First Recorded Hawaiian Occurrence of the Alien Ground Beetle, *Agonum muelleri* (Coleoptera: Carabidae), from the Summit of Mauna Kea, Hawaii Island

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Abstract. Adults of the non-native species, *Agonum muelleri* (Herbst) (Coleoptera: Carabidae) were collected from the summit of Mauna Kea in 2006 and again during 2008, indicating that a population of this European species is established on Mauna Kea volcano, Hawaii island (NEW STATE RECORD). *Agonum muelleri* is a synanthropic species that has been accidentally introduced from Europe to both the east and west coasts of North America, with the known North American distribution including 24 provinces and states of Canada and the United States. Characters for the adults are provided to permit diagnosis of this non-native species from all other native and introduced carabid beetle species known from Hawaii. Recorded environmental conditions from Mauna Kea summit taken during the months when specimens were collected are consistent with conditions associated with winged flight by *A. muelleri* individuals in the species' native European range.

Hawaii is the geographically most isolated archipelago in the World, with approximately 250 insect colonists (Zimmerman 1948, Liebherr 2001) speciating to result in over 5,200 present-day native endemic insect species (Eldredge and Evenhuis 2003). Among these, the *Nysius* seed bug (Hemiptera: Lygaeidae) radiation includes two remarkable species known from the mature shield volcanoes Mauna Kea and Mauna Loa; *N. wekiuicola* Ashlock and Gagné (1983), the wekiu bug, and *N. aa* Polhemus (1998), the Mauna Loa wekiu bug. Besides supporting the wekiu bug, Mauna Kea summit is also the site of several telescopes. Multiple uses of Mauna Kea summit by wekiu bugs and astronomers has led to long-term entomological surveys of the summit focused on how present and future telescope construction may impact wekiu bug distribution (Englund et al. 2006). This focused survey activity has provided a unique, historical view of the insect species that occur on this summit.

We report two collections of the non-native ground beetle *Agonum muelleri* (Herbst) derived from wekiu bug surveys, making Mauna Kea summit the first site in Hawaii where this alien European species has been observed. We provide diagnostic characters to allow the ready distinction of the non-native *A. muelleri* from all other native and non-native Carabidae occurring in the state of Hawaii. The nature of the reported collections separated by two years indicates that *A. muelleri* is resident on Mauna Kea, although whether *A. muelleri* is a breeding resident of the summit is not known. The geographic source of *A. muelleri* on Hawaii island is hypothesized based on the overall geographic distribution of *A. muelleri* as well as the colonization histories of several other introduced species. The potential ecological role of *A. muelleri* on Mauna Kea summit is evaluated based on knowledge gained about the species in its primordial range as well as in other areas to which it has been introduced.

Materials and Methods

Adult beetles were part of a soil and litter sample (2006 specimen), or collected via pitfall trapping (2008 specimens, methods identical to those reported in Englund et al. 2006). The 2006 survey was restricted to the area directly adjacent to the University of Hawaii 2.2-meter (88-inch) telescope on Mauna Kea. Three 2.0-liter soil samples, including surface litter, were removed from three locations and subjected to Berlese extraction. Specimens were identified by GAS and JKL, with the Hawaiian specimens compared to specimens in the Bishop Museum and Cornell University Insect Collection. Hawaiian specimens are deposited in the Bishop Museum, Honolulu. Genitalic dissections were made using protocols in Liebherr and Zimmerman (2000), and photographed using a Microptics (now Visionary Digital) photographic apparatus (Liebherr 2009). Distributional information for other non-native Carabidae known to have been introduced to Hawaii island is summarized in Liebherr (2000).

Results

The initial discovery of *A. muelleri* in Hawaii (Fig. 1A) is based on one female specimen labeled: S. L. Montgomery by Berlese HI,Hawaii,Mauna Kea (on front of label), U.H. 2.2 m Telesp 16 June 06 cinders (in pencil on back of label). The sample was collected at 13870 ft (5Q0241329 m E 2193793 m N, based on UTM grid and NAD 83 datum). The *A. muelleri* specimen and several unidentified Acari and Collembola were extracted from a sample that included abundant wind-collected debris; i.e. organic litter and wet cardboard. The second recorded Hawaiian collection of *A. muelleri* is based on one male and one female specimen with date-locality information: Collection No. 149 Hawaiian Is. Hawaii I. Mauna Kea 20 July 2008 (WGS 84) 18.81129 N 155.47688 [W] Elev. 13,020 ft / Locality: Lake Waiau (did not trap for Wekiu) Pitfall Glycol, Shrimp Paste RE, SJ, LE, SM, C1 Bishop Museum Voucher. The male specimen appears melanized externally, but not entirely sclerotized, as the elytra are slightly curled apically and partially translucent. The incomplete melanization is confirmed by the paler aedeagus (Fig. 1B) when compared to a specimen from Wayne Co., NY, collected 6 July 2004 (Fig. 1C).

The 2008 Mauna Kea male specimen exhibits an aedeagus (Fig. 1B) with the diagnostic characters for *A. muelleri* (Fig. 1C) including—1, smooth euventral surface without striation; 2, large basal bulb without sagittal crest; and 3, median lobe with acutely angled tip—all confirming the identity of the Mauna Kea specimens as *A. muelleri*.

Agonum muelleri is classified in the tribe Platynini of the Carabidae based on the following attributes specific to taxa known from Hawaii (Liebherr and Zimmerman 2000, figs. 1, 2): 1, mesocoxa surrounded laterally by caudal extension of mesosternum that adjoins anterior margin of metasternum; 2, mandibular excavation—the scrobe—glabrous, without a small seta near the scrobal anterior margin; 3, total body length less than 20 mm; 4, elytral apex broadly rounded, not truncate, and without an external plica, the elytral lateral margin continuous near subapical sinuation; 5, all elytral intervals and median portion of third visible abdominal ventrite without a fine covering of microsetae, the only setae present on elytra or abdomen being the larger articulated setae (of similar size to supraorbital and pronotal setae); 6, a short parascutellar elytral striole (Fig. 1A).

Externally *A. muelleri* can be told from all other platynine carabid beetles known from Hawaii, both introduced and native, by the following diagnostic combination: 1, dorsal body surface highly reflective, the head and pronotum metallic green, and the elytra metallic green to purple (Fig. 1A); 2, femora and tarsi piceous, contrasted with the medially paler tibiae (Fig. 1A); 3, two setae over each eye (the supraorbital setae), two setae each side of the pronotum, one laterally before midlength and the other along the curved basolateral margin, and three to four dorsal elytral setae positioned in the third elytral interval; 4, the

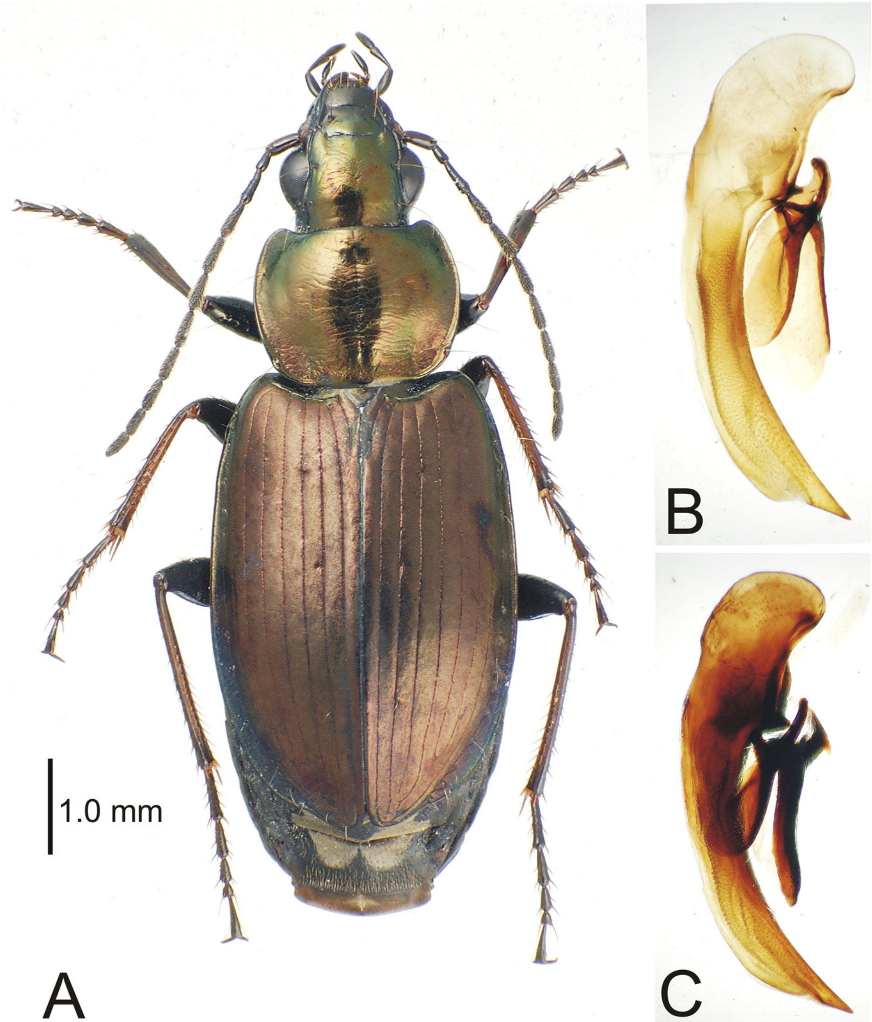

Figure 1. *Agonum muelleri*. A. 2008 female specimen, dorsal view (scale bar 1.0 mm). B. Male aedeagus right lateral view for 2008 Mauna Kea male; median lobe to the left and ventral parameres to the right. C. Male aedeagus right lateral view for 2004 New York male; median lobe and parmeres are more melanized than in Mauna Kea specimen.

two mentum setae medially proximate, situated posterad mentum median tooth (Fig. 2A); 5, profemur with three setae along the posterior margin; 6, metacoxa with three setae, two laterally and a third closer to body midline (Fig. 2B); and 7, tarsal claws simple, without any pectinations or irregularities along the inner arcuate surface.

The introduced non-native platynine *Metacolpodes buchanani* (Hope)—also recorded from Hawaii island—has a brightly metallic green body, but the mentum setae of this species are spaced further apart, the profemur bears two setae posteriorly, and the metacoxae

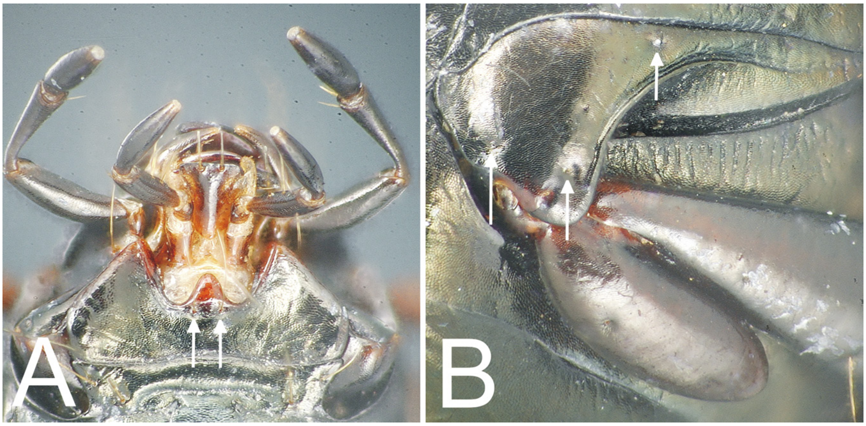

Figure 2. *Agonum muelleri*. A. ventral view of head capsule and mouthparts; arrows indicate diagnostic proximal positions of mentum setae. B. Left metacoxa, trochanter and femoral base, ventral view with body midline in upper left corner; arrows indicate positions of 3 metacoxal setae (setae broken off).

are bisetose (Liebherr and Zimmerman 2000, fig. 12B). In addition, the sutural apex of the elytra bears a small tooth in *M. buchanani* (Liebherr and Zimmerman 2000, fig. 12A), whereas the elytral apex is rounded in *A. muelleri* (Fig. 1A). The range of overall body length for *A. muelleri* is also discretely smaller than the range of body lengths—measured from median labral apex to elytral apex—among beetles of *M. buchanani* (7.5–9.5 mm for *A. muelleri* versus 11.0–13.2 for *M. buchanani*). A third non-native platynine species has also been recorded from Hawaii island; *Laemostenus complanatus* (Dejean) (Zimmerman 1972, Liebherr and Zimmerman 2000). This species can be distinguished from *A. muelleri* by the pectinate ventral surfaces of the tarsal claws, where 3–4 fine serrate teeth occur on the internal margin of each claw. Individuals of this species range in overall length from 12.5 to 16.0 mm.

Discussion

Several questions immediately come to mind relative to any introduction of an alien species to a novel environment: 1, what are the geographic source and the means of introduction; and 2, what is the ecological role of the introduced species? Given the extreme environment of Mauna Kea summit and the ability for *A. muelleri* to disperse via flight, a third question relevant to the question of ecological role might be addressed in this instance: is the novel insect resident to the summit, or merely an occasional visitor from lower elevations?

Geographic source? *Agonum muelleri* is native to a distributional range centered in Europe, with the southern range limits of Spain, Sicily, and the Balkan States, and northern limits including the British Isles and Ireland, and the southern halves of Norway, Sweden and Finland (Turin 2000). Its geographical range extends eastward to western Siberia (Lindroth 1992). In North America this species exhibits a disjunct distribution, being found in the northeastern United States and eastern Canada including the Maritime Provinces, and along the Pacific Coast from British Columbia to California (Bousquet and Larochelle

1993). The eastern distribution is currently bounded by Newfoundland, Quebec, Ontario, Minnesota, Wisconsin, Indiana, Ohio, West Virginia and Virginia.

A second platynine of the subtribe Sphodrina, *Laemostenus complanatus*, has been introduced to Hawaii island (Zimmerman 1972). This species was originally from North Africa but has been broadly introduced around the world including to the Pacific Coast of North America, where the species now ranges from British Columbia to California (Casale 1988). Similarly, a third alien platynine species introduced to Hawaii and resident on Hawaii island, *Metacolpodes buchanani*, was primordially distributed in Asia and subsequently introduced to Oregon (Habu 1978).

The common historical elements of all three of these alien introductions to Hawaii island include: 1, a species' propensity to be accidentally introduced by man to areas outside its native range; and 2, establishment of a non-native distribution on the Pacific Coast of North America. Given the common trade connections to Hawaii (Bess and Marcus 1998), we suggest a source for Hawaiian *Agonum muelleri* on the Pacific Coast of North America as the best working hypothesis. Such a hypothesis for a Pacific Coast source is consistent with the recent introduction of the originally European carabid beetle, *Trechus obtusus* Erichson, to Maui via propagules derived from non-native populations in Oregon or northern California (Liebherr and Takumi 2002).

Means of introduction? Newfoundland was first colonized by *A. muelleri* during the 1830s (Lindroth 1963), most likely via the movement of sailing ship ballast from Europe (Lindroth 1957). Lindroth made the point that *A. muelleri* adult individuals could persist on board ship during a long voyage, as long as soil associated with ballast offered a suitable microhabitat. The initial discovery of *A. muelleri* on the west coast of North America was made in 1933 in Vancouver (Leech 1935). By this time, faster steamships and the opening of the Panama Canal may have facilitated movement of the species. Across its native range in Europe, the species occurs in areas with moist loamy soil and grassy or weedy vegetation, such as fallow fields, refuse dumps, gardens and gravel pits (Lindroth 1992). Such a propensity to occur in association with landscapes disturbed by man predisposes this species to become associated with the appurtenances of modern-day commercial transport. *Laemostenus complanatus* is a similarly synanthropic species, being found in gardens, along disturbed coastal sand dunes, and near houses in California and New Zealand (Liebherr, unpubl. data). Thus, given their similar close associations with human activities, both *A. muelleri* and *L. complanatus* are prime candidates for accidental introduction to new landscapes via occupation of shipping containers or agricultural shipments.

Ecological role: resident or visitor? Previous studies have shown that *A. muelleri* adults and larvae are predaceous on *Drosophila melanogaster* (Fallen) pupae placed on the soil surface in agricultural fields, with feeding occurring both during day and night (Lys 1995). In New York state, *A. muelleri* is the most common carabid beetle in soybean fields, where its density is inversely associated with density of soybean aphid, *Aphis glycines* Matsumura (Hajek et al. 2007). Beetles overwinter as adults, and are the numerically dominant predator in soybean fields during early summer. *Agonum muelleri* adults readily climb soybean plants to feed on aphids, spending from 12 to 54% of their time climbing on the plants during laboratory trials (Hannam et al. 2008). Thus it is apparent that *A. muelleri* adults will act as effective and agile predators in any suitable habitat on Mauna Kea. Based on evidence from other distributional areas (Turin 2000, Hajek et al. 2007), they will be found to undergo a single generation per year, and overwinter as adults.

The impact of *A. muelleri* predation will be related to the degree that individuals in the habitat constitute a permanent breeding population. Permanent residency including egg and subsequent larval development followed by the adult stage would require many more resources than would dead-end adult visitors that might disperse into the habitat but never reproduce there. Of primary importance, then, is determining whether larval individuals occur on the summit of Mauna Kea, for this is the most direct means to establish the ability for populations of this predatory species to persist there.

The initial three summit specimens of *A. muelleri* provide only meager ecological information. The 2006 female was recovered from a Berlese sample of mixed organic litter and wet cardboard from alongside a building at the University of Hawaii 2.2 m telescope complex. The 2008 male and female were collected approximately 1.5 km distant near Lake Waiau; the sole permanent water source on the summit. Thus all specimens so far have been associated with limited sources of moisture available on the summit. The lack of complete melanization in the 2008 male specimen—viewed in context of larval rearing data for *Agonum muelleri* (Liebherr, unpublished data)—indicates that this male eclosed from the pupal stage within one to two weeks prior to capture by pitfall trap. Such a timeline supports origin of this individual from a source indigenous to Mauna Kea, and argues against independent introduction of this individual to Mauna Kea through activities associated with commercial transport or agriculture. Therefore based on the two reported collections, we conclude that *A. muelleri* is resident on Mauna Kea.

Though the summit experiences extreme meteorological conditions, there are numerous periods during which temperatures would be conducive to winged flight. Lindroth (1992) recorded a daytime flight record for *A. muelleri* when a beetle was held under glass during sunny conditions. In many European carabid beetles, flight behavior is recorded when temperatures exceed 16° C (van Huizen 1979). During April and May 2005 Englund et al. (2006, Fig. 20) recorded maximum surface soil temperatures on the trail to Lake Waiau that ranged from 0 to 19° C, with 20 4-hour intervals ≥ 16° C over that period, those intervals spread over more than 10 days. Thus at least soil surface temperatures suggest that day-active *A. muelleri* individuals could experience thermal conditions conducive to the commencement of flight.

Even though all Mauna Kea *A. muelleri* records are from the summit, the preference of *A. muelleri* for open grassy and weedy habitats in Europe and North America suggests that surveys in lower elevation grasslands and shrublands on Mauna Kea should be undertaken to determine whether the species occurs in that ecological zone. Lindroth (1992) noted that larvae require more moisture as they develop than do the adults, further suggesting that gulches watered by snow melt or springs should be searched for this species. As at the summit, discovery of representatives of the larval stages in the grasslands would ensure that populations were resident there.

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