First Record of Fossorial Behavior in Hawaiian Leafroller Moth Larvae, *Omiodes continuatalis* (Lepidoptera: Crambidae)[1]

Cynthia King[2,3] *and Daniel Rubinoff*[3]

Abstract: Larvae of the endemic Hawaiian leafroller moth, *Omiodes continuatalis* (Wallengren), were used in controlled exposure trials on the island of Maui, Hawai'i, in May–August 2006, to examine effects of introduced parasitoids on native Hawaiian Lepidoptera. During the trials we observed *O. continuatalis* larvae burrowing up to 14 cm into the soil beneath plants on which they were deployed. This discovery reflects the first record of fossorial behavior not associated with pupation in larvae of Hawaiian *Omiodes* and suggests how *O. continuatalis*, a species once listed as extinct by the U.S. Fish and Wildlife Service, may persist despite intense pressure from introduced biological control agents.

Omiodes continuatalis (Wallengren) is an endemic crambid leafroller moth, historically distributed throughout the main Hawaiian Islands. The species was noted by Thomas Blackburn to be the most common moth encountered during his collecting trips before 1880 (Zimmerman 1958). A century later, *O. continuatalis* and an additional 13 species in the genus *Omiodes* were listed as extinct or possibly extinct by the U.S. Fish and Wildlife Service and other agencies (Gagné 1982, Gagné and Howarth 1985, Evenhuis 2002, IUCN 2003). Likely reasons cited for their extinction were loss of habitat and decline of native host plant species, as well as the nontarget impacts of exotic parasitoids introduced for biological control programs (Gagné 1982). The nontarget impacts of introduced parasitoids are particularly relevant to *Omiodes* species disappearances because two endemic Hawaiian *Omiodes* species were the direct targets of biological control programs (Funasaki et al. 1988). *Omiodes accepta* (Butler), the sugarcane leafroller, and *O. blackburni* (Butler), the coconut leafroller, became important economic pests in their respective crops and were the subject of multiple biological control releases between 1895 and 1958 (Funasaki et al. 1988). After the releases, high rates of parasitism were observed in populations of target as well as nontarget *Omiodes* species, and biological control agents were implicated in subsequent species declines and disappearances (Zimmerman 1958, Bess 1974).

A review of unidentified material in museum collections and additional field surveys has resulted in the rediscovery of *O. continuatalis* and four other *Omiodes* species previously listed as extinct (Haines et al. 2003). Although the distribution and abundance of *O. continuatalis* has been dramatically reduced (Blackburn cited in Zimmerman 1958), the species persists on Maui, Kaho'olawe, and Hawai'i Island and can be locally abundant (W. Haines, unpubl. data). However the rediscovery of a few of the presumed extinct species of *Omiodes* has not lessened concerns over the impacts of introduced parasitoids (Howarth 2000), and biological control agents have been documented parasitizing a growing array of native Hawaiian Lepidoptera (Henneman and Memmott 2001, Oboyski et al. 2004). More ominous, bio-

[1] This project was funded by a U.S. Department of Agriculture (USDA) Cooperative State Research, Education, and Extension (CSREES) Special Research Grant Tropical and Subtropical Agricultural Research (USDA CSREES Award no. 2004-34135-14998). Additional funding was provided by USDA CSREES project HAW00942-H and HAW00956-H. Manuscript accepted 3 May 2007.

[2] Corresponding author (e-mail: cbaking@hawaii.edu).

[3] Department of Plant and Environmental Protection Sciences, 310 Gilmore Hall, 3050 Maile Way, University of Hawai'i at Mānoa, Honolulu, Hawai'i 96822.

Pacific Science (2008), vol. 62, no. 1:147–150

logical control agents have infiltrated largely native montane habitats not previously considered at high risk of invasion (Henneman and Memmott 2001).

To quantitatively assess the relative threat exotic parasitoids pose to endemic moth species, we initiated controlled exposure experiments on the island of Maui from May to August 2006. As part of this study, we recorded *O. continuatalis* larval behavior for all instars. Through detailed observations of more than 800 individual larvae, we recorded previously unknown behavior that may bear directly on the level of native moth vulnerability to introduced parasitoids. Early observations of *O. continuatalis* indicate that the larvae hide intermittently in leaf litter accumulated at the base of grasses and generally prefer to feed on foliage on the lower portion of plants (Swezey 1907). Many of the trial larvae exhibited this typical behavior, but on numerous occasions *O. continuatalis* larvae were also observed hiding underground. The purpose of this note is to describe the nature of this newly recognized fossorial behavior and to discuss the potential implications of such behavior on the ability of species to survive the pressures of introduced parasitoids.

MATERIALS AND METHODS

Laboratory colonies of *O. continuatalis* were established using female moths captured from ultraviolet light traps set on Ka'ili'ili Road in Kokomo, Maui (484 m). *Omiodes continuatalis* adults were placed in sleeve cages with potted sugarcane plants and housed in a greenhouse at the University of Hawai'i Kula Agricultural Research Station on Maui. Female moths oviposited readily, and resultant larvae were reared. Before our nontarget parasitism field trials, one to four larvae of various instars were transferred onto young sugarcane plants. Each plant was propagated in potting soil (Sunshine Mix 5) and contained within 12.7 by 15.2 cm plastic pots. These sugarcane plants were then transported to field sites and placed inside predator exclosures that prevented mammals, ants, and birds from removing the larvae. The head capsule width of each larva was measured before deployment and after retrieval from the field to confirm the larval instar at release and retrieval. Larvae and plants were retrieved and replaced after approximately 4 days of exposure. Field trials were conducted at five sites on East Maui: Hawai'i Commercial & Sugar (HCS) Hāli'imaile sugarcane field (274 m elevation), lower Makawao Forest Reserve (914 m), University of Hawai'i (UH) Kula Agricultural Research Station (975 m), upper Makawao Forest Reserve (1,280 m), and Haleakalā Ranch (1,280 m).

RESULTS AND DISCUSSION

On at least 12 occasions, when attempting to retrieve larvae from sugarcane foliage we discovered that larvae were not present on the plant. Instead, *O. continuatalis* larvae were found well below the surface of the soil. These fossorial larvae were found at depths ranging from 5.5 to 14 cm below the soil surface. *Omiodes continuatalis* larvae progress through 9–10 developmental instars, so it is notable that individuals retrieved from under the soil ranged from third to fourth instar (head capsule width: 0.625–1.9 mm) and were not the most mature larvae utilized in the trials. The developmental stage of these larvae discounts the likelihood that individuals burrowed into the soil to pupate. Previous observations of the species indicate that even when preparing to pupate, *O. continuatalis* may retreat to the base of the plant on which they are feeding and web together soil and leaf matter to create a shelter before pupating but remain at the soil surface (Swezey 1907; C.K., pers. obs.). We observed the fossorial behavior at the Hāli'imaile sugarcane field, UH Kula Agricultural Research Station, Haleakalā Ranch, and Makawao Forest Reserve (1,280 m) field sites. Additional records of fossorial behavior would likely have been documented, but such behavior has not been recorded previously and was not initially suspected to be the reason for larval "disappearance." Consequently, early in the trials, larval absence was attributed to unknown mortality when, in fact, larvae may simply have been underground.

Body coloration provides an indication of how fossorial larvae may have been spending their time. *Omiodes continuatalis* larval body color directly reflects recent dietary intake; larvae feeding on green or yellowing foliage are colored accordingly. If the larvae discovered underground were staying there and feeding on plant roots or dried foliage at the base of the sugarcane plant, they would have appeared light yellow or brown, however all of the larvae retrieved from beneath the soil exhibited a vivid green body. Their green coloration indicates that larvae were not feeding below the ground but periodically moving up from beneath the soil to feed on green foliage.

The larvae of many crambid species are known to be fossorial (Landry 1995); however this represents the first documented evidence of fossorial behavior in any Hawaiian *Omiodes* and has important practical and evolutionary implications. Our observations suggest that the behavior is not associated with pupation. To date, we have observed hundreds of larvae across five generations pupating in plant foliage and at the soil surface but never below the soil surface. Instead, the burrowing behavior may function as a facultative response to predation and parasitism that has been present in Hawai‘i throughout the evolution of Hawaiian *Omiodes* and may be triggered under certain conditions in segments of the population. A decreased risk of predation and parasitism and subsequent increase in larval survivorship is a potential benefit to individuals and species exhibiting the behavior. Hiding underground could provide temporary refuge not only from parasitoids but also from predators including wasps and spiders. It is possible that burrowing behavior may have been triggered as a result of unnatural conditions created by exclosures and a novel potted plant substrate. However, many of our observations are consistent with the documented tendency of *O. continuatalis* larvae to shelter and feed at the base of host plants, and fossorial behavior is commonly observed in other crambid larvae.

The frequency and distribution of fossorial behavior across species in the genus *Omiodes* are unknown but could have important implications for the persistence of particular species or populations that have burrowing larvae. The burrowing observed in the *O. continuatalis* larvae in our study may reflect the tendency of a local population rather than a widespread ability because the larvae used in our field trials originated from a single Kokomo population, though this would be an improbable coincidence. However it is possible that specific stimuli facilitate or inhibit larvae from hiding underground. Furthermore, species of *Omiodes* that occur on the leaves of arborescent host plants, such as banana and palms, or epiphytic host plants, such as the native Hawaiian lilies, probably do not have the opportunity to hide in soil and may therefore be more vulnerable to predators and parasitoids. If this behavior is unique to certain taxa, it could help explain why some species of *Omiodes* have persisted, albeit in reduced numbers, while other species seem to have truly gone extinct.

ACKNOWLEDGMENTS

We thank A. Arcinas (Hawai‘i Agricultural Research Center) and M. Nakahata (Hawai‘i Commercial & Sugar Company) for providing plant material, and D. Oka and G. Otani (University of Hawai‘i Kula Agricultural Research Station) for field preparation and greenhouse assistance. K. Camp, J. McNassar, and J. Muir provided essential field assistance. Access permits were granted by S. Meidel (Haleakalā Ranch), and G. Shishido and B. Gagné (Department of Land and Natural Resources, Division of Forestry and Wildlife). Special thanks to M. Wright and C. Hooks (University of Hawai‘i, Department of Plant and Environmental Protection Sciences) for valuable input on study design, and also W. Haines (University of Hawai‘i, Department of Plant and Environmental Protection Sciences) for access to unpublished data. Two anonymous reviewers provided valuable feedback on this publication.

Literature Cited

Bess, H. A. 1974. *Hedylepta blackburni* (Butler), a perennial pest of coconut on windswept sites in Hawai'i. Proc. Hawaii. Entomol. Soc. 21:343–353.

Evenhuis, N. L. 2002. Hawaii's extinct species—insects. http://hbs.bishopmuseum.org/endangered/ext-insects.html, version: 21 March 2002 (accessed 28 January 2004).

Funasaki, G. Y., P. Lai, L. M. Nakahara, J. W. Beardsley, and A. K. Ota. 1988. A review of biological control introductions in Hawai'i: 1890 to 1985. Proc. Hawaii. Entomol. Soc. 28:105–160.

Gagné, W. C. 1982. Working toward an assessment of the conservation status of Hawaii's endemic arthropods, with emphasis on the moths or Lepidoptera. Pages 63–72 *in* Proceedings of the 4th Conference on Natural Sciences, Hawai'i Volcanoes National Park Science Conference. University of Hawai'i, Honolulu.

Gagné, W. C., and F. G. Howarth. 1985. Conservation status of endemic Hawaiian Lepidoptera. Pages 74–85 *in* Proceedings, 3rd Congress on European Lepidoptera. Cambridge, England.

Haines, W. P., J. Giffin, and D. Foote. 2003. Rediscovery of five species of *Omiodes* Guenée (Lepidoptera: Crambidae) on Hawai'i Island. Rec. Hawai'i Biol. Surv., 2003, Part 2, Notes: 45–49.

Henneman, M. L., and J. Memmott. 2001. Infiltration of a Hawaiian community by introduced biological control agents. Science (Washington, D.C.) 293:1314–1316.

Howarth, F. G. 2000. Non-target effects of biological control agents. Pages 369–403 *in* G. M. Gurr and S. D. Wratten, eds. Measures of success in biological control. Kluwer Academic Publishing, Dordrecht.

IUCN. 2003. IUCN Red list of threatened species. International Union for the Conservation of Nature and Natural Resources, http://www.redlist.org (accessed 29 November 2003).

Landry, B. 1995. A phylogenetic analysis of the major lineages of the Crambinae and of the genera of Crambini of North America (Lepidoptera: Pyralidae). Associated Publishers, Gainesville, Florida.

Oboyski, P. T., J. W. Slotterback, and P. C. Banko. 2004. Differential parasitism of seed-feeding *Cydia* (Lepidoptera: Tortricidae) by native and alien wasp species relative to elevation in subalpine *Sophora* (Fabaceae) forests on Mauna Kea. J. Insect Conserv. 8:229–240.

Swezey, O. H. 1907. Life history notes and observations on three common moths. Proc. Hawaii. Entomol. Soc. 1:53–58.

Zimmerman, E. 1958. Insects of Hawai'i. Vol. 8. Lepidoptera, Pyraloidea. University of Hawai'i Press, Honolulu.