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New Record for *Woldstedtius flavolineatus* (Ichneumonidae: Diplazontinae), a Hymenopteran Parasitoid of Syrphid Flies in Hawaii

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Abstract. The parasitoid wasp *Woldstedtius flavolineatus* (Gravenhorst) (Ichneumonidae) attacks the larvae of syrphid flies (Syrphidae). *Woldstedtius flavolineatus* was collected in Hawaii for the first time during an extensive malaise trap-based survey of parasitoids in Hawaiian forests. Since its initial collection on Hawaii Island in January 2006, it has been collected at five additional sites on Hawaii Island and at one site each on Maui and Oahu. Malaise trap results from Hakalau Forest National Wildlife Refuge showed a strong seasonal pattern of abundance, with peak population levels reached during July–September. Rearing of its host, *Allograpta obliqua* (Say), collected from koa (*Acacia koa* Gray) at Hakalau over two days, revealed a parasitism rate of approximately 95%. Broader impacts of this alien wasp are unknown, but a reduction in host syrphid abundance could result in an increase in numbers of psyllids and aphids (Homoptera) that are preyed upon by syrphid larvae. Furthermore, a reduction in adult syrphids could impact the reproductive success of some of the plants they pollinate.

Key words: alien species, *Allograpta obliqua*, parasitoid, Hawaii, *Woldstedtius flavolineatus*

Introduction

The larvae of syrphid flies (Syrphidae) are voracious predators of aphids, psyllids, white flies and several other hemipteran groups (Weems 1954, Schneider 1969). In agricultural settings, syrphid larvae are generally considered beneficial as they can reduce population densities of these sap-sucking pests (Weems 1954, Smith et al. 2008). Adult syrphids are also of ecological importance as they feed on nectar and pollen and play a role in the pollination of some plants (Moldenke 1975, Larson et al. 2001). Syrphids are not native to the Hawaiian Islands, but 18 species have been recorded in the archipelago (Nishida 2002). Of these, all are considered adventive except one, *Allograpta radiata* (Bigot), which was purposely introduced to control aphids; this species, however, appears never to have become established (B. Kumashiro, Hawaii Department of Agriculture, pers. comm.). The impact of syrphids on native Hemiptera, or the extent to which adults compete with native pollinators, is poorly known.

Natural enemies of syrphids include a variety of invertebrate and vertebrate predators (Schneider 1969, Fréchette et al. 2007), but parasitoid wasps, which are represented by over 60 species within nine families in North America alone, have the greatest impact (Weems 1954). Parasitoids within the subfamily Diplazontinae exclusively attack syrphids and may have particularly strong impacts on these flies. Diplazontinae are presumably all endoparasitic, attacking egg and larval stages and emerging from the host's puparium (Fitton and Rotheray 1982).

Diplazontinae are largely cosmopolitan in distribution but Wahl and Gauld (1998) suggest that ancestral members of this subfamily originated in the North Temperate Region, with many species colonizing, or evolving in, southern regions. No Diplazontinae are native to Hawaii, but a single species, *Diplazon laetatorius* (Fabricius) is a long-established accidental introduction that is found throughout the main Hawaiian Islands (Nishida 2002). A second species, *Syrphoctonus maculifrons* (Cresson) was collected on Oahu in 1913 (Townes 1947), but no subsequent collection records exist. The objectives of our report are to document the presence in Hawaii of an additional species of Diplazontinae, *Woldstedtius flavolineatus* (Gravenhorst), and to describe its known distribution and temporal pattern of abundance. Our results are based on trap surveys in native forests on several of the Hawaiian Islands and laboratory rearing of host syrphids collected in the field.

Diplazontinae are readily distinguished from other ichneumonids by the presence of a bifid mandibular upper tooth and a sub-rectangular first tergite of the gaster (Fitton and Rotheray 1982, Wahl and Gauld 1998). Fitton and Rotheray (1982) characterize the genus *Woldstedtius* as having a blackish hind tibia with a white base, a wide face with a clypeus that is flat or concave in profile and a strongly coriaceous mesoscutum and clypeus. Prior to recent revision, species of *Woldstedtius* were considered to be within the genus *Syrphoctonus* Foerster (Carlson 1979, Fitton and Rotheray 1982). The classification of *Woldstedtius* is uncertain, but morphological differences among larvae suggest that *W. flavolineatus* may represent a complex of several species, despite similar adult forms (Wahl 1990). Its place of origin is unclear, but it is currently widespread in North and Central America, and Eurasia (Carlson 1979). *Woldstedtius flavolineatus* exhibits strong sexual color dimorphism, with males differing from females by being extensively marked in pale yellow, particularly on the face and ventral portions of the thorax.

Methods

Woldstedtius flavolineatus was collected using malaise traps (Townes 1972, Owen et al. 1981) and by rearing field-collected larvae in the laboratory. Collections from malaise traps were part of an ongoing study documenting the distribution and relative abundance of parasitoid wasps within native forests throughout Hawaii (Peck et al. 2008, U.S. Geological Survey unpubl. data). Since initiation of this research in 2003, most of the effort has been on Hawaii island (13 sites), but since 2006 sites have also been surveyed on Kauai (Alakai Swamp Wilderness), Maui (Manawainui section of Haleakala National Park) and Oahu (Kaala Natural Area Reserve). Sites were within mesic and wet forest dominated by native vegetation and ranged in elevation from 27 to 2115 m. At most sites, 2-6 traps were operated continuously for 3 to 12 months, but at one site (Crater Rim, Hawaii Volcanoes National Park) three traps were operated for >48 months. In addition to these general surveys, an intensive malaise trapping effort took place at Hakalau Forest National Wildlife Refuge (Hawaii island), where between 29 June 2006 and 18 July 2008, 16 traps were placed in stands of regenerating and old growth koa (*Acacia koa* Gray) and in mature mixed koa–ohia (*Metrosideros polymorpha* Gaud) forest that ranged from 1600 to 1875 m elevation. These traps ran continuously and were monitored at intervals of approximately 30 days.

The second collection method involved rearing parasitoids from syrphid larvae. This effort was part of a study documenting parasitism rates of holometabolous insects associated with koa-ohia communities at Hakalau Forest NWR. During 26–27 June 2007, syrphid larvae were collected from koa adjacent to malaise traps by shaking branches to dislodge arthropods in the foliage. Syrphid larvae were returned to Kilauea Field Station in Hawaii Volcanoes National Park and maintained individually through pupation in 240 ml ventilated plastic containers. The emerged adult syrphids were identified as *Allograpta obliqua* (Say). Preliminary identi-

fication of *W. flavolineatus* was made by L. Leblanc, University of Hawaii, Manoa, and later confirmed by D. Wahl, American Entomological Institute, Gainesville, Florida.

Results and Discussion

Malaise trapping. *Woldstedtius flavolineatus* was collected at seven of 17 sites on three islands, indicating that it is widespread in Hawaii (Table 1). Its habitat requirements are unknown, but we collected it only in mesic and wet forests at 973 m elevation or higher that are dominated by native vegetation, which may be an artifact of our focus on surveying parasitoids in relatively intact habitats rather than representatively across the landscape. Ultimately, it may track the distribution of its host, the syrphid *A. obliqua*, or perhaps other introduced syrphids that are found in a wide range of disturbed and undisturbed habitats throughout Hawaii.

Our results suggest that *W. flavolineatus* is expanding its range, at least on Hawaii, as it was recently collected at a site where it had not been collected in the past. At the Crater Rim site, three traps ran continuously for 19 months before the first *W. flavolineatus* was collected during April 2006. Since that time, it was collected in June and July 2006, June and August 2007 and August 2008, suggesting that it may be at least a seasonal resident of the site. Furthermore, similar trapping efforts (3 traps/site) between March 2003 and August 2004 at eight other wet forest sites ranging in elevation from 27 to 1792 m elevation on windward Mauna Loa and Kilauea volcanoes failed to produce any *W. flavolineatus* (Peck et al. 2008). Comparable data from other islands are few, but *W. flavolineatus* was not collected from January 1991 through January 1993 at 1200 m elevation at Kokee State Park on Kauai (Asquith and Miramontes 2001).

At Hakalau Forest NWR, *W. flavolineatus* abundance peaked briefly in the summer (Fig. 1). During August 2007, mean capture rates exceeded 19 individuals per day, a 28-fold increase in abundance over the rate during October 2006–April 2007. A similar increase in abundance began in the summer of 2008, but the survey was terminated in August, possibly before the population reached its highest level. The mechanism behind this pattern is unclear, but it was likely driven by an increase in *A. obliqua* abundance following the seasonal irruption of the introduced psyllid, *Acizzia uncatoides* (Ferris and Kylver) (formerly *Psylla uncatoides*), on koa (U.S. Geological Survey unpubl. data). The prey range of *A. obliqua* is poorly known in Hawaii, but it has been documented to feed upon *A. uncatoides* (Leeper and Beardsley 1973), and elsewhere it feeds upon aphids (Schneider 1969) and whiteflies (Nakahara et al. 1986). *Acizzia uncatoides*, a pest of several species of *Acacia*, was first detected in Hawaii in 1966 (Leeper and Beardsley 1973) and is now found on all of the main Hawaiian Islands (Nishida 2002). Although we collected *A. obliqua* in high numbers on koa, it is possible that it was also preying upon aphids or other psyllids associated with introduced kikuyu grass (*Pennisetum clandestinum* Hochst. ex Chiov.), which was common at higher elevations on the refuge. Other syrphids may reside in the area and act as hosts, but none were documented during our survey.

Laboratory rearing. From koa foliage, 198 *A. obliqua* larvae were reared to pupation (pupation occurred within 1 week of collection). The parasitism rate was extremely high, as 187 larvae (94.4%) were attacked by *W. flavolineatus* and one (0.5%) was parasitized by *Diplazon laetatorius* (Fabricius). The sex ratio of *W. flavolineatus* was significantly skewed toward males (67%; $\chi^2 = 21.2$; $P < 0.01$). *Diplazon laetatorius*, which has previously been reported to parasitize *A. obliqua* in Hawaii (Swezey 1929), appears relatively rare at the site as it comprised < 0.1% of all parasitoids collected in malaise traps. Both parasitoid species emerged from the pupal stage.

Although we consider the observed parasitism rate to be high, comparable data are scant

Table 1. Locations and collection dates of *Woldstedtius flavolineatus* sampled by malaise traps.

Island	Location	Date first collected	Latitude, longitude[1]	Elevation (m)[2]
Hawaii	Kona Hema Preserve, TNC	11 Jan 06	19°13.41N, 155°49.34W	1103–1450
Hawaii	Crater Rim, Hawaii Volcanoes NP	11 Apr 06	19°24.40N, 155°14.78W	1164
Hawaii	Hakalau Forest NWR	29 Jun 06	19°50.13N, 155°19.07W	1616–1902
Hawaii	Kau Preserve, TNC	28 Apr 08	19°15.18N, 155°30.14W	1004
Hawaii	Puu O Umi Natural Area Reserve	11 Jun 08	20°4.34N, 155°43.26W	1451–1572
Maui	Manawainui Section, Haleakala NP	7 Jun 06	20°41.58N, 156°7.82W	1603–1795
Oahu	Kaala Natural Area Reserve	13 Sep 08	21°30.81N, 158°9.19W	973

[1]Centralized location when collected in multiple traps in the same general vicinity
[2]Range of elevation when collected in multiple traps in the same general vicinity

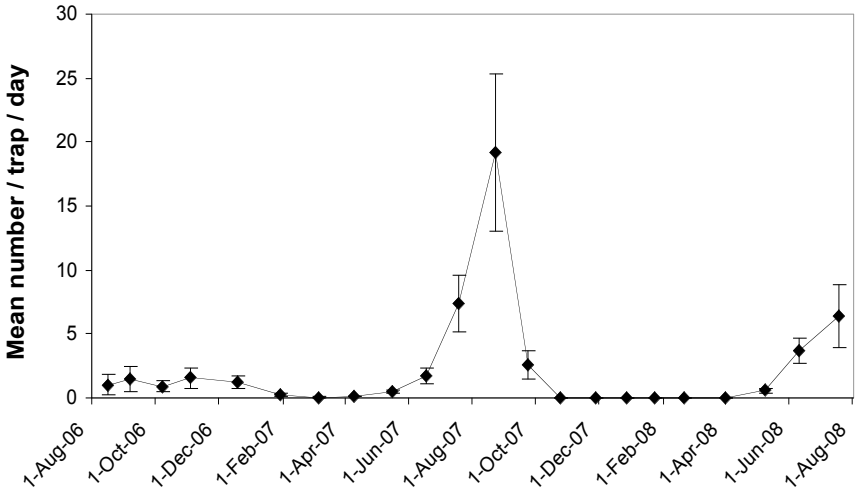

Figure 1. Mean (± SEM) abundance of *Woldstedtius flavolineatus* collected in 16 malaise traps placed in koa and mixed koa-ohia stands at Hakalau Forest NWR between 11 July 2006 and 18 July 2008.

as parasitism rates of syrphids are rarely determined in the field. However, a similarly high level of parasitism (89%) of an unidentified syrphid by a suite of parasitoids that included *W. flavolineatus* was found in Western Hemlock (*Tsuga heterophylla* (Raf.) Sarg.) forests of Oregon and Washington (Kohler 2007). The cosmopolitan *D. laetatorius* has been credited with parasitizing syrphid larvae at rates as high as 75% in Ohio (Weems 1954). However, since the syrphids in our study were collected over only two days, the length of time over which this rate of parasitism persisted is unknown. While it is possible that the observed rate was a maximum for the season, it was the minimum rate for the pool of individuals collected on those days, as their removal from the field precluded possible attack on subsequent days. The extent to which *W. flavolineatus* impacted the *A. obliqua* population at Hakalau Forest NWR is unclear, but a threshold parasitism rate of >32% has been considered necessary to have a significant effect on host population size (Hawkins and Cornell 1994), strongly suggesting that this parasitoid was reducing the abundance of its host.

At first consideration, the impact of *W. flavolineatus* in native forests appears relatively benign since it only attacks the larvae of alien syrphids that largely prey upon alien psyllids and aphids. However, adult syrphids forage for pollen and nectar in flowers of a wide range of both native and alien plants (Weller et al. 1990, U.S. Geological Survey unpubl. data), and may contribute to the reproductive success of those species via intra-specific transfer of pollen. Overall though, the ecological importance of *A. obliqua* in Hawaii has received little study. But, with the decline of native pollinators in many habitats (Daly and Mangnacca 2003, Magnacca 2007) and a possible reduction in abundances of feral honeybees (*Apis mellifera* L.) due to varroa mites (*Varroa destructor* Anderson and Trueman) that have recently invaded Hawaii (Oldroyd 1999, Sammataro et al. 2000), syrphids such as *A. obliqua* may play an increasingly important role in maintaining populations of some flowering plants.

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