this protocol, potential biocontrol agents are introduced to a sequence of plant species, from the most closely related to fireweed (tribe *Senecioneae*), to successively more distantly related species, until the host range has been adequately circumscribed. *S. madagascariensis* belongs to the family Asteraceae, and representatives from each tribe present in Hawaii were tested (naturalized, native, and endemic species) and in particular members in the tribes of the subfamily Asteroideae (Table 1). A few plants other than Asteraceae, which contain pyrrolizidine alkaloids (PA's) and suspected to be targeted by *S. extensa* were also tested.

Potted plants were raised from seeds or field collected saplings and grown until they were ready for host range testing. Most of the species took about two months from seeds. HDOA staff and botanists at the Bishop Museum using keys and descriptions in Wagner et al 1999 identified the plants. When ready for use, plants (usually 75 cm to fit in a test cage) were checked for contaminants (i.e. aphids, mites, thrips, and lepidopteran larvae or eggs), thoroughly cleansed with water, or dipped in non-chemical soapy solutions at least a week prior to testing. No insecticides were used on trial plants. Plants were propagated in outdoor cages and transferred into the quarantine room when needed for larval feeding experiments.

Larval feeding no-choice tests:

Potential host range was estimated by measuring the mortality and rates of development of newly hatched larvae when introduced to test plants. The ability of larvae to feed and develop on test plants was compared with control plants (the natural primary host, *S. madagascariensis*) and determined using first instar starvation tests. Potted plants were used most of the time and bouquets of foliage cuttings were occasionally used as indicated in Table 1. Test plants were used in the same way as the control.

Each plant was placed in a (80x50x50 cm) cage and 50 newly emerged unfed first instars (<12 hr old) were transferred onto the plant leaves using a soft camel hairbrush. Observations on the numbers of larvae remaining on the plant, feeding marks, and larval development were recorded every 24 hours. Trial tests were terminated when all larvae died in the cage and experiments for each plant species were replicated at least three times using new insect cohorts and new potted plants. If feeding occurred, new plants were added add libitum and larval development and mortality were recorded. Plants that supported larval development were tested further using more replicates and subjected to additional rigorous feeding and oviposition tests.

Estimation of feeding rates:

These are no-choice or starvation tests where the control species and the host species are simultaneously offered to different insect cohorts. Unfed newly hatched larvae (<12 h-old) were

transferred to the test plants and observations on larval feeding damage and development were rated daily until all larvae died or completed development to adult moths. Host plants were added ad libitum. Larval feeding damage was subjectively rated using graph paper as: (0) if no damage occurred; damage rate (1) indicated probing and superficial feeding with less than 5% damage on leaf area; damage rate (2) indicated light feeding by larvae on >5-20 % of leaf area; damage rate (3) indicated a moderate feeding on >20-40% of leaf area, damage rate (4) was severe damage and feeding occurred on >40 - 60 % of leaf area; and damage rate (5) was intense damage and larvae fed on >60% of leaf area and stems which eventually killed the plant.

The number of larvae remaining on the plant within the first 48 hours of placement is an indicator of host acceptance and their feeding activity was rated as described earlier. Surviving larvae were monitored and their development beyond the first instar was observed until they perished or successfully pupated. Numbers of larvae completing development to the pupal stage, and eclosed adults were also recorded to determine host suitability. More replicates and more host plant species per tribe were tested if some of the cohorts' first instars survived on the plant for more than 48 hours.

Larval feeding choice test:

Further studies including choice tests were conducted only on plant species producing viable adults from trials especially from species belonging to tribes with endemic plants. No endemic or economically important plant species in the tribe *Senecioneae* are found in Hawaii (Wagner et al.1999); they are all naturalized and some of them are considered invasive weeds in native forests (*Delairea odorata* and *Senecio vulgaris*).

Trials with the host plant and the test plant (sunflower) were conducted in (80x50x50 cm) cages, one sunflower plant and one fireweed plant per cage. These were control-choice tests as the control (*S. madagascariensis*) was offered in sequence with a choice of test plant species (Heard 2002). Twenty-five first instars (<12 h-old) were carefully brushed and transferred into a paper cone attached with tape to the upper cage wall, giving the wandering larvae a choice between the two plants. Plants were placed adjacent to each other with the leaves touching one another and the cage walls. Two hours after placement of larvae, the number of larvae on each plant was counted and observations on their feeding rates and development were continued every day until all larvae reached the pupal stage. This test was replicated at least five times using new sets of plants and larvae of different generations. Another five replicates of this experiment were repeated by placing the larvae directly on the test plant, sunflower, instead on the cage walls.

Larval feeding no-choice test on species recommended by U.S. Fish and Wildlife Service:

A separate colony of *S. extensa* was shipped to the Island of Hawaii, Hawaii Volcanoes National Park Quarantine Facility (USDA-Forest Services) for assistance on host testing and maintenance of a backup colony. The United States Fish and Wildlife Service had recommended six species of native plants for testing against proposed biocontrol agents of invasive weeds in Hawaii.

These plants are considered major components of the Hawaiian native ecosystems:

1) Koa , *Acacia koa* A. Gray (Family Fabaceae)

- 2) Ohia lehua, *Metrosideros polymorpha* Gaud. (Family: Myrtaceae)
- 3) Mamane, *Sophora chrysophylla* (Salisb.) Seem. (Family: Fabaceae)
- 4) Naio, *Myoporum sandwicense* A. Gray (Family: Myoporaceae)
- 5) Hapuu, *Cibotium glaucum* (Sm.) Hook & Arnott (Family: Dicksoniaceae)
- 6) Aalii, *Dodonaea viscosa* Jacq. (Family: Sapindaceae)

Potted plants of these species were used in tests in the Hawaii Volcanoes National Park, USDA Forest Services Quarantine Facility (20.5°C, 80%RH) using the same protocols described earlier. Tests were repeated five times for each species and larval feeding preference were simultaneously compared with a control fireweed plant. Plants were potted in plastic pots (.2.0 liter). Fifty first instars were placed on each test plant. A potted *S. madagascariensis*, infested with 25 first instars was used as a control for each replicate. Plants were carefully examined for feeding marks and larval survival every other day until all larvae perished.

Feeding tests with non-Asteraceae plants and species containing PA:

Because this arctiid species feeds on plants of *Senecioneae* known to contain pyrrolizidine alkaloids (PA's), samples of non-Asteraceae plants known to contain these chemical compounds were also tested. Bouquets of the smooth rattle pod, *Crotalaria mucronata* Desv. (Family: Fabaceae), and the common rattle pod, *Crotalaria spectabilis* Roth were introduced to 50 first instars per replicate for feeding evaluation. This test was replicated five times per plant species.

Representatives of other plants regularly found around rangelands were also tested:

Common cultivated banana, *Musa acuminata* Colla (Family: Musaceae, three replicates of 25, 35, and 50 larvae each); Papaya, *Carica papaya* L. (Family: Caricaceae, 3 replicates, 50 larvae each); Mamaki, *Pipturus albidus* (Hook. & Arn.) Gray (Family: Urticaceae, 2 replicates, 50 larvae each); Sprouted coconut palm, *Cocos nucifera* L. (Family: Arecaceae, one replicate, 50 larvae); Dasheen, *Colocasia esculenta* (L.) Schott (Family: Araceae, one replicate 25 larvae); Ivy gourd, *Coccinia grandis* (L.) Voigt (Family: Cucurbitaceae, 3 replicates, 50 larvae each); Sorghum, *Sorghum bicolor* (L.) Moench (Family: Poaceae, one replicate, 50 larvae per plant); Sugar cane, *Saccharum officinarum* L. (Family: Poaceae, one replicate, 50 larvae per plant); Sweet potato, *Ipomoea batatas* (L.) Lam., (Family: Convolvulaceae, one replicate, 50 larvae per plant). All were potted plants.

Adult oviposition choice tests with *Helianthus annuus*:

Oviposition tests were conducted only when the larval feeding test proved positive. Tests were conducted in large cages that fit two potted plants. This is a choice plus target test (i.e. a fireweed plant present) Heard 2002.

Five pairs of newly emerged (<12 h-old) *S. extensa* adults were confined for a day in a plastic container (1,900 ml), provided with water and honey, for mating and ovarian maturation. On the second day, the moths were transferred to a large cage (1.0 x1.0 x1.7 m) with a walk through screen door, upper-back glass, and screened top. One sunflower (trial) and one fireweed (host) potted plant were placed in the cage center, honey streaks on top screen and water were provided

for moth feeding.

Plants were about 40 cm apart, and were watered and rotated daily with minimal disturbances. Because the outcome of host evaluation behavior may depend on mating status and female age, moths were tested for a period longer than the age of peak oviposition (M. Ramadan, unpublished observations, Renwick and Chew 1994). Female mating status was indicated by dissection and observations on egg hatching. Plants were examined daily for seven consecutive days for oviposition. Leaves containing eggs were excised, and eggs counted. Eggs on cage walls were also recorded and removed daily. Relative acceptability of plants for oviposition was calculated as the percentage of total eggs laid on each plant divided by the total eggs deposited in the cage. This test was replicated five times using new plants and cohorts of different generations. Some reports show that flowers may be an important factor for oviposition choice, therefore, all plants used were flowering (Papaj and Rausher 1983).

Adult oviposition choice with *Crassocephalum crepidioides*, *Senecio vulgaris* and *Bidens pilosa*:

This experiment was important to determine a female's oviposition preference on plants that supported larval development to the pupal stage. One newly emerged pair was placed in a cage (80x50x50 cm) provided with one bouquet each of *C. crepidioides* and *S. madagascariensis*. The bouquets were rotated and leaves checked daily for eggs until the adult female died. The test was replicated ten times using new cuttings and new insects of >40 generations old. Leaves with eggs were excised, and the number of eggs on leaves or cage walls were counted and removed daily. Eggs were kept in Petri dishes for hatching to determine female's mating status.

Oviposition preference of *S. extensa* were tested on cuttings of *S. vulgaris*, *B. pilosa* and *S. madagascariensis* using the same protocols invoked on *C. crepidioides*. Tests were replicated ten and nine times for *S. vulgaris* and *B. pilosa*, respectively.

Data analysis:

Data from oviposition tests, number of leaves used as substrate, number of eggs laid on each leaf, percentage of eggs laid on the plant (calculated as the total eggs laid on plant divided by the total eggs laid on plant and cage walls) were analyzed using student's *t*-test at $p < 0.05$. Proportion data were arcsine-square root transformed before statistical analysis (Sokal and Rohlf 1981) and were analyzed using proc ANOVA (SAS Institute 1985). Only untransformed mean values are reported in the text and tables. Survival data were analyzed by one way analysis of variance (ANOVA) and means were separated by the Tukey Kramer honestly significant difference (HSD) multiple comparison test (Zarr 1999).

Results

Reproductive biology:

A summary of the reproductive attributes of *S. extensa* ($n = 30$) reared on *S. madagascariensis* is presented in Table 2. Mean \pm SEM longevity of individually reared females (16.9 ± 1.0 d) was about three days shorter than males. Females had a three day pre-oviposition period, during which ovaries matured and mating took place. This period appeared to be longer in unmated females, if males are not available or unfit for mating. Egg deposition was regulated during the next 11.1 d with an average of 21.8 eggs deposited per day. Peak egg deposition was about one fourth of the female's egg load (54.4 ± 3.2 eggs) at age 3.8 d. Females survived to deposit 99.9% of their potential ovarian eggs and realized fecundity was 226.9 ± 10.9 eggs per female. A mean of less than one mature ovarian egg was dissected from dead females. Overall egg hatching rate was 77.3% for the first 21 generations ($n = 21$, 115 - 937 eggs per sample) and most of the females (86.7%) mated in plastic rearing containers (1,900 ml) under quarantine conditions. Male to female sex ratio was 1:1.

Table 2. Reproductive attributes of *Secusio extensa* reared on *Senecio madagascariensis* potted plants under 28 ± 2 EC and 60-80% RH.

Parameter	(Mean \pm SEM) $n = 30$	Unit
Longevity (%)	20.6 ± 1.1	Days
Longevity (&)	16.9 ± 1.0	Days
Age at first oviposition	3.1 ± 0.4	Days
Post-oviposition period	0.9 ± 0.2	Days
Egg deposition period	11.1 ± 0.7	Days
Age at peak oviposition	3.8 ± 0.4	Days
Peak oviposition	54.4 ± 3.2	Highest no. eggs per day
Reproductive fecundity	226.9 ± 10.9	Total egg deposited
Potential fecundity	227.1 ± 10.7	Total egg deposited and ovarian eggs at death
Oviposition per day	21.8 ± 1.3	No. eggs deposited per day
Mating rate	86.7 ($n = 226$ pairs)	Percentage
Egg hatching rate ^a	77.3 ± 5.3	Percentage

^aEgg batches ranged from 115 - 937 eggs, a total of 8,312 eggs ($n = 21$)

Immature stages and development:

Eggs are dome shaped, 0.8 mm in diameter and 0.75 mm in height, flattened from bellow ($n=15$).

They are smooth with no reticulations, creamy to white when freshly deposited and turn black one day before hatching. Usually, eggs are laid in batches of 1- 62 eggs. However, unmated females tend to lay eggs individually or in small batches of 1- 35 eggs. In the field, the undersides of leaves are usually selected for oviposition. Upper sides of leaves, stems, and occasionally flower-heads may be used as oviposition substrates. In the laboratory, females lay eggs on the sides of rearing plastic containers and cage surfaces (glass, metal, and screen) and frequently deposit fresh eggs onto previously laid batches. Unlike other Lepidoptera, the presence of a host plant in a rearing container is not necessary for oviposition. Mean egg duration is 5.7d at ambient temperature ($n= 369$, Table 3). Egg hatching rate was estimated from random samples taken from every generation. Mean (\pm SEM) egg hatch for the first 21 generations (all reared on fireweed under quarantine conditions) from a total of 8,312 eggs was 77.3 ± 5.3 % and ranged from 36.2% to 98.3%, depending on the mating rates among cohorts (Table 2).

S. extensa has five instars that crawl rapidly and feed at night. Young larvae (first and second instars) feed gregariously on the lower surface of leaves and disperse as they mature. The head is smooth with only primary setae and six ocelli. The head is covered dorsally by long thoracic setae. Like most arctiids, the larvae are densely covered with dark plumose setae. Tarsi of thoracic legs show spatulate setae near the distal end. Abdominal segments (A3-A6 and A10) have prolegs distinguished by the presence of heteroideous crochets arranged in a mesoseries pattern with all crochets near the two ends greatly reduced in size while those in the center are well developed. Four verrucae above coxae are on mesothoracic (T2) and metathoracic (T3) segments. There are no integumental spicules on the body segments. Verrucae with many plumose setae of various lengths extend over the entire body (Figure 3).

The first instar fed on the underside of leaves and increased in size to a length of 2.8 mm with a head capsule width of 0.4 mm when fed on fireweed ($n=20$). It lasted 4.3 days ($n=374$), Table 3.

The entire head capsule is dark brown (lighter in preserved specimens) with six approximately equal size stemmata arranged in a semicircle on each side of the head. Light brown, dorsal verrucae are found on each body segment. Dorsal verrucae on T2 are the most peculiar and can be used to distinguish instars. Each verruca has three, brown, simple setae with small hairs. The setae become plumose in succeeding instars. T2 dorsal setae are longer than the thorax and head combined. Each thoracic leg has one spatulate hair near the apex of the tarsus. The abdomen has five pairs of prolegs each possessing 5-6 uniordinal crochets designated as homoideous mesoseries (Peterson 1948).

When the host plant is not found, first instars may feed on other eggs present in the rearing container. However, larval cannibalism has never been observed among all five instars, and if the natural host is not available, first instars may perish within 48 hours without any sign of feeding on each other. Unlike the succeeding instars, first instars are capable of producing silken

thread when brushed away from the host. Other instars prefer to curl and drop from the plant when disturbed.

The second instar also feeds on the underside of leaves and is 5.8 mm long with a 0.59 mm wide, yellow, head capsule. Verrucae and setae are light brown. T2 dorsal verrucae have eight long and five shorter plumose setae. Crochets are arranged on prolegs in a heteroideous mesoseriis pattern, with 3-4 long crochets in the center and 4-6 smaller ones on each side. Second instar duration is 3.0 days (Table 3).

The third instar is 9.9 mm long with a 0.83 mm wide, yellow, head capsule. T2 dorsal verrucae have 14 long setae directed forward overhead as feelers and 7-11 erect smaller setae on each verruca. Crochets pattern as in second instar with 4-5 long median crochets and 6-7 smaller ones on each side. Long crochets on the anal prolegs reduced to three. Duration of the third instar is 3.9 days.

The fourth instar is 13.9 mm long with a 1.4 mm wide, yellow, head capsule. T2 dorsal verrucae have 17-18 dark, brown, long, plumose setae with black bases, seven of which are directed forward over the head capsule. White to yellow smaller setae (19-20) are on the periphery of each verruca. Prolegs have 8-9 long median crochets with 8-9 smaller ones on each side. Long crochets on the anal proleg are reduced to six. Duration of the fourth instar is 4.3 days.

The fifth instar is 26.4 mm long with a 2.2 mm wide, light brown head capsule with a dark stigma around the stemmata. The first ocellus is bigger in size than the rest, with about half of its diameter located outside the dark pigmented stigma. T2 dorsal verrucae have about 19 long and medium plumose setae, nine of which are directed forward above the head. Twenty more small setae are located on each T2 dorsal verruca. All body segments are dark brown to black with lighter brown intersegmental coloration. Thoracic legs, prolegs, and most ventral body segments are light yellow. All setae are black (dark brown under scope) with numerous hairs bunched at apex of each seta like a fan. Prolegs have 11-12 long median crochets and 9-12 smaller ones on each side. The anal proleg has 9-10 long medial crochets and 14 smaller ones on each side. Duration of the fifth instar is 7.3 days and depends largely on the quality of the host plant.

Larvae feed for about three weeks then retire for pupation. Feeding by the fifth instar is the most damaging to the plant. They feed voraciously on leaves, and may strip the outer layers (epidermis and cortex) of the stems. Fireweed flowers are not preferred and most of the time are left intact. Fifty larvae are able to completely defoliate four full-grown potted fireweed plants during the fifth instar. Defoliated plants die and never recover.

The fifth instar spins a light silken cocoon sprinkled with larval setae. Mature larvae usually pupate between layers of newspaper at the bottom of rearing cage. Unlike other arctiids, no pupae are formed on cage walls or on the plant. The prepupa loses most of the long setae, becomes .1 cm shorter than the average mature larva and stays as a prepupa for a day before

developing into a pupa (Table 3).

The pupa is oblong, about half the length of a mature larva, stout, brown with dark stripes. The frons has dark, tent shaped mark with dark tentorial pits on the sides. The forewing has eight dark longitudinal bands. All abdominal segments have dark stripes. The cremaster is weak on the dorsal side of segment 10 with 25-30 elongated small (half-length of anal slit) bristle-like hooks coiled distally and ending in a club shape. The male antenna has a dark stripe on the outer margin extending for more than half its length. It extends to less than half the antennal length in the female pupa. The middle of the male antenna is wider than the maximum width of the adjacent mesothoracic leg in the male and about equal the width of mesothoracic leg in the female pupa. The pupa has seven pairs of spiracles on A2 to A8. Spiracles A2 and A3 are in an oblong orange spiracular plate not completely surrounded by the dark abdominal stripe. Spiracles A4 and A8 are in the middle of the stripe, surrounded by the dark coloration. Spiracles A5-A7 are closer to the upper edge of the dark stripe. Spiracle A8 is nonfunctional and is represented by a closed slit with no atrium. Body spicules are crowded around the spiracular plate.

The male's ninth abdominal segment is complete, bearing a genital slit between two slightly elevated kidney shaped pads. The female's 8th abdominal segment is divided by the 9th with a genital opening in middle. The male pupa is slightly smaller in length and width compared to the female pupa. The duration of the pupal stage is 11.3 days for both sexes (Table 3).

The whole life span of *S. extensa* is 41.1 days, producing up to nine generation per year when fed on fireweed under HDOA Quarantine Facility conditions.

Table 3: Developmental periods of *Secusio extensa* reared on *Senecio madagascariensis*, in HDOA Insect Containment Facility.

Immature stages	Duration (days)		Size (mm) ^a		Head capsule width (mm)	
	<i>n</i>	mean ± SEM	<i>n</i>	mean ± SEM	<i>n</i>	mean ± SEM
Eggs	369	5.69 ± 0.02	15	0.80 ± 0.002d 0.75 ± 0.005h		
First instar	374	4.27 ± 0.03	20	2.83 ± 0.05	20	0.41 ± 0.003
Second instar	150	3.01 ± 0.07	20	5.84 ± 0.21	20	0.59 ± 0.005
Third instar	141	3.94 ± 0.10	20	9.91 ± 0.39	20	0.83 ± 0.01
Fourth instar	179	4.28 ± 0.14	20	13.87 ± 0.22	20	1.39 ± 0.03
Fifth instar	140	7.33 ± 0.17	20	26.35 ± 0.79	20	2.19 ± 0.33
Prepupa	22	1.27 ± 0.10	20	17.32 ± 0.26		
Pupa (%%)	67	11.37 ± 0.13	20	12.10 ± 0.09		
Pupa (&&)	58	11.33 ± 0.10	20	13.37 ± 0.16		
Total life span		41.14				

^a Diameter (d) and height (h) of fresh eggs, length of larvae, prepupae and pupae. Median larval instar were killed in hot water and preserved in 75% alcohol before measurement.

Larval feeding no-choice tests:

Host specificity tests indicated that plant species of the tribe *Senecioneae* were suitable for larval development with limited survival on the weeds *Emilia* and *Erechtites* (Table 4). Among the *Senecioneae* tribe, first instars transferred onto potted plants in no-choice tests completed development to the adult stage on *Senecio madagascariensis*, *Delairea odorata*, *Senecio vulgaris*, *Crassocephalum crepidioides*, *Emilia fosbergii*, and *Erechtites hieracifolia*. Besides fireweed, *S. extensa* developed adequately on *D. odorata* and *S. vulgaris* causing intense damage that eventually kills the plants (Table 5). Mean survival to adult stage was $66.1 \pm 2.0\%$ and $57.1 \pm 2.1\%$ for *D. odorata* and *S. vulgaris* and was not significantly different from mean survival on the habitual plant. Mean survival to adult stage was significantly reduced to $41.2 \pm 7.4\%$ when larvae developed on *C. crepidioides* ($df = 6, 47; f = 51.08; p = 0.0001$). *E. fosbergii* and *Er. hieracifolia* were not adequate hosts and less than 2% of the tested larvae developed to the adult stage (Figure 4). Larvae also fed on the Mexican flame vine, *Senecio confusus* (DC), one replicate of cutting foliage. No larval development occurred on cuttings of the ground cover, Japanese silver leaf, *Farfugium japonicum* (L.) Kitam (both in tribe *Senecioneae*), Table 4.

Out of 71 species belonging to 52 genera and 13 tribes of Asteraceae the larvae fed and developed to adult stage only on species of *Senecioneae* and to a limited degree on sunflower, *Helianthus annuus*, tribe *Heliantheae*. A mean of $11.6 \pm 3.2\%$ of cohorts developed to adult stage when fed on *H. annuus* during the starvation no-choice tests (Table 5, Figure 4).

Results of developmental and damage rates of *S. extensa* exposed as first instar to *H. annuus* and *S. madagascariensis* in choice and no choice tests are presented in Tables 6, 7 and Figures 5, 6. The larvae caused superficial feeding damage (feeding rate = 1) to *H. annuus* during choice test. Survival rates of all immature stages and adults reared on *H. annuus* during no choice trials were significantly reduced compared to those reared on the natural host ([second instar: $df = 2, 22; f = 301.15; p = 0.0001$], [third instar: $df = 2, 22; f = 319.84; p = 0.0001$], [fourth instar: $df = 2, 22; f = 248.41; p = 0.0001$], [fifth instar: $df = 2, 22; f = 126.08; p = 0.0001$], [pupa: $2, 22; f = 115.68; p = 0.0001$], [adult: $df = 2, 22; f = 99.71; p = 0.0001$]).

Values of reproductive attributes of *S. extensa* reared on *H. annuus* were significantly less than values obtained from cohorts reared on the natural host, *S. madagascariensis* (male longevity: $t = -4.014, df = 58, p = 0.0002$; female longevity: $t = -3.149, df = 49.7, p = 0.0028$; egg deposition period: $t = -2.9687, df = 58, p = 0.0043$; peak oviposition: $t = -2.4895, df = 58, p = 0.0157$; potential and reproductive fecundity: $t = -5.4869, df = 58, p = 0.00001$). Moths reared on *H. annuus* were significantly smaller and males had less mating ability than those reared on the natural host. Reduction in moth size and female reproductive output of *S. extensa* fed on *H. annuus* is evidence of inferior host quality for the survival of this species.

Aside from members of the tribe *Senecioneae*, the larvae did not commence or complete development to adult stage on 63 (46 genera) other species belonging to 12 tribes of native, endemic and naturalized Asteraceae (Table 4).

A mean of 4.9 ± 2.9 (9.1%) of the tested larvae developed to the final fifth instar when fed on *Bidens pilosa* (tribe: *Heliantheae*). However, larvae were very much smaller in size, 57 - 83%

than a normal size larva fed on fireweed, caused minor damage to plant, and required a longer time to reach the pupal stage. While larvae were still feeding on trial plants, the control larvae on fireweed pupated and emerged to adults. Only 0.3 ± 0.2 (= 0.5%, two out of 410 larvae) of initial cohort larvae continued development to undersized yet unclosed pupal stage. The outcome of feeding trials on one more naturalized (*B. alba*) and six endemic species (*B. campectans*, *B. bipinnata*, *B. campylotheca*, *B. cosmoides*, *B. menziesii*, and *Bidens* species ex. Mt Kaala) proved negative for larval development, Table 4.

Larval development no-choice tests with six endemic forest trees and shrubs recommended by the US Fish and Wildlife as the forest dominant species in the Hawaiian ecosystem indicated that none of the tested larvae survived beyond the first instar. In comparison, a mean of 79.2% of the cohorts developed to adult stage on the natural host, *S. madagascariensis* ($n=5$, Table 6).

In no choice larval feeding experiments with the smooth rattle pod ($n=5$) and the common rattle pod ($n=5$), introduced to 50 first instars per replicate for feeding evaluation of non-asters containing PAs, the first instars died out without any attempt to nibble at the plants. Furthermore, no feeding or tasting marks and all larvae died within 48 hours on representatives of non-asters regularly found nearby rangelands (common cultivated banana [$n=3$], papaya [$n=3$], mamaki [$n=2$], coconut palm [$n=1$], dasheen [$n=1$], ivy gourd [$n=3$], sorghum [$n=1$], sugar cane [$n=1$], and sweet potato [$n=1$]). Other non-asters of different families found around fireweed populations in Madagascar showed that *S. extensa* is highly restricted to fireweed.

Helenieae	<i>Dubautia raillardioides</i>	5	20	0	0	0	0	0	0	0	0	-
Helenieae	<i>Dubautia scabra</i>	5	50	0	0	0	0	0	0	0	0	-
Helenieae	<i>Dubautia arborea</i>	5	30	0.2 ± 0.2	0	0	0	0	0	0	0	-
Helenieae	<i>Flaveria trinervia</i>	5	50	0	0	0	0	0	0	0	0	-
Helenieae	<i>Gaillardia grandiflora</i>	9	10	0	0	0	0	0	0	0	0	-
Helenieae	<i>Tagetes erecta</i>	5	25	0	0	0	0	0	0	0	0	-
Helenieae	<i>Wilkesia hobdyi</i>	8	46	2.0 ± 1.3	0	0	0	0	0	0	0	-
Heliantheae	<i>Bidens alba</i>	5	50	1.4 ± 0.7	0-1	0	0	0	0	0	0	-
Heliantheae	<i>Bidens amplexans</i>	1	50	0	0	0	0	0	0	0	0	-
Heliantheae	<i>Bidens bipinnata</i>	5	50	0	0	0	0	0	0	0	0	-
Heliantheae	<i>Bidens campylotheca</i>	6	30	2.8 ± 1.4	0-1	0	0	0	0	0	0	-
Heliantheae	<i>Bidens cosmooides</i>	5	50	1.4 ± 0.7	0-1	0	0	0	0	0	0	-
Heliantheae	<i>Bidens menziesii</i>	4	62	9.5 ± 4.8	0-1	9.3 ± 2.8	8.0 ± 2.9	0	0	0	0	-
Heliantheae	<i>Bidens pilosa</i>	7	59	10.1 ± 4.3	1-2	10.1 ± 4.3	9.3 ± 4.5	7.4 ± 3.8	4.9 ± 2.9	0.3 ± 0.2	0	-
Heliantheae	<i>Bidens</i> sp. (Ex. Kaala mt)	6	50	3.5 ± 1.8	0-1	1.5 ± 1.0	0	0	0	0	0	-
Heliantheae	<i>Eclipta prostrata</i>	5	50	0	0	0	0	0	0	0	0	-
Heliantheae	<i>Gallinsoga quadriradiata</i>	6	50	6.3 ± 3.0	0-1	3.0 ± 1.6	0.5 ± 0.5	0.3 ± 0.3	0.3 ± 0.3	0	0	-
Heliantheae	<i>Helianthus annuus</i>	11	59	13.0 ± 3.1	1-2	12.5 ± 3.0	12.2 ± 3.0	11.6 ± 3.1	10.7 ± 3.2	8.3 ± 3.2	7.7 ± 2.7	+ inferior host
Heliantheae	<i>Lipochaeta subchordata</i>	5	50	0	0	0	0	0	0	0	0	-
Heliantheae	<i>Lipochaeta connata</i>	4	50	0	0	0	0	0	0	0	0	-
Heliantheae	<i>Montanoa hibiscifolia</i>	5	50	0	0	0	0	0	0	0	0	-
Heliantheae	<i>Parthenium hystreophorus</i>	5	42	1.0 ± 0.8	0-1	0	0	0	0	0	0	-
Heliantheae	<i>Sigesbeckia orientalis</i>	6	50	0.2 ± 0.2	0-1	0	0	0	0	0	0	-

Heliantheae	<i>Synedrella nodiflora</i>	5	50	0.2 ± 0.2	0-1	0	0	0	0	0	0	-
Heliantheae	<i>Tithonia diversifolia</i>	5	42	0	0	0	0	0	0	0	0	-
Heliantheae	<i>Tridax procumbens</i>	5	38	0	0	0	0	0	0	0	0	-
Heliantheae	<i>Verbesina encelioides</i>	5	50	0	0	0	0	0	0	0	0	-
Heliantheae	<i>Wedelia trilobata (c)</i>	11	20	0	0-1	0	0	0	0	0	0	-
Heliantheae	<i>Xanthium strumarium</i>	5	50	6.8 ± 3.4	0-1	1.2 ± 0.6	0	0	0	0	0	-
Heliantheae	<i>Zinnia peruviana</i>	5	47	0.4 ± 0.4	0-1	0	0	0	0	0	0	-
Pluceae	<i>Pluchea indica</i>	5	50	0	0	0	0	0	0	0	0	-
Pluceae	<i>Pluchea chrolinensis</i>	5	50	0	0	0	0	0	0	0	0	-
Senecioneae	<i>Crassocephalum crepidioides</i>	8	54	38.0 ± 6.2	4-5	40.0 ± 3.9	38.0 ± 4.8	37.1 ± 4.6	36.5 ± 4.8	29.6 ± 6.0	22.6 ± 4.3	+ permissible host
Senecioneae	<i>Emilia fosbergii</i>	8	40	14.1 ± 4.5	2	14.1 ± 4.5	12.1 ± 4.2	11.3 ± 4.2	9.1 ± 3.8	1.3 ± 0.8	0.9 ± 0.6	+ inferior host
Senecioneae	<i>Erechtites hieracifolia</i>	6	50	19.8 ± 3.5	2	17.5 ± 3.5	16.5 ± 4.1	13.5 ± 4.2	11.7 ± 4.2	0.8 ± 0.3	0.7 ± 0.2	+ inferior host
Senecioneae	<i>Farfugium japonicum</i>	5	25	4.4 ± 1.2	1	0	0	0	0	0	0	-
Senecioneae	<i>Delairea odorata</i>	3	50	45.0 ± 24.5	5	39.3 ± 18.9	38.7 ± 19.3	38.7 ± 19.3	38.7 ± 19.3	35.3 ± 18.4	32.7 ± 16.2	+ permissible host
Senecioneae	<i>Senecio madagascariensis</i>	16	67	66.6 ± 4.5	5	61.8 ± 1.1	61.5 ± 4.4	61.1 ± 4.5	60.3 ± 4.6	57.4 ± 4.4	52.3 ± 4.0	+ normal host
Senecioneae	<i>Senecio vulgaris</i>	3	62	61.3 ± 4.7	5	55.7 ± 1.2	55.7 ± 1.2	48.7 ± 3.5	43.7 ± 3.3	40.3 ± 3.4	35.0 ± 1.2	+ permissible host
Arctoteae	<i>Gazania rigens</i>	5	50	0.4 ± 0.4	0	0	0	0	0	0	0	-
Cardueae	<i>Arctium lappa</i>	9	87	5.6 ± 2.5	0-1	4.2 ± 1.4	2.2 ± 1.0	0.1 ± 0.1	0	0	0	-
Cardueae	<i>Centaurea melitensis</i>	3	50	4.0 ± 4.0	0-1	0.7 ± 0.7	0	0	0	0	0	-

Cardueae	<i>Cirsium vulgare</i>	4	50	0	0	0	0	0	0	0	0	-
Lactuceae	<i>Lactuca sativa</i>	7	50	3.9 ± 0.7	0 -1	1.4 ± 0.5	0.6 ± 0.6	0.4 ± 0.4	0.3 ± 0.3	0	0	-
Lactuceae	<i>Lactuca serriola</i>	6	46	0.8 ± 0.8	0 -1	0	0	0	0	0	0	-
Lactuceae	<i>Sonchus oleraceus</i>	5	50	1.0 ± 0.4	0 - 1	0	0	0	0	0	0	-
Lactuceae	<i>Taraxacum officinale</i>	5	47	1.6 ± 0.9	0	0	0	0	0	0	0	-
Lactuceae	<i>Youngia japonica</i>	6	29	0.2 ± 0.2	0	0	0	0	0	0	0	-
Vernonieae	<i>Elephantopus mollis</i>	5	50	0.4 ± 0.2	0	0	0	0	0	0	0	-
Lactuceae	<i>Reichardia picroides</i>	5	50	0.2 ± 0.2	0	0	0	0	0	0	0	-

^aFeeding rate: 0 = no damage; 1 = probing and superficial damage (<2% feeding on leaf area); 2 = light damage (feeding on 5-20 % of leaf area); 3 = moderate damage (feeding on 21 - 40 % of leaf area); 4 = severe damage(feeding on 41 - 60% of leaf area); 5 = intense damage (>60 % of leaf area and stems that eventually kills the plant).

N = number of replicates.

^bNegative sign (-) indicates unsuitability for development, positive sign indicates some degree of suitability (inferior, permissible, and normal hosts support <25%, <50 to <75% , and >75% of the cohorts to adult stage, respectively).

Table 5. Comparison of survivorship to adult stage of *Secusio extensa* reared on host plant (*Senecio madagascariensis*) and six other test plants.

Plant species	Replicates	% survival to adult stage (mean \pm SEM) ^a	Feeding rate ^b
<i>Senecio madagascariensis</i>	16	78.3 \pm 3.7 a	5
<i>Delairea odorata</i>	3	66.1 \pm 2.0 ab	5
<i>Senecio vulgaris</i>	3	57.1 \pm 2.1 ab	5
<i>Crassocephalum crepidioides</i>	8	41.2 \pm 7.4 b	4 -5
<i>Erechtites hieracifolia</i>	6	1.3 \pm 0.4 c	2
<i>Emilia fosbergii</i>	8	1.8 \pm 1.3 c	2
<i>Helianthus annuus</i>	11	11.6 \pm 3.2 c	2

^a Means followed by the same letter are not significantly different (Tukey HSD; $\alpha=0.05$). Survivorship data were arcsine transformed to assume a normal distribution (Zarr 1999) and were analyzed using Proc ANOVA (SAS Institute 1985).

^bFeeding rate: 2 = light damage (feeding on 5-20 % of leaf area); 3 = moderate damage (feeding on 21 - 40 % of leaf area); 4 = severe damage (feeding on 41 - 60% of leaf area); 5 = intense damage (>60 % of leaf area and stems that eventually kills the plant).

Table 6. Host specificity of *Secusio extensa* on six endemic plants designated by USDA-Fish and Wildlife Service as the forest dominant species in the Hawaiian ecosystem.

Family and subfamily	Species and common name	N	Average cohort per replicate	No. larvae remains on plant within 48 hr (Mean ± SEM)	Feeding rate ^a	No. larvae survived beyond first instar (Mean ± SEM)				No. pupae reared (Mean ± SEM)	No. adults eclosed (Mean ± SEM)	Suitability for development ^b
						II instar	III instar	IV instar	V instar			
Dicksoniaceae	<i>Cibotium glaucum</i> (Sm.) Hook. & Arnott Hapuu	5	50	0.4 ± 0.2	0	0	0	0	0	0	0	-
Fabaceae; Mimosoideae	<i>Acacia koa</i> A. Gray Koa	5	50	0.4 ± 0.2	0	0	0	0	0	0	0	-
Fabaceae	<i>Sophora chrysophylla</i> (Salisb.) Seem Mamane	5	50	0.2 ± 0.2	0	0	0	0	0	0	0	-
Myoporaceae	<i>Myoporum sandwicense</i> A. Gray Naio	5	50	1.4 ± 0.5	0	0	0	0	0	0	0	-
Myrtaceae	<i>Metrosideros polymorpha</i> Gaud. Ohia lehua	5	50	1.2 ± 0.7	0	0	0	0	0	0	0	-
Sapindaceae	<i>Dodonaea viscosa</i> Jacq. Aalii	5	50	0.4 ± 0.4	0	0	0	0	0	0	0	-
Asteraceae	<i>Senecio madagascariensis</i> Fireweed (Control plant)	5	25	25 ± 0.0	5	22.2 ± 1.2	21.2 ± 0.6	21.2 ± 0.6	21.2 ± 0.6	20.4 ± 0.5	19.8 ± 0.4	+ normal host

^aFeeding rates: 0 = no feeding or probing marks; 5 = intense feeding that eventually kills the plant.

^bNegative sign (-) indicates unsuitability for development, compared to the normal host, positive sign (+).

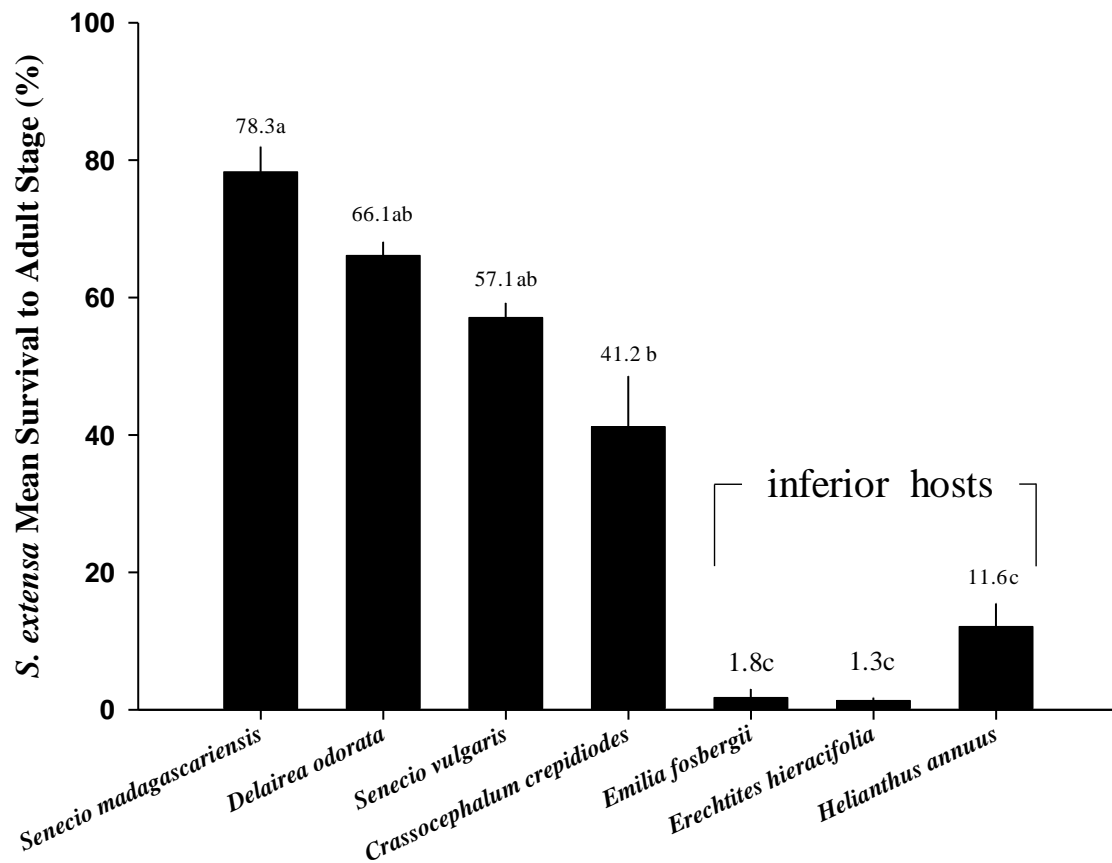


Figure 4: Survival to adult stage of *Secusio extensa* reared on the habitual plant (*S. madagascariensis*) and six other test plants during no-choice larval feeding trials. Bars (mean \pm SEM) topped by the same letters are not significantly different ($p > 0.05$; Tukey's studentized range test, HSD [SAS Institute, 1985]).

Larval feeding choice test with sunflower:

Within two hours of releasing the larvae in a cage containing the sunflower and fireweed, first instar moved to the natural host, fireweed. No larvae remained on cage surfaces or sunflower plants and no movement back to the sunflower plant occurred during observation hours. When larvae were placed directly on the sunflower, they moved quickly to adjacent fireweed branches and no larvae remained on sunflower after placement, indicating a negative feeding response. Larvae matured to the fifth instar on fireweed with no feeding on sunflower except for probing and superficial damage of less than 2% of leaf area (Table 7). In one replicate when all the fireweed leaves were consumed the hungry fifth instars were still hanging onto the fireweed plant, devouring the stems but did not attack the sunflower. Larvae were seen on sunflower, occasionally molting, but no feeding was observed. New fireweed plants were added *ad libitum* when larvae reached the fifth instar. During the choice experiments, larvae spent the entire larval duration (23 d) in the cage with the sunflower intact, feeding only on fireweed until pupation (Figure 5, 6). This confirms similar observations in Madagascar where larvae were seen feeding only on fireweed, and not even on the related plants of the same tribe (*Emilia* spp.).

Larval feeding preference in choice tests with *H. annuus* indicate that this plant is not likely to be selected for feeding in the presence of the natural host, *S. madagascariensis* (Table 8).



Figure 5: Feeding damage to fireweed (left and middle, most leaves consumed) in the presence of sunflower (right, broad leaves), during choice tests. Larvae (black, 5th instar on stems) selected fireweed leaving sunflower intact.

Table 7. Damage rate and development of *Secusio extensa* subjected to a choice test comprising one host plant and one test plant per cage until pupation ($n = 5$).

Parameter	Test plant (<i>Helianthus annuus</i>)		Host plant (<i>Senecio madagascariensis</i>)	
	Number of larvae seen on plant	Feeding rate ^a	Number of larvae seen on plant	Feeding rate ^a
Feeding by:				
first instar	0	0-1	25	1
second instar	0	0	25	1
third instar	0	0	25	2
fourth instar	0	0	25	3
fifth instar	0	0-1	25	4-5
Mean (\pm SEM) number pupae reared	-	-	24.6 \pm 0.24	-
Mean (\pm SEM) number of adults emerged	-	-	23.4 \pm 0.51	-

Five replicates, 25 first instar unfed larvae per replicate placed in a cage with one test and one host plant. Observations on larval feeding damage and development were rated daily until pupation. Host plants added *ad libitum*. Numbers of larvae on plants were counted once during morning hours.

^aFeeding rate: 0 = no damage; 1 = probing and superficial damage (<2% feeding on leaf area); 2 = light damage (feeding on 5-20 % of leaf area); 3 = moderate damage (feeding on 21 - 40 % of leaf area); 4 = severe damage (feeding on 41 - 60% of leaf area); 5 = intense damage (>60 % of leaf area and stems that eventually kills the plant).

Table 8. Developmental and survival rates of *Secusio extensa* exposed as first instar to *Helianthus annuus* (test plant) and *Senecio madagascariensis* (host plant) in choice and starvation no-choice tests.

Developmental stage	Percentage survival on test plant				Percentage survival on host plant (N=10) Mean ± SEM	Feeding rate ^a
	Choice test (N=5) Mean ± SEM	Feeding rate ^a	No-choice test (N=10) Mean ± SEM	Feeding rate ^a		
Second instar	0c	0-1	21.0 ± 5.1b	1	100.0 ± 0a	1- 2
Third instar	0c	0	17.4 ± 4.8b	2	100.0 ± 0a	2 -3
Fourth instar	0c	0	16.0 ± 4.9b	2	100.0 ± 0a	4
Fifth instar	0c	0-1	14.0 ± 4.9b	3	96.2 ± 1.3a	5
Pupa	0b	-	10.2 ± 3.7b	-	92.4 ± 3.3a	-
Adult	0b	-	9.0 ± 3.2b	-	85.8 ± 3.9a	-

^aFeeding rate: 0 = no damage; 1 = probing and superficial damage (<2% feeding on leaf area); 2 = light damage (feeding on 5-20 % of leaf area); 3 = moderate damage (feeding on 21 - 40 % of leaf area); 4 = severe damage (feeding on 41 - 60% of leaf area); 5 = intense damage (>60 % of leaf area and stems that eventually kills the plant).
N = number of replicates.

Means on the same row followed by the same letter are not significantly different (Tukey HSD; $\alpha = 0.05$). Survivorship data were arcsine transformed to assume a normal distribution (Zarr 1999) and were analyzed using Proc ANOVA (SAS Institute 1985).

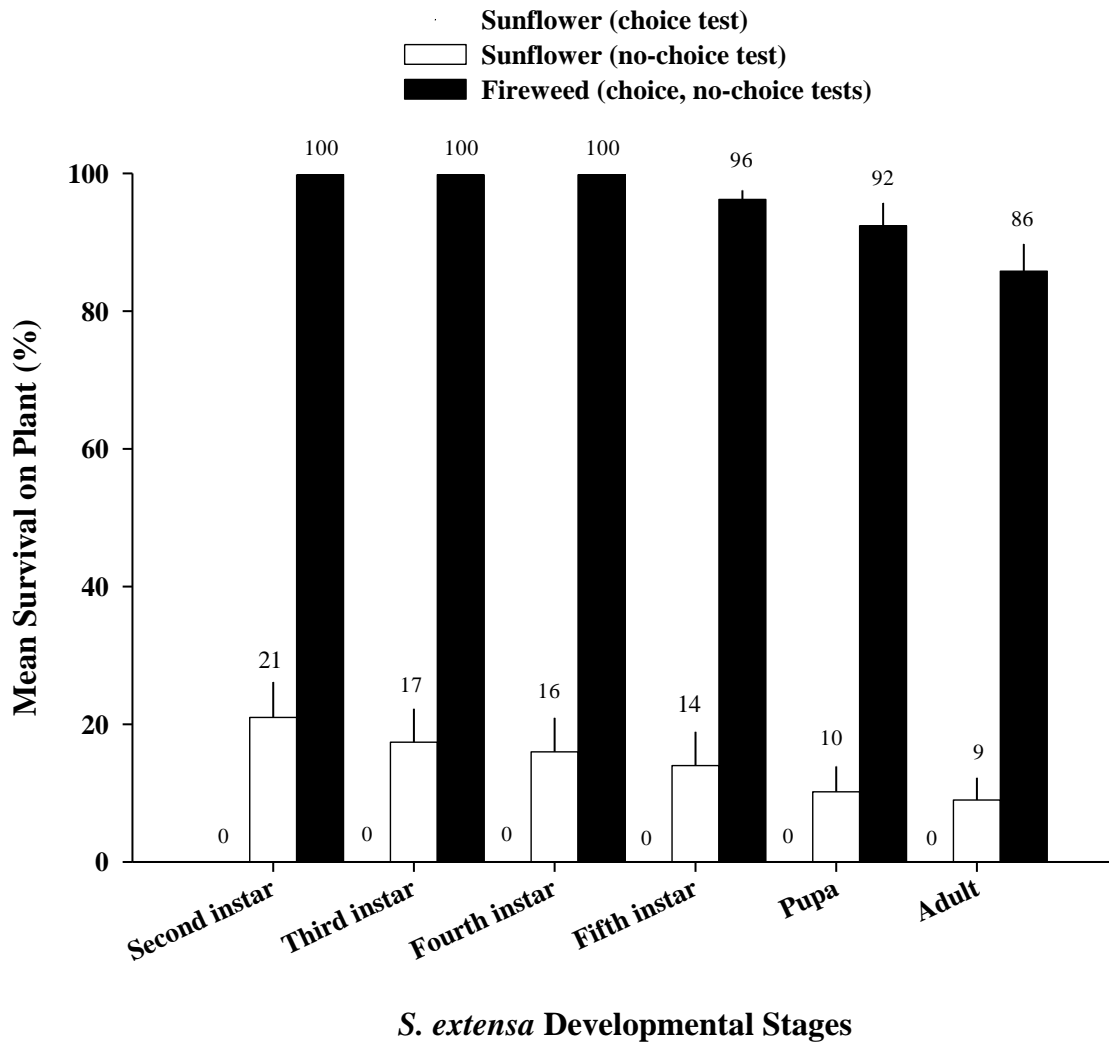


Figure 6: Survivorship rates of *Secusio extensa* (mean \pm SEM) on sunflower and fireweed during choice and no-choice larval feeding trials.

Oviposition choice test with Sunflower:

Oviposition preference of *S. extensa* was determined in a choice test between sunflower (test plant) and fireweed (host plant), (Table 9, Figure7). Mean number of eggs laid on fireweed was 75.2 ± 29.6 ($n=5$, 18% of total eggs). The moth did not select the sunflower as a potential substrate for egg deposition and none of the eggs were laid on the plant. Out of the five replicates, *S. extensa* deposited 376 eggs all on 28 fireweed leaves. Most of the eggs however, were deposited on cage walls, a common finding when Lepidoptera are held in close confinement (Palmer 1989).

Table 9. Oviposition preference of *Secusio extensa* on potted plants of *Helianthus annuus* and *Senecio madagascariensis*.

Parameter (mean \pm SEM)	Test plant (<i>H. annuus</i>)	Host plant (<i>S. madagascariensis</i>)
Total plant leaves used as oviposition substrate	0	5.6 ± 2.6
Total eggs deposited on plant	0	75.2 ± 29.6
% eggs deposited on plant ^a	0	18.0 ± 6.1

Five replicates, five pairs of newly emerged *Secusio extensa* per replicate held for a week in a cage (170X100X100 cm) with a test and a host-potted plants.

^a Calculated as the number of eggs deposited on plant divided by total eggs deposited on plant and cage walls multiplied by 100.

Oviposition choice test with *Crassocephalum crepidioides*, *Senecio vulgaris* and *Bidens pilosa*:

In this test, oviposition of *S. extensa* on the natural host, *S. madagascariensis* was 5.4 folds higher than eggs laid on the test plant, *C. crepidioides* (number of eggs on plants: $t = -3.5309$, $df = 11.1$, $p = 0.0047$; %eggs on plants: $t = -3.5789$, $df = 15.2$, $p = 0.0027$), Table 10, Figure 7. This oviposition preference coincided with results from the larval feeding experiments that demonstrate the inefficient capacity of *C. crepidioides* to support immature development in comparison with fireweed.

Table 10. Oviposition preference of *Secusio extensa* on foliage cuttings of *Crassocephalum crepidioides* and *Senecio madagascariensis*.

Parameter per replicate (mean \pm SEM)	Test plant (<i>C. crepidioides</i>)	Host plant (<i>S. madagascariensis</i>)
plant leaves used as oviposition substrate	1.1 ± 0.4	3.2 ± 0.7
Total eggs deposited on plant	6.7 ± 2.7	35.9 ± 7.8
% eggs deposited on plant ^a	4.6 ± 1.9	21.0 ± 3.8

Ten replicates, one pair of newly emerged *Secusio extensa* per replicate held until death in a cage (65X45X45 cm) with bouquets of test and a host plants. ^aCalculated as the number of eggs deposited on plant divided by total eggs deposited on plant and cage walls multiplied by 100.

Oviposition choice tests with *S. vulgaris* and *S. madagascariensis* showed no significant difference between number of leaves used as substrate ($t = 0.7365$, $df = 18$, $p = 0.4709$), total number of eggs ($t = 0.4153$, $df = 18$, $p = 0.6829$) and percentages of eggs ($t = 1.5349$, $df = 18$, $p = 0.1422$) laid on the plants, Table 11. Acceptance of *S. vulgaris* for oviposition by female *S. extensa* coincided with results on the suitability of *S. vulgaris* for immature development, Figure 4.

Table 11. Oviposition preference of *Secusio extensa* on foliage cuttings of *Senecio vulgaris* and *Senecio madagascariensis*.

Parameter per replicate (mean ± SEM)	Test plant (<i>S. vulgaris</i>)	Host plant (<i>S. madagascariensis</i>)
plant leaves used as oviposition substrate	1.9 ± 0.6	2.6 ± 0.7
Total eggs deposited on plant	17.3 ± 6.5	20.8 ± 5.4
% eggs deposited on plant ^a	15.2 ± 6.4	23.1 ± 5.1

Ten replicates, one pair of newly emerged *Secusio extensa* per replicate held until death in a cage (65X45X45 cm) with bouquets of test and a host plants.

^aCalculated as the number of eggs deposited on plant divided by total eggs deposited on plant and cage walls multiplied by 100.

Similar to results on sunflower, *Bidens pilosa* was not selected by *S. extensa* as a suitable substrate for oviposition ($t = -3.638$, $df = 8$, $p = 0.0066$). Mean eggs deposited on the natural host was 30.6 ± 8.4 eggs ($n=9$, 14.3% of total eggs) and none of the eggs were laid on *B. pilosa* (number eggs on plants: $t = -3.6333$, $df = 8$, $p = 0.0067$; % eggs on plants: $t = -7.3498$, $df = 8$, $p = 0.0001$), Table 12.

Table 12. Oviposition preference of *Secusio extensa* on foliage cuttings of *Bidens pilosa* and *S. madagascariensis*.

Parameter per replicate (mean ± SEM)	Test plant (<i>B. pilosa</i>)	Host plant (<i>S. madagascariensis</i>)
plant leaves used as oviposition substrate	0	5.0 ± 1.4
Total eggs deposited on plant	0	30.6 ± 8.4
% eggs deposited on plant ^a	0	14.3 ± 3.3

Nine replicates, one pair of newly emerged *Secusio extensa* per replicate held until death in a cage (65X45X45 cm) with bouquets of test and a host plants.

^aCalculated as the number of eggs deposited on plant divided by total eggs deposited on plant and cage walls multiplied by 100.

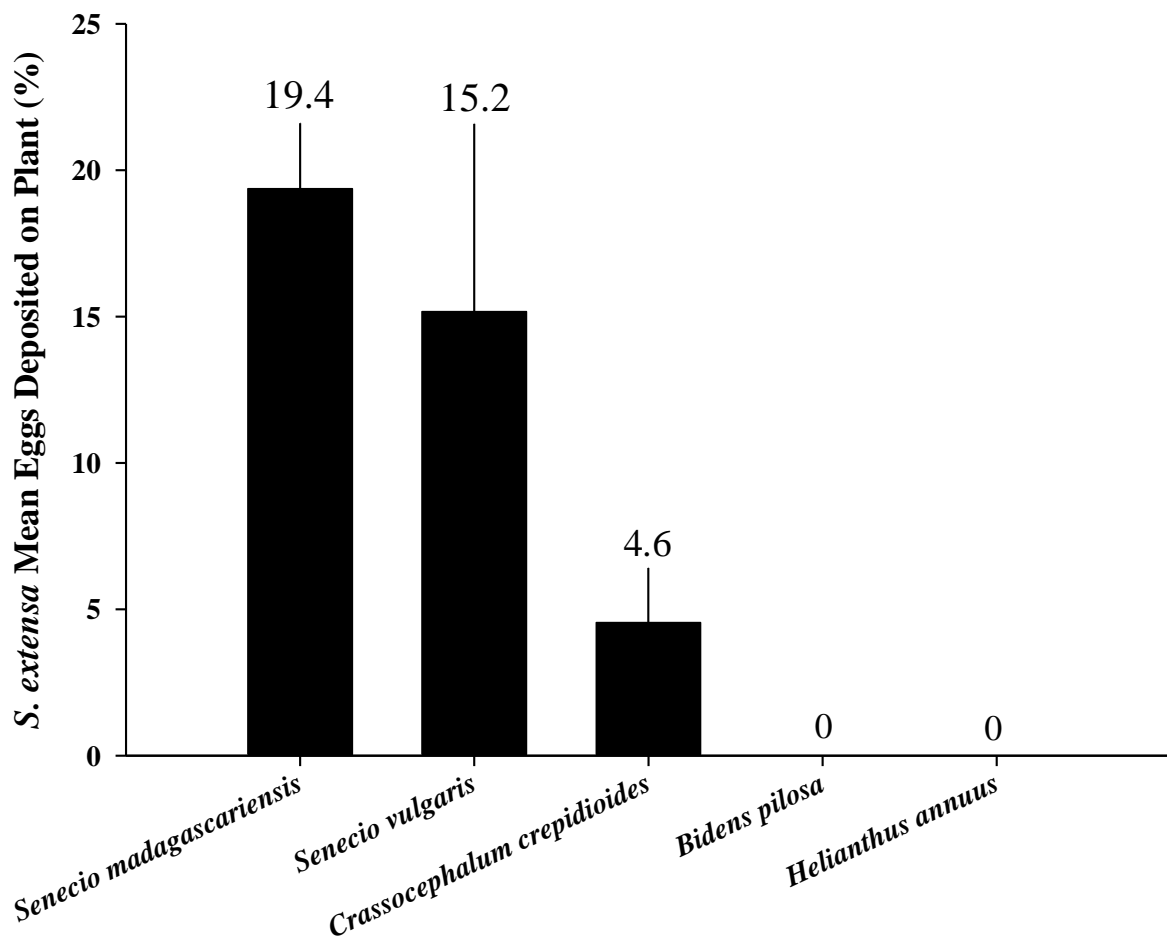


Figure 7: Oviposition preference of *Secusio extensa* in choice tests with the natural host, *S. madagascariensis* and trial plants.

Discussions

Field observations in Madagascar and reproductive attributes show that *S. extensa* is a prolific species capable of causing serious damage to fireweed. It has the advantage of a short life cycle compared to other potential biocontrol agents of fireweed. The female has high fecundity and easily reared under laboratory conditions. It is a tropical species without need for diapause and equipped with chemical protection against major predators. Larvae and adults are nocturnal enabling them to avoid heat, desiccation, and daytime predators. Usually insects containing poisonous chemicals exhibit warning coloration indicating that they are unpalatable (i.e. aposematic species). In this case, however, *S. extensa* is alkaloid laden and nocturnal. Therefore, the need for warning coloration is not critical. All these qualities are indicators of a successful biocontrol agent (Harris 1973). The high reproductive output of this species and its ease for mass production under laboratory conditions can enhance its success for successful establishment when field released.

There are mixed taxonomic opinions on the genus identity of this moth. Butler first described *S. extensa* under the genus *Sommeria* from specimens collected from Betsileo, Madagascar. *S. extensa* was then placed in genus *Diota* and changed to *Galtara*. The type species is *Galtara extensa* Butler, the only species in this genus from Madagascar. *Galtara purata* Walker, 1860 is the type for the genus *Galtara* and *Secusio strigata* Walker, 1854 is the type for the genus *Secusio*. If *G. purata* and *S. strigata* are congeneric, then the senior valid generic name would be *Secusio*. Until this problem is solved, our taxonomist prefers to place it under the senior name *Secusio* (J. Rawlins, Carnegie Museum, personal communication). Nonetheless, since described by Butler in 1880, there are no records for both names (*G. extensa* or *S. extensa*) anywhere in the world showing the insect as a pest on any crop or having preferences for any plant except herb and weed members of the tribe *Senecioneae*.

The other mottled beige arctiid species in mainland Africa is *Diota rostrata* (Wallengren) and this too has been found only on *Senecioneae* and USDA is studying it for biocontrol of *Delairea odorata* in California (Wing 2005). *Secusio pustularia* Walker is another related species common in fauna from Mlawula, Swaziland. There are no records of this species as a pest on any African crops or other plants.

While other species of the genus *Secusio* (*S. pulverata* (Hampson), *S. pustularia* Walker, *S. strigata* Walker, *Secusio* spp.) are common on mainland Africa (Swaziland, Rwanda, South Africa), *S. extensa* is not recorded in any survey. It is only found in Madagascar in habitats where populations of *S. madagascariensis* are present. Two field surveys were conducted in Madagascar during the summer (October 1999) and the rainy seasons (April 2005). During these seasons, careful examination of all plants around and within fireweed populations infested with *S. extensa* (sweet potato, cassava, cucurbits, rice fields, Asteraceae, Rubiaceae, pineapple, tomato, and grasses) indicated that this insect was restricted to *S. madagascariensis*. Examination of four common herbs of Asteraceae (*Emilia tranvaalensis*, *Tridax provumbens*, *Sonchus oleraceus*, and *Bidens pilosa*) present at the survey sites in Madagascar showed that these plants were not attacked by this arctiid.

No moths were added to the colony and all host testing were conducted using the original cohorts of 1999.

The production of mating volatile components in arctiid moths is contingent on larval access to their natural host plants containing PAs precursors (Davidson et al. 1998). Decreases in rates of male mating success were also observed from *S. extensa* cohorts fed on *H. annuus* and members of *Senecioneae*. This observation may be explained by inadequate pheromonal discharge by males feeding on lower quality plants. For example, male coremata (i.e. tubular abdominal scent organ everted during courtship) of Arctiidae are known to secrete a pheromonal substance, derived from plant toxins obtained during larval feeding and carried over to the adult stage, that affect mate choice by female. The size of the coremata and their pheromonal charge may have behavioral consequences in the mating system of these species (Davenport and Conner 2003). A pattern of mating failure has been observed among pairs of *S. extensa* fed on low quality hosts during larval development (Figure 8). Rates of unmated females among pairs of *S. extensa* reared from *D. odorata* (22%, $n=36$ pairs), *S. vulgaris* (24.2%, $n=33$ pairs), *E. fospergii* (25%, $n=4$ pairs), *H. annuus* (30.5%, $n=36$ pairs) and *C. crepidioides* (50%, $n=22$ pairs) were 1.5 - 3.3 folds higher than rates of unmated females reared from the natural host, *S. madagascariensis* (15.0%, $n=226$ pairs). This is an indication of lower quality males reared on plants with a smaller amount or different chemotypes of PA than senecionine of the natural host. Larvae of several European and Asian arctiid moths metabolized free PA bases into precursor of male pheromone (Von Nickisch and Wink 1993). Alkaloid-free males of the moth *Utetheisia ornatrix* (L.) (Lepidoptera: Arctiidae) failed to produce the pheromone and were less successful in courtship (Eisner and Meinwald 1995, Rossini et al. 2001). Likewise, colonies of *S. extensa* reared exclusively for three generations on *C. crepidioides* were in decline under laboratory conditions. Therefore, based on these observations, it is possible that the continuous rearing on non-habitual plants will not sustain a stable population in the field.

Laboratory studies with Lepidoptera have shown the importance of visual and plant volatiles in the orientation of moths towards their host plants (Hanson 1983, Papaj and Rausher 1983). Even though most of the eggs were deposited on cage walls during oviposition experiments, female *S. extensa* did not use sunflower as an oviposition substrate nor lay any eggs on it. If the female chooses fireweed and cage walls over the test plant this may imply a deterrent effect of sunflower. Features of the leaf surface of sunflower may affect female selection not to lay eggs on a plant. Females can also be repelled by volatiles from that plant that solicit avoidance behavior, or discourage the selection of a plant for oviposition. Egg deposition on cage walls may also indicate that females desired to distribute eggs in small batches per plant. This behavior is evident by the low number of eggs laid per day (21.8 eggs) in comparison with the total egg load in ovaries (227.1 eggs) (Table 2). In Madagascar while the moth populations were very high, only an average of eight mature larvae were collected per plant.

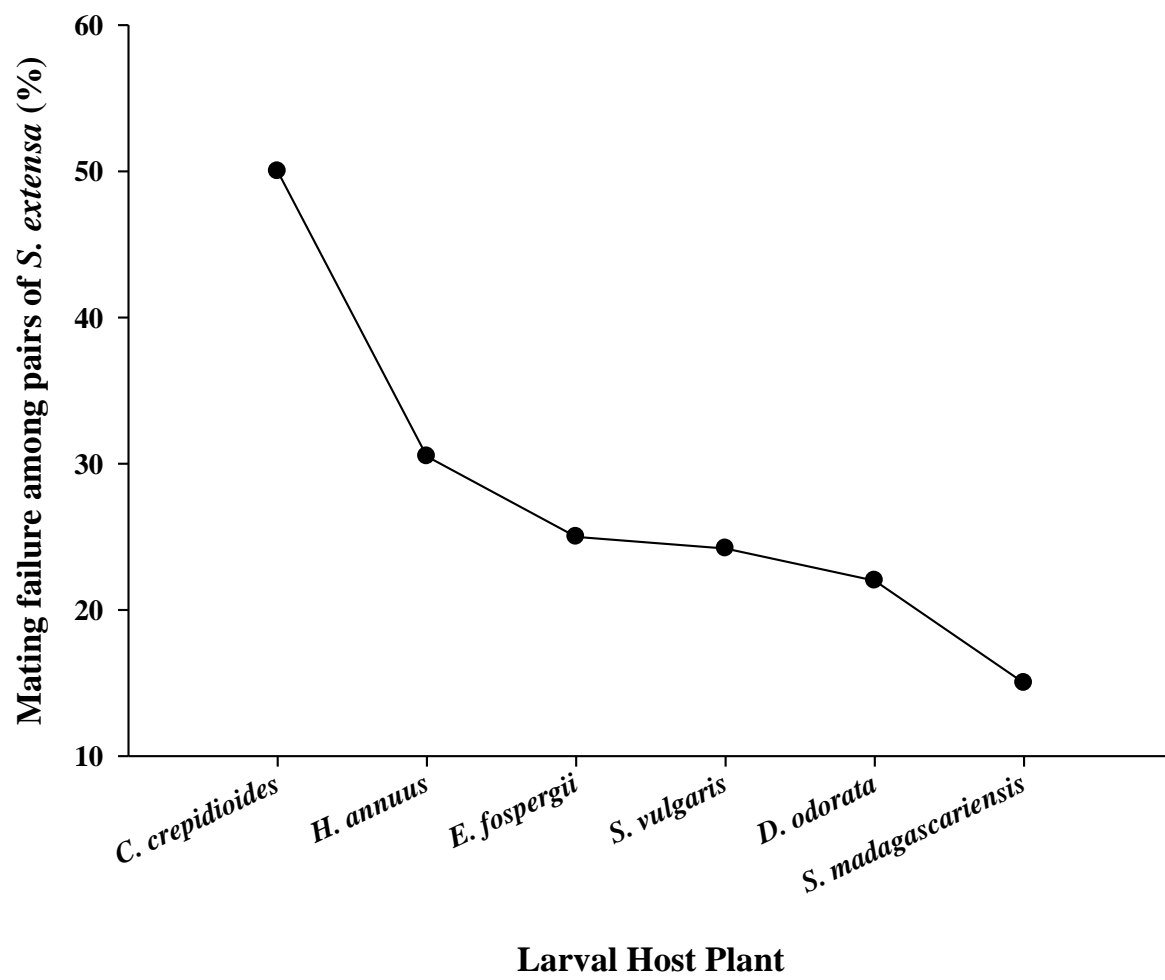


Figure 8: Pattern of mating failure (percentages of unmated females) among pairs of *Secusio extensa* developed as larvae on the natural host, *S. madagascariensis* and other inadequate hosts.

Several types of PAs of Asteraceae are restricted to 26 genera of tribes *Eupatorieae* and *Senecioneae*. Members of *Crassocephalum*, *Emilia*, *Erechtites*, *Farfugium*, and *Senecio* are known to contain alkaloids that may differ from the senecionine chemotype of fireweed (Röder 1995). Hence, the feeding response, reproductive output, and mating rates of *S. extensa* may also be altered. In addition, all parts of *H. annuus* are known to contain slightly toxic levels of secondary compounds (nitrate fatty acids with biological activity) that may act as phagostimulants, modify oviposition, or interfere with the life cycle of insects (Relf 1996, Ashfaq and Aslam 2001). Such compounds may be the reason for some feeding, larval development, and male mating success during forced feeding trials.

Results of larval feeding and oviposition preferences indicate that *S. extensa* is not likely to be a threat to neither agriculture nor the environment in the State of Hawaii. *H. annuus* is an exotic ornamental plant of North American origin, naturalized in Hawaii on the high plains between Mauna Loa and Mauna Kea on the island of Hawaii (Wagner et al. 1999). It is grown occasionally in Hawaii with a variety of other seed crops (total of 309.6 acres on all islands), whereas corn is the bulk crop accounting for 92 % of the seed industry (Anonymous 2005a). While *H. annuus* proved acceptable for 11.6 % *S. extensa* to complete development during forced feeding, it was not selected by any of the five larval instars during well replicated feeding choice trials ($n = 10$). This is strong evidence that *S. extensa* will not choose the plant as a host in the field. Female moths did not lay eggs on sunflower during choice oviposition tests, indicative of a negative response to the plant. Furthermore, comparative studies on the reproductive attributes of female *S. extensa* emerging from sunflower are significantly reduced compared to fireweed, a confirmation of an inferior host that is unlikely to sustain a permanent population.

PA's often serve as chemical mediators of plant-herbivore-predator interactions (Von Nickisch et al. 1993). Arctiid moths usually store PA from plant sources and thereby become protected against antagonists. In addition, they may serve as precursors for the biosynthesis of courtship pheromones (Davenport and Conner 2003). Behavioral response of the Puerto Rican tree frog, *Eleutherodactylus coqui* Thomas (Anura: Leptodactylidae), introduced to *S. extensa* showed that adult moth and larvae are unpalatable to the frog. Three field collected *E. coqui* starved for three days were introduced to eight male *S. extensa* in a gallon jar. Two of the frogs successfully captured *S. extensa* but the moths were rejected immediately. The third male frog never tried. The frogs repeatedly ignored the moths even when in close proximity. After two days, a frog captured a male *S. extensa* and rejected it. In the process, all frogs starved to death without re-capturing the moths. A second test with two new *E. coqui* frogs and mature *S. extensa* larvae during a two hours observation, showed that the frog may take the larva but it spat it out at once without injury to the larva, and the frog never tried again (M. Ramadan, unpublished). A moth will bubble out alkaloid-laden hemolymph through membranes on thoracic segments when disturbed. There are some reports suggesting a chemical defense of arctiids against predation by spiders (Conner et al 2001). Alkaloid laden eggs were rejected and not pierced by larvae of the green lacewing, *Ceraeochrysa cubana* (Hagen) (Neuroptera: Chrysopidae), Eisner et al. 2000. PAs are known to protect Arctiidae, Danainae, and

Ithominiinae butterflies against the orb-weaving spider *Nephila clavipes* (L.) (Araneae: Araneidae), Silva and Trigo 2002. Ingested PAs, which are toxic to unspecialized insects and vertebrates, are efficiently metabolized in the hemolymph of the cinnabar moth, *Tyria jacobaeae* L. (Naumann et al. 2002)

While parasitoids and predators are often suspected to suppress the rate of establishment of lepidopteran biocontrol agents in Hawaii, there are no quantitative examples demonstrating severe effects on these agents. To the contrary, the ivy gourd moth, *Melittia oedipus* Oberthür (Lepidoptera: Sesiidae) was not hit by larval and pupal parasitoids except for a few (<10%) *Eupelmus* sp. (Hymenoptera: Eupelmidae) which emerged from field collected eggs (Chun 2001, and M. Chun unpublished data). On the Big Island of Hawaii, mean egg parasitism by *Trichogramma chelonis* Ishii of *Pyrausta perelegans* Hampton (Lepidoptera: Crambidae), introduced for biological control of banana poka, *Passiflora mollissima* (H.B.K.) and *Schreckensteiniella festaliella* (Hübner) (Lepidoptera: Schreckensteiniidae) introduced for biocontrol of *Rubus* species, were 9.2 % and 33%, respectively (M.Ramadan, unpublished data). In Madagascar, *S. extensa* larvae were attacked by *Apanteles* sp. (Hymenoptera: Braconidae), a larval and a larval pupal tachinid parasitoids (Diptera: Tachinidae, undetermined species). However, the overall rate of field parasitism by the three species was less than 10% during a high population season in 1999.

S. extensa possess only plumose setae of no stinging or respiratory concern to humans unlike other arctiids whose caterpillars possess urticating hairs that can cause irritating encounters with humans. Rearing and handling thousands of *S.extensa* larvae and adults for >56 generations during the past six years, indicates that caterpillars will not cause any health concerns if released in the field.

Of all the species of Asteraceae studied, only *S. madagascariensis*, *S. vulgaris* and *D. odorata* (formerly placed in genus *Senecio*), proved to be adequate hosts for *S. extensa*. The rest of the plants were either unsuitable hosts or only supported limited percentages of larval development under larval starvation tests (Figure 4). Six native forest species recommended by USDA-FW also proved to be unsuitable as potential hosts for this moth and the larvae did not even taste them. Therefore, results of this study demonstrate that the release and subsequent establishment of *S. extensa* in Hawaii should pose no threat to plants other than a few members of the tribe *Senecioneae*. Fortunately, there is no native or endemic species in this tribe in Hawaii.

The ability of larvae to develop on *Bidens pilosa* was minimal. Out of 7 replicates and 410 larvae, only two larvae completed development to the unclosed pupal stage. The larvae were very small, causing minimal damage to the plants, and developed very slowly compared to larvae feeding on the natural host. Consequently, pupae were malformed and undersized. Similar results were obtained from *B. pilosa* tested against a variety of phytophagous species, suggesting low plant deterrents, allowing insect to feed on the plant. The limited feeding during cage trials may also be a result of confinement (Zachariades et al. 2002).

Field and laboratory observations on fireweed showed that caterpillars fed on leaves, leaving the flower heads mostly intact. This feeding behavior can complement the efforts of the flower-head

feeders and the stem borers under evaluation for future release as biocontrol agents.

This is the first attempt to release and establish an arctiid biocontrol agent from the native region of fireweed to suppress its populations to manageable densities and to limit incidences of poisoning in Hawaii's pastures and rangelands. Examples of success using arctiid moths for biological control of Asteraceae weeds are well documented in the literature (Timbilla and Braimah 2000, Coombs et al. 1996, McEvoy et al. 1991). Siam weed, *Chromolaena odorata* (L.) R. M. King & H. Robinson (Asteraceae: Eupatoriae) is South American in origin and is one of the most serious weeds in pastures, forests, orchards and commercial plantations in Africa and Asia, and the Pacific region (Zachariades and Goodall 2002, **Desmier de** Chenon et al. 2002). The introduction of the arctiid moth, *Pareuchaetes pseudoinsulata* Rego Barros to the Mariana Islands in 1985 to control this weed has been successful in reducing its dominance (Muniappan et al. 1989). Furthermore, the establishment of *P. pseudoinsulata* in Ghana, Africa, has led to considerable reduction in *C. odorata* populations from initial 85% to 37% of total infested land. Biocontrol has positively enhanced forest regeneration and biodiversity in an estimated 52,349 km² within 7 years (Timbilla and Braimah 2000). Similar successful biocontrol programs with the cinnabar moth, *Tyria jacobaeae* (L.), also an arctiid, were undertaken to control tansy ragwort, *Senecio jacobaeae* L., in the continental United States and New Zealand (McLaren 2002, Coombs et al. 1996, McEvoy et al. 1991). Within a span of five years, in Oregon, the average density of the weed was reduced to about 10 percent of the original coverage and reported cases of tansy ragwort poisoning have declined more than twenty fold (Burrill et al. 1994).

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