Distribution of *Parmarion* cf. *martensi* (Pulmonata: Helicarionidae), a New Semi-Slug Pest on Hawai'i Island, and Its Potential as a Vector for Human Angiostrongyliasis[1]

Robert G. Hollingsworth,[2,3] *Rachel Kaneta*,[3,4] *James J. Sullivan*,[5,8] *Henry S. Bishop*,[5,8] *Yvonne Qvarnstrom*,[5,6,8] *Alexandre J. da Silva*,[5,8] *and David G. Robinson*[7]

Abstract: The semi-slug *Parmarion* cf. *martensi* Simroth, 1893, was first discovered on O'ahu, Hawai'i, in 1996 and then on the island of Hawai'i in 2004. This species, which is probably native to Southeast Asia, is abundant in eastern Hawai'i Island, reportedly displacing the Cuban slug, *Veronicella cubensis* (Pfeiffer, 1840), in some areas. A survey in July–August 2005 found *P.* cf. *martensi* primarily in the lower Puna area of Hawai'i Island, with an isolated population in Kailua-Kona (western Hawai'i Island). It is now established in commercial papaya plantations, and survey participants reported it as a pest of lettuce and papaya in home gardens. Survey respondents considered *P.* cf. *martensi* a pest also because of its tendency to climb on structures where it deposits its feces and because of its potential to transmit disease. Individuals of this species were found to carry large numbers of infective third-stage larvae of the nematode *Angiostrongylus cantonensis* (Chen, 1935), the causative agent of human angiostrongyliasis and the most common cause of human eosinophilic meningoencephalitis. Using a newly developed polymerase chain reaction test, 77.5% of *P.* cf. *martensi* collected at survey sites were found infected with *A. cantonensis*, compared with 24.3% of *V. cubensis* sampled from the same areas. The transmission potential of this species may be higher than that for other slugs and snails in Hawai'i because of the high prevalence of infection, worm burdens, and its greater association with human habitations, increasing the possibility of human-mollusk interactions.

The semi-slug *Parmarion* cf. *martensi* Simroth, 1893, is a recent introduction to the island of Hawai'i. The first record was made in the summer of 2004 in Paradise Park, a residential area in the district of Puna (East Hawai'i Island) (Arnold Hara, University of Hawai'i, pers. comm., 2005). The species was recognized as being similar to, or the same as, a semi-slug species collected for the first time on the island of O'ahu in 1996 and provision-

[1] Manuscript accepted 9 January 2007.

[2] Corresponding author (phone: 808-959-4349; e-mail: rholling@pbarc.ars.usda.gov).

[3] U.S. Department of Agriculture, Agricultural Research Service, U.S. Pacific Basin Agricultural Research Center, P.O. Box 4459, Hilo, Hawai'i 96720.

[4] Current address: 190 Southwest Brumback Street, Linfield College, McMinnville, Oregon 97128.

Pacific Science (2007), vol. 61, no. 4:457–467

[5] Centers for Disease Control and Prevention, 4770 Buford Highway Northeast, Atlanta, Georgia 30341.

[6] Atlanta Research and Education Foundation in conjunction with the Atlanta Veterans Administration Medical Center, Decatur, Georgia.

[7] U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Academy of Natural Sciences, 1900 Benjamin Franklin Parkway, Philadelphia, Pennsylvania 19103.

[8] The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention/the Agency of Toxic Substances and Disease Registry.

ally identified as *Parmarion martensi* Simroth, 1893 (Cowie 1997). The taxon *Parmarion martensi* was originally described from Cambodia (Simroth 1893), but it has also been reported from Vietnam, Malay Peninsula, Sumatra, Java, Borneo, Japan, Taiwan, Singapore, Samoa, and American Samoa (van Benthem Jutting 1950, Minato 1975, Minato and Okubo 1991, Ho 1995, Cowie 1998, Asato et al. 2004). However, due to the difficulty of identifying *Parmarion* to the species level, the accuracy of the records listed here requires further investigation. Plate I shows photos of this semi-slug collected from a site in Koa'e, East Hawai'i Island, in December 2004. Voucher specimens (2) collected from the site at that time were deposited in the Academy of Natural Sciences malacological collection (Philadelphia, Pennsylvania) and designated as ANSP A21014.

In December 2004, before learning that *P.* cf. *martensi* had been found on Hawai'i Island, R. Hollingsworth was requested by a local resident to investigate the presence of a new slug species on a property in Koa'e, near the eastern tip of the island. The request was prompted by the resident's concern about transmission of rat lungworm disease caused by *Angiostrongylus cantonensis* (Chen, 1935), a rodent nematode that develops to the infective larval stage in a slug or snail host (Mackerras and Sandars 1955). The disease, which manifests itself in humans as eosinophilic meningitis (Kliks and Palumbo 1992), can be acquired by the intentional or accidental consumption of raw or undercooked slugs or snails or paratenic hosts (such as shrimps or flatworms) (i.e., animals capable of carrying the infective stage of the parasite but not supporting further development [Alicata and Jindrak 1970, Ash 1976, Kliks and Palumbo 1992]). The resident requesting the visit and two of her dinner guests became ill with symptoms consistent with angiostrongyliasis after consuming home-grown lettuce reportedly contaminated with immature semi-slugs. Important intermediate hosts of *A. cantonensis* in Hawai'i include veronicellid slugs [primarily the Cuban slug, *Veronicella cubensis* (Pfeiffer, 1840)]; the giant African snail, *Achatina fulica* (Bowdich, 1822); and the marsh slug, *Deroceras laeve* (Müller, 1774) (Wallace and Rosen 1969*a*, Alicata 1991).

Parmarion cf. *martensi* has the potential for becoming an important vector of *A. cantonensis* in Hawai'i, as happened in Okinawa (Asato et al. 2004) after *P. martensi* became more prevalent there starting around the year 2000. Our initial survey in Koa'e indicated that *P.* cf. *martensi* was extremely common; it was found in trash cans, in a composting toilet, in an outdoor shower area, in a planting of spider lilies (*Crinum asiaticum* [Amaryllidaceae]), under plastic sheeting, and in a vegetable compost pile where egg masses of *P.* cf. *martensi* were also found. Specimens of *P.* cf. *martensi* collected during the initial survey were sent to the Division of Parasitic Diseases, Centers for Disease Control and Prevention (CDC), Atlanta, Georgia, to be examined for infection. The 26 semi-slugs examined were all positive for *A. cantonensis*, as determined by pepsin digestion (Graeff-Teixeira and Morera 1995). The importance of *P.* cf. *martensi* as a vector of this disease may be exacerbated by its high population densities, climbing behavior, attraction to food items associated with human dwellings, and potentially high parasite load.

Our objectives for this study were to: (1) determine the geographical distribution of *P.* cf. *martensi* on Hawai'i Island; (2) survey homeowners to gain information about pest status, feeding preferences, and foraging behavior; (3) compare levels of infection of *A. cantonensis* in *P.* cf. *martensi* and *V. cubensis* collected from the same sites; and (4) compare the feeding patterns of *P.* cf. *martensi* and *V. cubensis* in the laboratory on selected types of food.

MATERIALS AND METHODS

The *Parmarion* survey was publicized with advertisements in two local newspapers on 7 July 2005. The advertisement included a black-and-white picture of an adult *P.* cf. *martensi* semi-slug, a caption detailing its distinguishing characteristics, and a request for information from anyone who had seen this species on his or her property. An article about this species and our survey that ap-

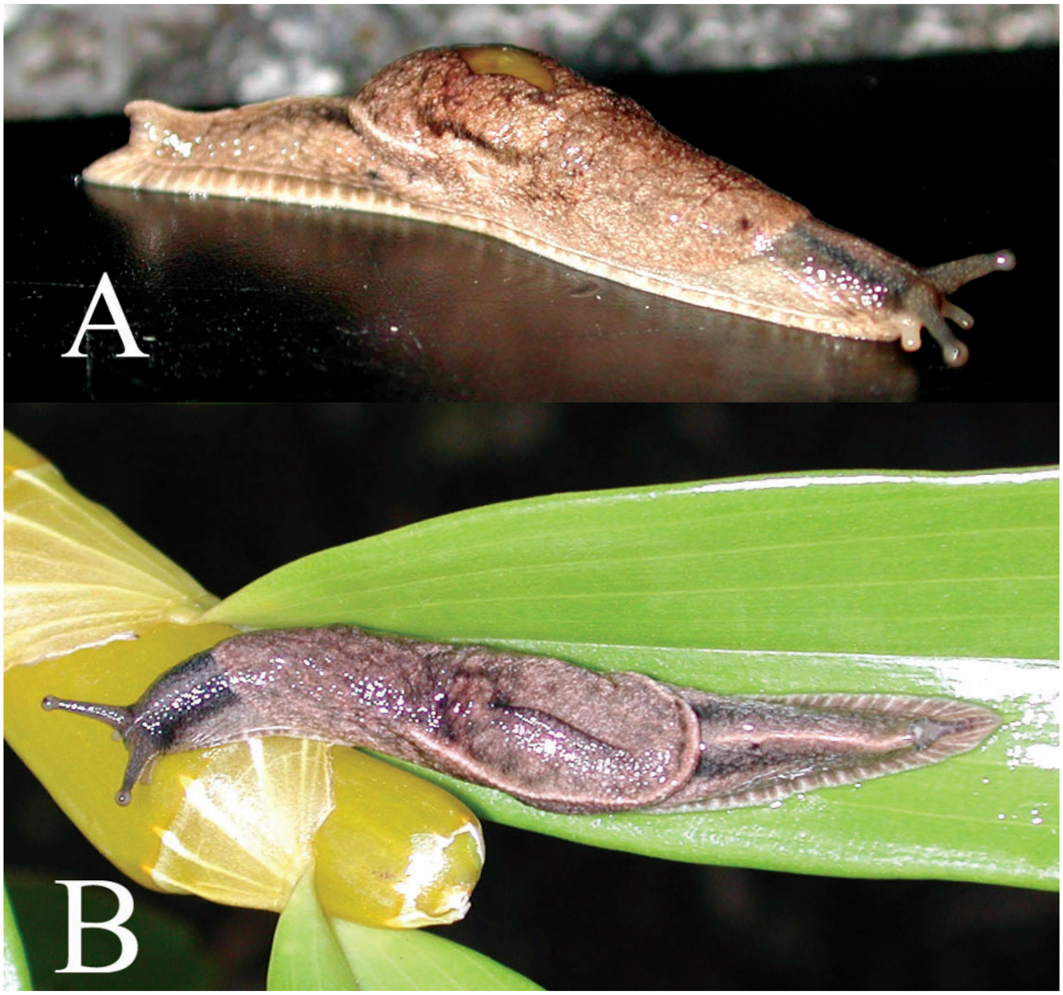

Plate I. *Parmarion* cf. *martensi* Simroth from East Hawai'i Island, photographed December 2004. The distinct keel along the posterior dorsal midline helps distinguish this species from similar-looking species in Hawai'i. A yellowish brown, flattened, fingernail-shaped shell is present on the dorsum *(A)*, but the shell is frequently covered by mantle folds *(B)*.

peared in both newspapers on 15 July generated an even greater response.

Site visits were made to follow up all credible reports of semi-slug sightings made within 7 weeks of the initial newspaper advertisement. Residents were asked where they had seen this species on their property, what types of food they had observed the semi-slugs to eat, and whether they considered this species a pest. At least 20 min per site was spent collecting semi-slugs and other mollusks. The locations where *P.* cf. *martensi* were found were recorded.

Specimens collected from each site during the July survey were sorted by species and divided into size groups (large, medium, small, or neonate). For *V. cubensis* and *P.* cf. *martensi*, large specimens were about 4.5–5.5 cm and 3.5–4.5 cm long, respectively; medium and small specimens were about one-half and one-third as long, respectively, as "large" specimens of the same species. Neonates were <0.5 cm in length. These specimens were shipped on dry ice to the CDC, where an experimental polymerase chain reaction (PCR) method was used to determine the percentage infected with *A. cantonensis*. DNA from intact slug tissue pieces was extracted using one of two methods: either using selected reagents from the FastDNA kit (MP Biomedicals, Solon, Ohio) or the DNeasy tissue kit (QIAGEN Inc., Valencia, California). The FastDNA extraction was performed as described previously (da Silva et al. 1999) with one modification: the sample disruption was performed for 30 sec at speed 5.5 in the FastPrep 120 Disruptor (Q-Biogene, Carlsbad, California). PCR inhibitors were removed from DNA extracted with FastDNA method by further purification with the QIAquick PCR purification kit (QIAGEN Inc., Valencia, California). DNA extracted by the DNeasy tissue kit did not need further purification. The PCR method amplified 1,134 base pairs from the small subunit ribosomal gene in *Angiostrongylus* species (Qvarnstrom et al. 2007). *Angiostrongylus*-specific primers AngioF1 (5′-ATCATAAACCTTTTTTCGAGTATCCAG-3′) and AngioR1 (5′-TCTCGAGACAGCTCAGTCCCGG-3′) were designed based on positions 456 to 482 and 1,569 to 1,590 of *Angiostrongylus cantonensis* 18S rRNA gene; GenBank entry AY295804. PCR was performed with 0.4 μM of each primer, 2 μl of DNA and AmpliTaq Gold PCR Master Mix (Applied Biosystems, Foster City, California) for a 50-μl total PCR reaction volume. PCR cycling parameters were 95°C 5 min, 45 cycles of 95°C 15 sec, 65°C 15 sec, 72°C 1 min, and 72°C 10 min. To achieve identification at species level, PCR amplified products were subjected to DNA sequence analysis.

Data used to compare infection levels in *P.* cf. *martensi* and *V. cubensis* were derived from collections of mollusks from five sites, each of which contained multiple individuals of each species. The statistical model consisted of logistic regression implementing the generalized estimating equations (GEE) procedure to adjust for correlation among mollusks of the same species being collected from the same site. Analyses were performed using the GENMOD procedure of SAS on-line version 9.1 (SAS Institute, Inc. 2000–2004). Alpha was set at 0.05.

Feeding preferences of *P.* cf. *martensi* and *V. cubensis* were compared in unreplicated bioassays. The bioassay arena consisted of a ventilated 2-liter plastic container holding moist soil (about 2.5 cm deep) and three mature semi-slugs, held for 5 days in an environmental chamber (27°C, 80% RH, 12:12 L:D). Various types of plant foods were placed on the soil surface after weighing. Data collected included weights of plant material and observations of feeding damage.

RESULTS

The majority of the 51 survey respondents were from the Puna district, although calls were also received from residents in/near Kailua-Kona (West Hawai‘i), Waimea (Northwest Hawai‘i), Honoka‘a (Northeast Hawai‘i), Hilo (East Hawai‘i), and Ocean View Estates (South Hawai‘i). Based on telephone interviews, we determined that many respondents had actually seen other types of slugs. We confirmed the presence of *P.* cf. *martensi* at 27 of 29 properties that in our

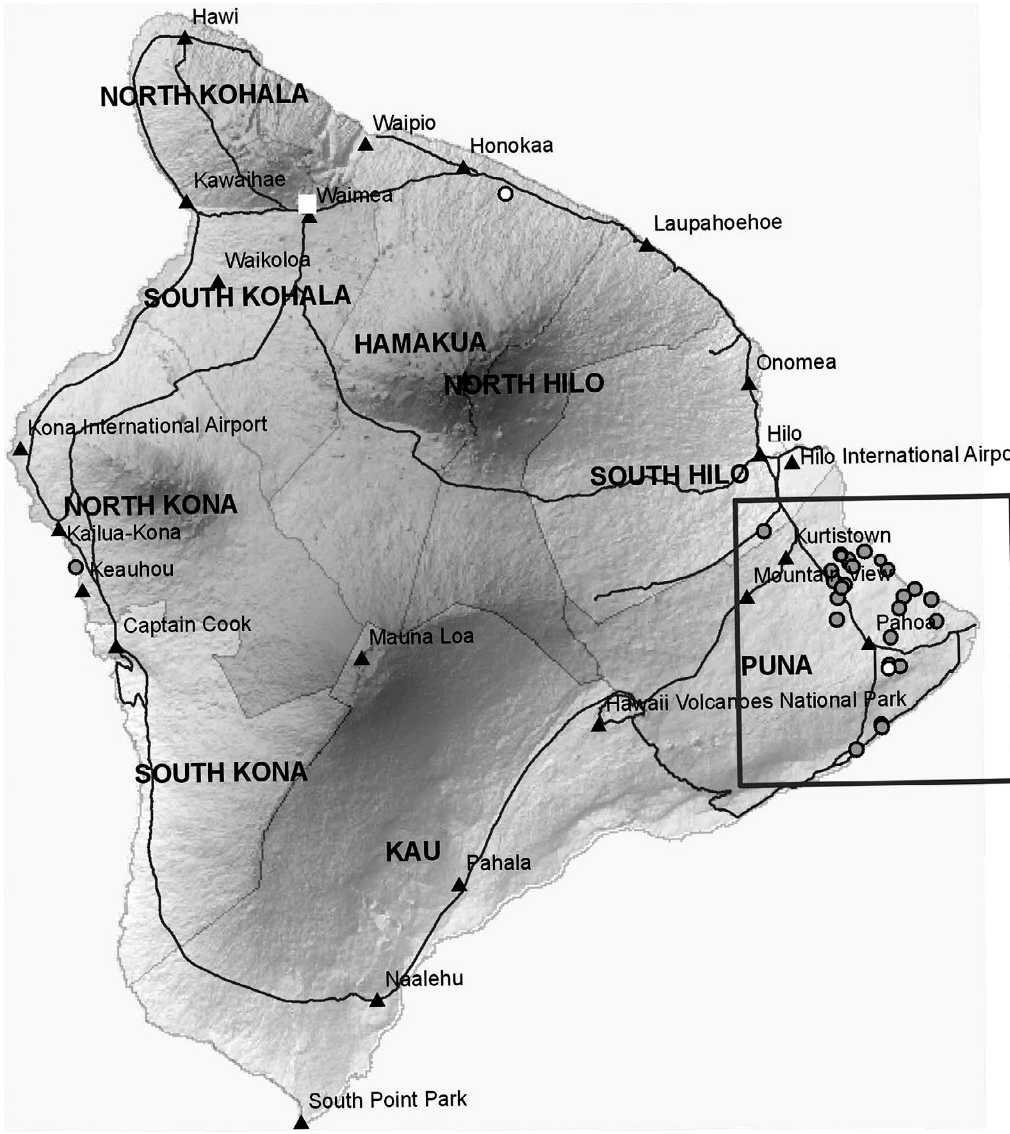

FIGURE 1. Survey locations for *Parmarion* cf. *martensi* in Hawai'i Island (shaded circles). White circles indicate sites where *P.* cf. *martensi* was searched for but not found. A white square (in the Waimea area) indicates location of a population detected during a 2006 survey carried out by University of Hawai'i scientists. The large square shows Puna district. Towns are indicated by black triangles.

judgment were associated with credible sightings of this semi-slug. The greatest concentration of sightings was in the Paradise Park Subdivision (Figures 1 and 2).

At the time of our survey, populations of *P.* cf. *martensi* were very low throughout the Puna district. At least four survey participants independently noted that populations had crashed within the previous 2–3 months. We also observed such a decline on an organic farm near Kapoho, near the eastern tip of Hawai'i Island, where we had regularly been

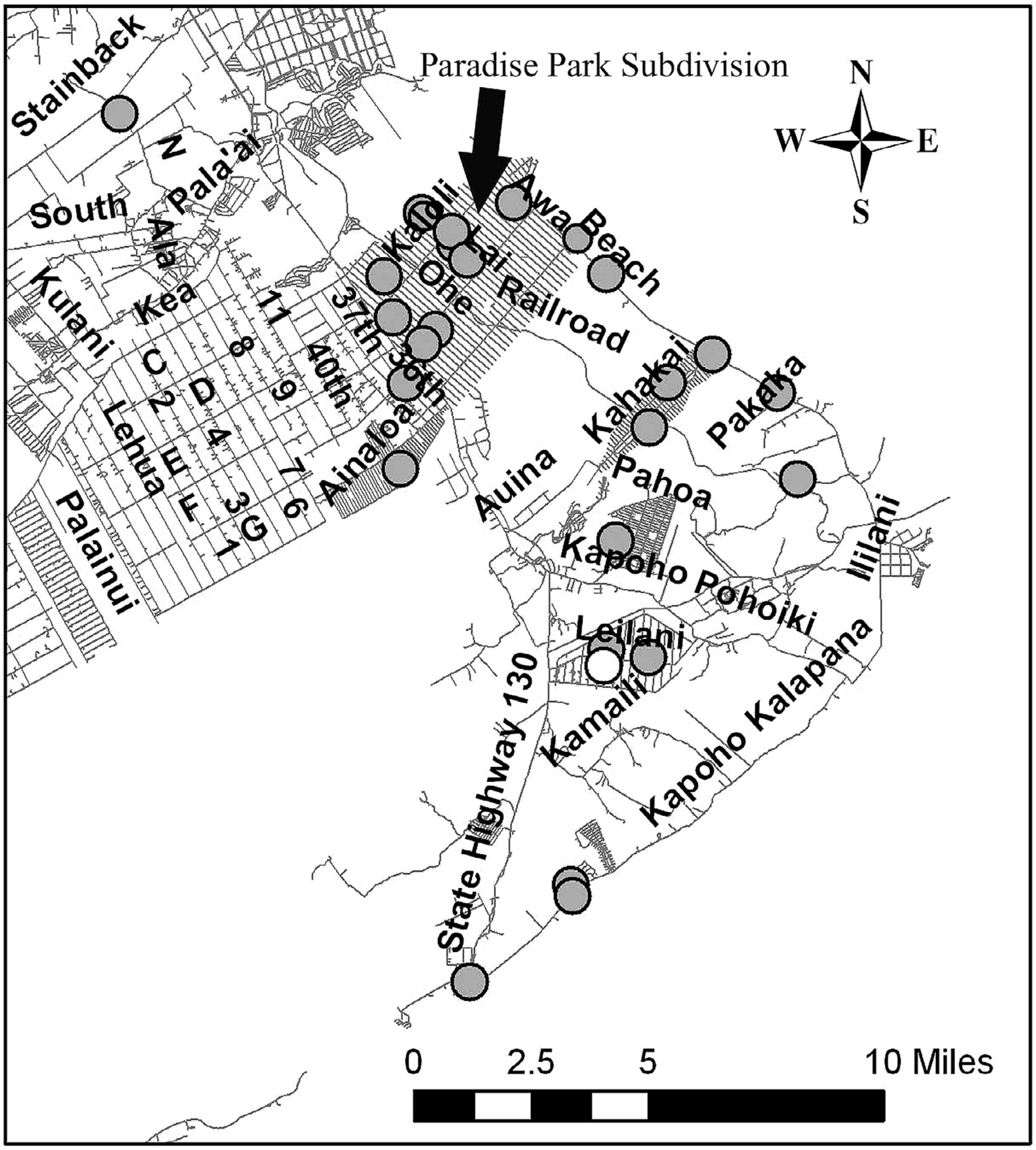

Figure 2. Map inset showing the lower Puna area where *Parmarion* cf. *martensi* was generally abundant. See Figure 1 for explanation of symbols.

collecting *P.* cf. *martensi* adults since January 2005. In early June, we found large numbers of *P.* cf. *martensi* egg masses on the undersides of halved coconuts being used as mulch but saw few individuals of any other life stage. Subsequent observations at various sites in the Puna district indicated that populations of *P.* cf. *martensi* returned to a higher level during the fall of 2005.

Thirty-seven percent of survey respondents indicated that they had first noticed this semi-slug species within the few weeks

TABLE 1

Types of Habitat Where *Parmarion* cf. *martensi* Was Observed by Survey Participants (Day and Night Observations)

Location	No. of Reports
On green plants (lettuce, fennel, sweet potato, banana, passion fruit, lemongrass, *Heliconia*)	10
On fallen fruit (avocado, guava, citrus, papaya, mango)	9
On/under plastic or plasticlike materials, including black plastic sheeting, tarps, drainpipes, plant pots	8
In compost (especially covered compost) or inside trash cans	6
In food preparation and sink areas (outdoor sinks, on dishes, grills, on toothbrush)	5
In pet food bowls or eating spilled pet food	5
On deck or stairs	5
On concrete, tile, or asphalt	5
On walls of home	4
On palm fronds or trunks or under coconut shells	4
On catchment tank (on outside, under black saran cover at top)	3
On ripe papaya fruits (on tree)	2
In plant debris other than palms	2

preceding the publicity generated by survey announcements. However, one respondent, an organic gardener, claimed to have noticed this species in lower Paradise Park in 1999. This would be the earliest report of *P.* cf. *martensi* on Hawai'i Island, and another resident ~3 km distant remembered seeing the semi-slug on his property in 2000 or 2001. Sixty-seven percent of survey participants considered this species a pest because of the disease risk and/or fecal deposits on houses. However, 22% did not consider it a pest, and the remaining 11% were either indifferent or did not provide a response.

The types of habitat where semi-slugs were found as determined by survey responses and our observations are summarized in Table 1 and Table 2, respectively. Many survey participants reported that *P.* cf. *martensi* demonstrated a remarkable propensity to climb objects, including drainpipes, wood decks, the walls of homes, water tanks, and barbeque grills. Although this climbing behavior occurred mainly at night, its extent was evidenced by the large number of fecal deposits we saw on the upper walls of houses and on water tanks.

Respondents observed semi-slugs most commonly on green plants, fallen fruits, and plastic surfaces (Table 1), including four reports on lettuce, two of them in home gardens and two involving lettuce purchased at markets on the east side of Hawai'i Island. There were five reports of *P.* cf. *martensi* being attracted during daytime to food preparation and sink areas. In this context, several respondents remarked that *P.* cf. *martensi* moved more quickly than other slug species they had seen around their houses, appearing soon after food sources first became available. Five people reported semi-slugs feeding on dog food, cat food, or parrot food that was either spilled or left in bowls (Table 1).

Six survey participants noted seeing the semi-slugs feeding in their covered compost

TABLE 2

Types of Habitat Where *Parmarion* cf. *martensi* Was Collected during Daytime Site Visits

Location	No. of Properties
On/under plastic or plasticlike materials, including black plastic sheeting, ground tarps, drainpipes, plant pots, tires	10
On palm fronds (fallen or within mulch pile)	4
Under rocks or tiles	3
In covered compost	2
Under banana trees	2
On drainpipe	1
In citronella grass	1
Under woven grass mat ("goza")	1
Palm leaves (living)	1
Coconut shell halves (overturned)	1

bins or in trash cans, and we collected numerous *P.* cf. *martensi* adults and egg masses from several covered compost bins. Two survey participants noted that *P.* cf. *martensi* sometimes fed on ripe papaya still attached to the tree.

In our own daylight searches, *P.* cf. *martensi* was most often found on or under plastic or other objects, including tires, tarps, black plastic sheeting, and drainpipes. Eggs found were generally in clutches of ca. 10–30 eggs each, laid inside overturned coconut shells, underneath plastic plant pots, or attached to the underside of plastic sheeting that was in contact with the ground or compost. In one case, eggs and neonate semi-slugs were found singly within rotting leaves of Alexander palms, *Archontophoenix alexandrae* (F. Muell.) H. Wendl. & Drude (Arecaceae). Our searches frequently found *V. cubensis* underneath plastic objects. However, unlike *V. cubensis*, *P.* cf. *martensi* life stages (including egg masses) were seldom found in direct contact with soil. Egg masses of the two species can be easily distinguished; eggs in the egg masses of the Cuban slug are larger, are chained together, and a black threadlike material (slug feces) runs through the masses. In egg masses of *P.* cf. *martensi*, eggs are not chained together and no black threadlike material is present.

Survey participants were asked if they had recently noted rats or mice on their property. Rats are the usual definitive host for *Angiostrongylus cantonensis*, and mice are potential hosts that can be infected in the laboratory. Seventy-four percent and 48% of respondents, respectively, indicated that they had recently noticed rats or mice on their property.

None of those surveyed considered *P.* cf. *martensi* to be a serious agricultural pest, and several people volunteered that *P.* cf. *martensi* did not eat plant leaves to the same extent as *V. cubensis*. These observations were supported by results in laboratory bioassays comparing the feeding preferences of these two species. *Parmarion* cf. *martensi* semi-slugs completely consumed a large, tender hibiscus flower but left hibiscus leaves present within the same container untouched. In contrast, *V. cubensis* presented with the same two choices consumed both flower and leaf material. A similar preference for tender plant material was noted in containers holding both red-leaved and green-leaved varieties of ti (*Cordyline* sp.): *P.* cf. *martensi* fed only slightly on the red-leaved variety, which was more tender than the green-leaved variety, and did not feed on the green-leaved variety held in the same container. *Veronicella cubensis* demonstrated a preference for the red leaves but also fed on the green-leaved variety. In containers holding a mixture of orchid flowers, orchid leaves, and pseudobulb material, both mollusk species fed exclusively on flowers and avoided the other plant parts.

The average level of infection by *A. cantonensis* in *P.* cf. *martensi* and *V. cubensis* was 77.5 and 24.3%, respectively (Table 3). This difference was significant ($P = 0.0007$, based on logistic regression using generalized estimating equations procedure). In both species, percentage infection was highest for large individuals (Table 3).

DISCUSSION

Our survey indicated that *P.* cf. *martensi* has essentially a continuous distribution in lower elevations of the Puna district. Such a widespread distribution is surprising for a species whose presence was confirmed only in 2004. However, two residents of Paradise Park provided credible reports of having first seen this

TABLE 3

Percentage Infection[a] by *Angiostrongylus cantonensis* in Slugs Collected from Five Sites in Hawai'i Island

Slug Species	Size	% Infected[a]	n[b]
Veronicella cubensis	Small	0	9
	Medium	0	2
	Large	34.6	26
	All sizes	24.3	37
Parmarion cf. *martensi*	Neonate	100	1
	Small	25	4
	Medium	76.9	13
	Large	86.4	22
	All sizes	77.5	40

[a] Infection determined by PCR and confirmed by sequencing of PCR amplicons.
[b] Number of slugs or semi-slugs analyzed.

species on their properties in 1999 and 2001. The rapid spread of the semi-slugs in this area has almost certainly been aided by the activities of people. There has been a construction boom in the lower Puna area during the past 6 yr, and it is likely that semi-slugs were transported between construction sites on building materials, building machinery, and in potted plants. The semi-slugs found in South Hilo were in trash that had been dumped in an isolated area near Stainback Highway (Figure 2). It is possible that the semi-slugs were derived from trash that originated in the Puna district. As for the presence of *P.* cf. *martensi* in North Kona, the owners of the residence have a second home in the Puna district (Paradise Park Subdivision), and it is possible that semi-slugs were accidentally transported from their Puna home to their Kona residence. After our survey was completed, an additional population of *P.* cf. *martensi* was found in the town of Waimea (Northwest Hawai'i Island) (Figure 1), detected during a statewide survey for mollusk pests carried out by University of Hawai'i researchers. In their 2006 survey, *P.* cf. *martensi* was also found on the island of O'ahu, in a plant nursery near Kahalu'u and in a commercial farming area in Waimānalo (Kenneth Hayes, University of Hawai'i, pers. comm., 2006).

As previously mentioned, the taxon *Parmarion martensi* is apparently native to Southeast Asia. It is not known how *P.* cf. *martensi* arrived in Hawai'i or whether its presence is the result of a single introduction. Interception data maintained by the U.S. Department of Agriculture's Animal and Plant Health Inspection Service indicate that semi-slugs in the genus *Parmarion* were intercepted on *Dracaena* plants shipped from Malaysia to Kailua-Kona in July 2003. On two occasions (February 2001 and April 2004), *Parmarion* has been intercepted in Honolulu during preclearance inspections on plant material being exported to the U.S. mainland. Interception records from 1996 to 2006 document seven other cases in which plants destined for locations in the United States were infested with "*Parmarion.*" Orchids were the infested commodity in five of these seven cases, with "origin" listed as Vietnam, Thailand, Indonesia, or Malaysia [USDA APHIS PPQ Pest Interception Database (PestID), Riverdale, Maryland].

The ecological consequences of the invasion of *P.* cf. *martensi* into Hawai'i are difficult to predict. Anecdotal evidence suggests that *P.* cf. *martensi* has displaced *V. cubensis* as the dominant large mollusk in certain residential areas. However, during our survey we frequently found both species in the same property. Our survey was based on a convenience sample, and information provided by respondents on pest status may constitute a biased sample of surveyed areas. The dietary habits of *P.* cf. *martensi* have not been studied in detail, but *V. cubensis* is known as a serious pest of ornamental and garden crops in Hawai'i (Furutani and Arita-Tsutsumi 1998). Many slug species are known to feed on a wide variety of vegetable and animal matter, including fruits, foliage, decaying vegetable matter, dead arthropods and earthworms, and algae and fungi that grow on surfaces of plants, rocks, or wood (Ebeling 2002). Herbivorous slugs generally prefer tender plant tissues, such as flowers, plant seedlings, or mature plants that have tender leaves or stems. Larger species (>2.5 cm) are more likely than smaller species to feed on healthy plant tissue. In feeding tests, *P.* cf. *martensi* preferred flowers over leaves of the same species and readily fed on fruits such as papaya. Acceptable foliage included lettuce, cabbage, and hibiscus leaves. The acceptability of these food sources to *P.* cf. *martensi* (a relatively large species, with extended length sometimes >5 cm) is not surprising. What is unusual, relative to other slug species in Hawai'i, is the propensity of *P.* cf. *martensi* to climb and locate rich food sources, including bird food, dog food, cat food, fish entrails, and papayas (including fruit on the tree and fruit set out on the railing of a deck high off the ground). This climbing behavior, in combination with an apparent attraction to rich food sources and a naturally high rate of infection by *A. cantonensis*, increases the likelihood that people will come into contact with semi-slugs and the parasitic nematodes they carry. Increased contact can occur when people handle items contaminated by semi-slugs or accidentally ingest a semi-slug or part of one. Current evidence suggests that the slime of mollusks (if accidentally ingested on fruits and vegetables) may not contain sufficient numbers of *A. cantonensis* to cause disease symptoms (Hollingsworth and Cowie 2006). Accidental ingestion of the slugs themselves on poorly washed fruits and vegetables (consumed raw) probably represents a much greater risk and would presumably be more likely to occur when semi-slugs are very small. Our data show that even neonate *P.* cf. *martensi* can be hosts for *A. cantonensis*. One survey respondent reported finding neonate semi-slugs on her garden-grown lettuce; the neonates were very difficult to see because of their small size (about 2 mm in length). Even larger specimens could be accidentally consumed on lettuce or other fresh greens if these are not thoroughly washed and checked for semi-slugs before chopping. Further research is necessary to determine whether neonates and very small semi-slugs carry a sufficient number of nematodes to potentially cause disease symptoms.

The climbing behavior of *P.* cf. *martensi* on water tanks is a potential health concern because of the chance that semi-slugs might transmit various types of disease organisms into drinking water. Contaminated drinking water is a potential source of *A. cantonensis* infection for humans (Wallace and Rosen 1969*b*). Cheng and Alicata (1964) found that infective-stage *A. cantonensis* were released into water from both damaged and undamaged *Achatina fulica* and *Subulina octona* (Bruguière, 1792) and survived in water for up to 72 hr. Similar results have been found for *Angiostrongylus costaricensis* Morera & Cespedes, 1971, released from the freshwater snail *Biomphalaria glabrata* (Say) (Ubelaker et al. 1980). None of our survey respondents reported finding *P.* cf. *martensi* inside their water tanks, but we received such a report subsequently. Many Puna residents rely on water collected from roofs for household use, including more than one-half of the respondents in our survey. Several respondents expressed concerns about the possible health risks associated with *P.* cf. *martensi* climbing on their water tanks. However, the majority of survey respondents using catchment water said they did not use this water for drinking. Four respondents mentioned that they drank their catchment water, but all said they used particle filtering systems.

The association of *P.* cf. *martensi* with plastic and other smooth surfaces may indicate a feeding preference for surface-growing algae or fungi, although semi-slugs were frequently found on plastic apparently free of microorganism growth. Alternatively, the association could be related to water conservation or could represent an adaptation for avoiding disease-causing organisms. Asato et al. (2004) hypothesized that *P. martensi* is more susceptible to infection with *A. cantonensis* than "*Veronicella alte*" [an apparent misnaming of *Laevicaulis alte* (Férussac, 1821)] because of the lower density of muscle tissue in the former species. Artificial infection by *A. cantonensis* was found to increase mortality rates in the aquatic snail *Physa elliptic*a (Lea, 1834) relative to snails in the experimental control (Wallace and Rosen 1969*a*). However, it is not clear whether infection by *A. cantonensis* increases mortality of mollusks generally.

Working in Malaysia, Lim and Heyneman (1965) studied *Microparmarion malayanus* (Collinge) a semi-slug species in the same family as *P. martensi*. They noted that *M. malayanus* climbed trees at night, was particularly common under heaps of dead palm leaves during the day, and was an important carrier of *A. cantonensis*. We observed these same characteristics in *P.* cf. *martensi* in Hawai'i. In Malaysia, *M. malayanus* was observed to feed on rat feces, and rats were observed to feed on *M. malayanus*. These aspects of the biology of. *P.* cf. *martensi* in Hawai'i have not been studied. However, their elucidation would be an important step toward understanding the importance of *P.* cf. *martensi* for the epidemiology of angiostrongyliasis in Hawai'i.

ACKNOWLEDGMENTS

We thank Robert Cowie and Kenneth Hayes (University of Hawai'i at Mānoa, Honolulu) for providing additional information about the distribution of *P.* cf. *martensi* in Hawai'i and for critically reviewing early drafts of the manuscript.

Literature Cited

Alicata, J. E. 1991. The discovery of *Angiostrongylus cantonensis* as a cause of human eosinophilic meningitis. Parasitol. Today 7:151–153.

Alicata, J. E., and K. Jindrak. 1970. Angiostrongylosis in the Pacific and Southeast Asia. Charles C. Thomas, Springfield, Illinois.

Asato, R., K. Taira, M. Nakamura, J. Kudaka, K. Itokazu, and M. Kawanaka. 2004. Laboratory and epidemiology communications: Changing epidemiology of *Angiostrongylus cantonensis* in Okinawa Prefecture, Japan. Jpn. J. Infect. Dis. 57:184–186.

Ash, L. R. 1976. Observations on the role of mollusks and planarians in the transmission of *Angiostrongylus cantonensis* infection to man in New Caledonia. Rev. Biol. Trop. 24:163–174.

Cheng, T. C., and J. E. Alicata. 1964. Possible role of water in the transmission of *Angiostrongylus cantonensis* (Nematoda: Metastrongylidae). J. Parasitol. 50:39–40.

Cowie, R. H. 1997. Catalog and bibliography of the nonindigenous nonmarine snails and slugs of the Hawaiian Islands. Bishop Mus. Occas. Pap. 50:1–66.

———. 1998. Catalog of the nonmarine snails and slugs of the Samoan Islands. Bishop Mus. Bull. Zool. (3):1–122.

da Silva, A. J., F. J. Bornay-Llinares, I. N. Moura, S. B. Slemenda, J. L. Tuttle, and N. J. Pieniazek. 1999. Fast and reliable extraction of protozoan parasite DNA from fecal specimens. Mol. Diagn. 4:57–64.

Ebeling, W. 2002. Chapter 12, Miscellaneous pests, urban entomology (Web site). University of California, Riverside, Entomology Department. http://www.entomology.ucr.edu/ebeling/ (accessed 4 January 2006).

Furutani, S. C., and L. Arita-Tsutsumi. 1998. Feeding preference of the two-striped slug, *Veronicella cubensis* (Pfeiffer) on taro. J. Hawaii. Pac. Agric. 9:1–6.

Graeff-Teixeira, C., and P. Morera. 1995. Método de digestão de moluscos em ácido clorídrico para isolamento de larvas de metastrongilídeos. Biociencias 3:85–89.

Ho, W. H. 1995. A review of the land-snail fauna of Singapore. Raffles Bull. Zool. 43:91–113.

Hollingsworth, R. G., and R. H. Cowie. 2006. Apple snails as disease vectors. Pages 121–132 *in* R. Joshi and L. Sebastian, eds. Global advances in ecology and management of golden apple snails. Philippine Rice Research Institute (PhilRice), Muñoz, Nueva Ecija.

Kliks, M. M., and N. E. Palumbo. 1992. Eosinophilic meningitis beyond the Pacific basin: The global dispersal of a peridomestic zoonosis caused by *Angiostrongylus cantonensis*, the nematode lungworm of rats. Soc. Sci. Med. 34:199–212.

Lim, B.-L., and D. Heyneman. 1965. Host-parasite studies of *Angiostrongylus cantonensis* (Nematoda, Metastrongylidae) in Malaysian rodents: Natural infection of rodents and molluscs in urban and rural areas of central Malaya. Ann. Trop. Med. Parasitol. 59:425–433.

Mackerras, M. J., and D. F. Sandars. 1955. The life history of the rat lungworm, *Angiostrongylus cantonensis* (Chen) (Nematoda: Metastrongylidae). Aust. J. Zool. 3:1–21.

Minato, H. 1975. A new record of *Parmarion martensi* from Ishigaki Island, the Southern Ryukyus, Japan. Venus 34 (3–4): 109–111.

Minato, H., and K. Okubo. 1991. A record of *Parmarion martensi* Simroth, 1893 (Pulmonata: Helicarionidae) collected from Taiwan. The Chiribotan 22:3–4.

Qvarnstrom, Y., J. J. Sullivan, H. S. Bishop, R. G. Hollingsworth, and A. J. da Silva. 2007. PCR-based detection of *Angiostrongylus cantonensis* in tissue and mucus secretions from molluscan hosts. Appl. Environ. Microbiol. 73:1415–1419.

SAS Institute, Inc. 2000–2004. SAS online version 9.1. Cary, North Carolina.

Simroth, H. 1893. Ueber einige *Parmarion-Arten.* Pages 100–110, pl. 7, 8 *in* Weber, M., ed. Zoologische Ergebnisse einer Reise in Niederländisch Ost-Indien herausgegeben von Dr. Max Weber. Vol. 2. E. J. Brill, Leiden.

Ubelaker, J. E., G. R. Bullick, and J. Caruso. 1980. Emergence of third-stage larvae of *Angiostrongylus costaricensis* Morera and Cespedes 1971 from *Biomphalaria glabrata* (Say). J. Parasitol. 66:856–856.

van Benthem Jutting, W. S. S. 1950. Systematic studies on the non-marine Mollusca of the Indo-Australian Archipelago. II. Critical revision of the Javanese pulmonate land-snails of the families Helicarionidae, Pleurodontidae, Fruticicolidae & Streptaxidae. Treubia 20:381–505.

Wallace, G. D., and L. Rosen. 1969*a*. Experimental infection of Pacific island mollusks with *Angiostrongylus cantonensis*. Am. J. Trop. Med. Hyg. 18:13–19.

———. 1969*b*. Studies on eosinophilic meningitis. V. Molluscan hosts of *Angiostrongylus cantonensis* on Pacific islands. Am. J. Trop. Med. Hyg. 18:206–216.