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FOODPLANT SPECIFICITY AND BIOLOGY OF *OIDAEMATOPHORUS BALANOTES* (PTEROPHORIDAE): A NORTH AMERICAN MOTH INTRODUCED INTO AUSTRALIA FOR THE BIOLOGICAL CONTROL OF *BACCHARIS HALIMIFOLIA*

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ABSTRACT. The stem-boring moth, *Oidaematophorus balanotes* (Meyrick) (Pterophoridae), was investigated as a biological control agent for *Baccharis halimifolia* L. (Asteraceae), an introduced weed in Australia. *Oidaematophorus balanotes* occurs from New York to the Rio Grande Valley and its larval hosts are *B. halimifolia* and *B. neglecta* Britton. It is univoltine throughout its range except in Florida where there may be two overlapping generations per year. The host range of *O. balanotes* was determined by observing the response of moths and neonate larvae on 64 economically important plants and *B. halimifolia*. In multiple choice tests, moths oviposited almost exclusively on *B. halimifolia*. Larvae placed on foliage of the test plants were able to complete development only on *B. halimifolia*. As a result, *O. balanotes* was considered safe for release in Australia where it was established in southeastern Queensland in 1985.

Additional key words: Asteraceae, host plant, Florida, Texas.

The woody shrub *Baccharis halimifolia* L. (Asteraceae: Astereae: Baccharidineae), an introduction from North America, is a serious weed in Queensland, Australia (Stanley & Ross 1986, Palmer 1987). The Queensland Department of Lands, through the Alan Fletcher Research Station, therefore initiated a long-range research program in 1960 to find biological control agents in the New World for release against this weed in Australia. Following initial surveys by F. D. Bennett (Palmer & Bennett 1988), officers of the Alan Fletcher Research Station, including the second author, commenced a three year research program in 1967 at the Archbold Research Station, Lake Placid, Florida, to determine the host specificity of selected insects. In the next decade, efforts focused on South American fauna but in 1982 the North American Field Station was established to continue work in the North American region.

The genus *Baccharis* is one of the largest in the Astereae, with approximately 450–500 species, all of which are native to the New World (Nesom 1990). About 90% of the species occur in South America (Nesom 1990); twenty species occur in the United States (Mahler & Waterfall 1964). Nesom (1990) divided the 43 species occuring in North and

Central America into six sections. *Baccharis halimifolia* was nominated as the type species of the section Baccharis. Other species of relevance to this study that were placed in this section include *B. angustifolia* Michx., *B. dioica* Vahl, *B. glomerufolia* Pers., and *B. neglecta* Britt. *Baccharis sarathroides* Gray was placed by Nesom (1990) in the section Sergilae, which is very closely related to the section *Baccharis*.

The insect fauna on *B. halimifolia* has been described by Palmer (1987) and Palmer and Bennett (1988). One of the first insects selected in 1967 for further study at Lake Placid was the moth, *Oidaematophorus balanotes* (Meyrick) (Pterophoridae), larvae of which frequently were found boring in the stems of *B. halimifolia* and occassionally causing considerable damage to the shrub. Moreover, search of the literature, examination of previously collected specimens, and observation of surrounding flora suggested that *O. balanotes* larval foodplant range might be confined to *Baccharis* spp.

Oidaematophorus balanotes

Taxonomy

Oidaematophorus Wallengren is a large genus containing 73 species (Hodges et al. 1983). Within this genus, the *balanotes* group (Cashatt 1972) includes *O. balanotes*, *O. grandis* (Fish), *O. lacteodactylus* (Chambers), *O. kellicottii* (Fish), and *O. glenni* Cashatt.

Until the revision of the group by Cashatt (1972), who examined the genitalia of both sexes, these species were very difficult to separate. Indeed, specimens collected from *B. halimifolia* prior to 1972 were frequently identified as either *O. balanotes*, *O. kellicottii*, or *O. lacteodactylus*. We now believe that these specimens were most probably *O. balanotes*.

Distribution and Larval Food Plant Range

Although some adults have been captured in Arizona, *O. balanotes* is essentially an eastern species (Cashatt 1972) that occurs along the eastern seaboard from New York in the north to the Rio Grande Valley in Texas. This distribution approximates that of its *Baccharis* hosts.

The first author has collected larvae of *O. balanotes* from *B. halimifolia* and *B. neglecta* on many occasions (Palmer 1987). Almost certainly it also occurs on the Florida species *B. glomeruliflora* and *B. angustifolia*. Its host in Arizona is probably *B. sarathroides*.

Cashatt (1972) gives *Myrica* sp. (Myrtaceae) as a larval host based on one specimen record in the material he examined. However, we believe that this record is in error. *Myrica* and *B. halimifolia* are similar looking shrubs growing in the same habitat and sharing the same com-

mon name, "sea myrtle". Apart from this one record, *Baccharis* spp. are the only known hosts for *O. balanotes* (Cashatt 1972).

Indeed, all species in the *balanotes* group appear to have very narrow larval host ranges within the tribe Astereae. *Oidaematophorus grandis* has been collected from *B. pilularis* (Cashatt 1972); *O. kellicotti* from *Solidago* (Cashatt 1972), *B. neglecta*, and *B. dioica* (Palmer unpubl. data); *O. lacteodactylus* from *Solidago* sp. (Cashatt 1972); and *O. glenni* from *Solidago canadensis* (Cashatt 1972).

Biology and Phenology

The moths are rather delicate with brownish white wings spanning about 40 mm. Females oviposit eggs singly on the leaves, leaf axils, young twigs, and probably inflorescences. The eggs are oval, 0.5 mm long, and translucent white. Accurate egg counts were not made but we estimate that a female might produce a brood of several hundred eggs.

Larvae feed initially on leaves, inflorescences, and young stems. Although pterophorids are not known to be leaf miners, early instar *O. balanotes* tunnel into leaves to feed on the mesophyll. After a few days they move to the stem, either at the leaf axil or at the terminal, enter, and then feed for two to three weeks. A further migration then occurs as the larvae seek out more mature tissues further down the stems. Tunnels are made in mature stems of more than a year in age and these may reach over a meter in length. The entrance to this tunnel remains open although surrounded by a characteristic, granular frass. The larva is similar to that of *O. grandis*, which was described by Peterson (1962), except that the granulated texture of the anal shield is more uniform. Both of these species have two "urogomphi-like" hooks present on the anal shield, a character present only on very few Lepidoptera species. Larvae pupate in the tunnel and the moth emerges through the tunnel opening.

Throughout most of its range there appears to be one generation a year with moths emerging over summer. Early instars are found in autumn and often can be collected from inflorescences. Terminal twig death of the hosts occurs as these early instars attack new growth of stem tips. Tunnelling in more mature tissue then commences and the larvae overwinter in these tunnels. Larval tunnelling continues in the spring until the larvae pupate.

In Florida, where the winter is less pronounced, there appear to be two generations a year and the generations are not discreet. For example, in central Florida in February 1983, all stages from early instars to mature pupae were found in the stem tunnels.

Four species of hymenopteran parasitoids were reared from the lar-

vae: three Braconidae: *Macrocentrus cerasivoranae* Vierick, *Chelona* sp., *Chelonus* (*Microchelonus*) sp.; and one Ichneumonidae: *Temelucha cartipetiolata* Dasch. Parasitism rates ranged from 40–60% with *M. cerasivoranae* being the most abundant species.

Host Plant Specificity

Oviposition preference. Oviposition behavior was tested by randomly assigning each of two potted plants of 64 test plant species (Table 1) to one of eight cages. *Baccharis halimifolia* was included as a control in all eight cages. Twenty unsexed moths were released into each cage and honey-water wicks were placed in the cages for their nourishment. After five days, when the control plants were infested with eggs, the cages were dismantled and all eggs on the potted plants and cage walls were counted. The plants then were transferred to a greenhouse and observed until feeding was seen on the *B. halimifolia* controls. All plants were then reexamined for evidence of larval feeding.

Plants of *B. halimifolia* in all cages had dozens of eggs attached. Only five other plant species had eggs: *Leucaena leucocephala* (Lam.) de Wit., *Cucumis melo* L., and *Triticum aestivum* L. each had one egg; one plant of *Carica papaya* L. had seven eggs; both plants of *Paspalum dilatatum* Poir had one egg. The foliage of all these plants was in close proximity to that of *B. halimifolia*. On no other plant were eggs or feeding damage found. Hatch rate of eggs on *B. halimifolia* was greater than 80% and feeding on the plant tips and boring into the stems were seen on all these plants. The eggs on all the other plants hatched but no feeding occurred. We conclude that *O. balanotes* is highly selective about its choice of larval food plants, that oviposition of a few eggs laid on other plants probably was an artifact of caging, and that, of the plants tested, only *B. halimifolia* is a suitable host.

Larval feeding. Moths confined in cages with *B. halimifolia* plants oviposited, after which leaves with eggs were cut into sections so that each section contained 4 eggs. These leaf sections were then glued to the leaves of the test plants (Table 1), which were arranged in groups of eight with one *B. halimifolia* plant as a control. There were two replications of each plant species except sunflower, *Helianthus annuus* L., which had seven replications. Eggs hatched normally with a hatching rate above 95%. After 5 weeks, when vigorous larval tunnelling was seen in the controls, all plants were examined carefully.

Eggs hatched and larvae developed normally on all *B. halimifolia* plants. In most cases feeding was seen immediately below the eggs. In other cases larvae moved up to 50 mm from the egg to enter the leaf petiole, leaf axil, or the stem. With one exception, larvae made no attempt to feed on any test plant; no tissue abrasions could be seen

TABLE 1. Plant species tested as potential hosts of *Oidaematophorus balanotes*.

Apiaceae: *Daucus carota* L.; *Pastinaca sativa* L.
Anacardiaceae: *Mangifera indica* L.
Asteraceae: *Baccharis halimifolia* L.; *Carthamus tinctorius* L.; *Chrysanthemum* sp.; *Dahlia* sp.; *Helianthus annuus* L.; *Lactuca sativa* L.
Brassicaceae: *Brassica oleraceae* (L.) Alef.; *Brassica rapa* L.
Bromeliaceae: *Ananas comosus* (L.) Merr.
Caricaceae: *Carica papaya* L.
Chenopodiaceae: *Beta vulgaris* L.
Convolvulaceae: *Ipomoea batatas* (L.) Lam.
Cucurbitaceae: *Cucumis melo* L.; *Cucumis sativus* L.; *Curcubita maxima* Duch.
Fabaceae: *Arachis hypogaea* L.; *Centrosema pubescens* Benth. Desmodium canum (Gmel.); *Glycine wightii* (R. Grah. ex Wight & Arn.) Verdc.; *Glycine max* (L.) Merr.; *Medicago sativa* L.; *Phaseolus atropurpureus* DC.; *Phaseolus vulgaris* L.; *Pisum sativum* L.; *Stizolobium* sp.; *Stylosanthes gracilis*.; *Trifolium repens* L.; *Vigna catjang* V.
Linaceae: *Linum usitatissimum* L.
Malvaceae: *Gossypium hirsutum* L.
Mimosaceae: *Leucaena leucocephala* (Lam.) de Wit.
Musaceae: *Musa sapientum* M.
Passifloraceae: *Passiflora edulis* Sims
Pinaceae: *Pinus radiata* D. Don.; *Pinus taeda* L.
Poaceae: *Avena sativa* L.; *Digitaria decumbens* Stent.; *Panicum maximum* Jacq.; *Paspalum dilatatum* Poir.; *Pennisetum clandestinum* Chiov.; *Saccharum officinarum* L.; *Sorghum vulgare* L.; *Triticum aestivum* L.; *Zea mays* L.
Porteaceae: *Macadamia integrifolia* Maid & Betche
Rosaceae: *Fragaria vesca* L.; *Malus sylvestris* Mill.; *Prunus domestica* L.; *P. persica* (L.); *Pyrus communis* L.; *Rosa* sp.
Rutaceae: *Citrus limon* (L.) Burm. F.; *Citrus paradisi* Macfady.; *Citrus reticulata* Blanco; *Citrus sinsensis* (L.)
Sapindaceae: *Litchi chinensis* Sonn.
Solanaceae: *Capsicum annum* L.; *Lycopersicum esculentum* Miller; *Nicotiana tabacum* L.; *Solanum tuberosum* L.
Vitaceae: *Vitis vinifera* L.
Zingiberaceae: *Zingiber officinale* Roscoe.

under 10× magnification. In *H. annuus* L., however, some larvae commenced feeding and formed mines in leaves of the seven replicates (2, 2, and 3 mines respectively). Although some mines reached 10 mm in length, no larvae on *H. annuus* advanced to the next feeding stage of entering and feeding in the stem.

Release in Australia

Approval was received in 1968 from the Commonwealth Department of Health to release *O. balanotes* in Australia. This approval was given with the usual proviso that the insect be reared through one full generation in quarantine facilities to ensure that it was free of parasites and diseases before being released.

Oidaematophorus balanotes was first imported into Australia as larvae in 1969. Small numbers of moths and larvae were released on three

occasions (25 late instars, 20 moths, and 70 first instars, respectively) in southeastern Queensland but establishment was not successful, probably because the numbers released were inadequate.

Further attempts at introduction were made in 1982–83. In autumn 1982 and spring 1983 in Texas, Louisiana, and Florida, larvae were collected by dissecting stems of both *B. halimifolia* and *B. neglecta* at the North American Field Station and placed individually into 2 cm sections of plastic tubing containing Harley-Willson artificial diet (Harley & Willson 1968). A wad of cotton wool acted as a stopper at both ends. In this manner some 500 larvae were shipped to Australia where they were placed on fresh artificial diet to complete their life cycle. However, the larvae responded poorly to this diet and eventually the colony was lost.

A third attempt was made in 1984. Larvae were collected in the summer and autumn of 1984 from Texas and Florida. The finding of a large population of larvae relatively free of parasites near Gainesville, Florida, was an important factor in the ultimate successful colonization of this insect. Approximately 1000 larvae were shipped, mostly from this population at Gainesville, to Australia. This time larvae were reared on potted plants of *B. halimifolia* instead of on artificial diet, using a technique developed by A. J. Tomley at the Alan Fletcher Research Station. The development of this technique was the single most important factor in the success of the program and was the basis for a mass rearing program implemented from 1985–88. Potted plants were exposed to adult moths and plants with eggs were then kept in shade houses until the insect completed its development. As larvae began pupating, their food plants were placed inside temporary cloth cages so that emerging moths could be captured and then released in the field.

Oidaematophorus balanotes reared by this mass production technique were first released in 1985. Over the next 3 years some 10,000 moths were released at various sites in southeast Queensland. Establishment was confirmed in 1985 and the moth is now found throughout most of the range of its foodplant (A. J. Tomley pers. comm.). We anticipate that *O. balanotes* may prove to be one of the better biocontrol agents introduced for this weed (see also Palmer 1989).

DISCUSSION

Oidaematophorus balanotes displays a number of useful characteristics of good biocontrol agents, in addition to its being sufficiently host specific to be used safely in Australia. Its broad native distribution includes a wide range of climatic conditions, including an area with a climate similar to southeast Queensland (Florida), so that its prospects

of successful establishment should have been good. As an endophage, it has a somewhat better chance of success than an ectophage, primarily because endophages are less susceptible to generalist parasitoids and are less less likely to be attacked by specialist parasitoids.

A major potential problem of using an insect such as this for biocontrol lies in the difficulty of rearing it in the laboratory. Stem boring insects with relatively long lifecycles can be difficult to rear and the problem is compounded if they do not adapt to artificial diets. Almost certainly the ultimate success of this project was due to the development of suitable mass rearing techniques that produced large numbers of healthy, robust adults available for release.

The successful establishment of *O. balanotes* in Australia provides an example of a problem confronting those involved in biological control. That is, how much effort should be expended on a species when first attempts to establish it fail? Is it better to persevere with such an insect or divert attention to other species? Obviously the answers depend on many factors, but this example suggests that multiple attempts at establishment may be worthwhile.

The effects of *O. balanotes* on *Baccharis halimifolia* in Australia have not yet been ascertained. Populations of the moth, although increasing, have not yet reached damaging levels. Even when the moth is fully established the effects may be difficult to gauge. Unless plants become grossly infested they are unlikely to be killed. Rather, *O. balanotes* may weaken the plants and predispose them to the deleterious effects of other herbivores and pathogens.

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