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New species of *Hammerschmidtiella* Chitwood, 1932, and *Blattophila* Cobb, 1920, and new geographical records for *Severianoia annamensis* Van Luc & Spiridonov, 1993 (Nematoda: Oxyurida: Thelastomatoidea) from Cockroaches (Insecta: Blattaria) in Ohio and Florida, U.S.A.

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Abstract

Two new species of thelastomatid nematodes parasitic in the hindgut of cockroaches are described. *Hammerschmidtiella keeneyi* **n. sp.** is described from a laboratory colony of *Diploptera punctata* (Eschscholtz, 1822) from a facility in Ohio, U. S. A. This species is characterized by having females with a short tail and males smaller than those described from other species. The new species also differs from others in the genus by a number of differing measurements that indicate a distinct identity, including esophageal, tail, and egg lengths as well as the relative position of the excretory pore. *Blattophila peregrinata* **n. sp.** is described from *Periplaneta australasiae* (Fabricius, 1775) and *Pycnoscelus surinamensis* (Linnaeus, 1758) in a greenhouse from Ohio, U.S.A. and from wild *P. surinamensis* in southern Florida, U.S.A. This species differs from others in the genus by having a posteriorly directed vagina, vulva in the anterior third of the body, no lateral alae in females, and eggs with an operculum. In *P. surinamensis* from southern Florida, an additional species, *Severianoia annamensis* Van Luc & Spiridonov, 1993 was found and did not co-parasitize the host with *B. peregrinata* **n. sp.** *Blattophila peregrinata* **n. sp.** and *S. annamensis* also occur in the Galápagos Islands, Ecuador, indicating that these have a widespread global range.

Key words: *Blattophila*, *Hammerschmidtiella*, pinworms, *Severianoia*, Thelastomatidae

Introduction

Nematodes of the Order Oxyurida include the Thelastomatoidea whose hosts are invertebrates (primarily arthropods). Cockroaches constitute one of the definitive hosts with a high diversity of thelastomatoid parasites (Adamson, 1994; Carreno, 2014). Recent collections of these parasites, both from lab colonies and wild specimens, have yielded two undescribed species of thelastomatid nematodes. One of these is from the genus *Hammerschmidtiella* Chitwood, 1932 and was discovered in a laboratory colony of the Pacific beetle cockroach, *Diploptera punctata* (Eschscholtz, 1822). The second is a species of *Blattophila* Cobb, 1920 that has been collected from both the Australian cockroach *Periplaneta australasiae* Fabricius, 1775 and the Surinam cockroach, *Pycnoscelus surinamensis* (Linnaeus, 1758) in three separate geographic localities. A population of *P. australasiae* infesting a local greenhouse (Ohio, U.S.A.), has yielded large numbers of specimens for description and for comparison with lower numbers of specimens from wild cockroaches. In a second locality, the Galápagos Islands (Ecuador), specimens of the same *Blattophila* sp. were collected and a general description given (Sinnott *et al.*, 2015). However, the specimens collected in Ecuador were not of a quality sufficient for species description and no males were recovered. The nematodes from the Galápagos Islands study had been acquired from cockroaches that had been preserved in ethanol and that were dissected many years after collection, resulting in the recovery of worms that had not been preserved using appropriate methods. Collections from a third locality, Key Largo (Florida), in 2011 and 2014 initially did not yield enough males for description and comparison to those from *P. australasiae*. The new *Blattophila* species from these three locations, together with the *Hammerschmidtiella* sp. from *D. punctata*, are described here. A new geographic locality, namely Florida (U.S.A.), is reported for an

additional species, *Severianoia annamensis* van Luc and Spiridonov, 1993, and the identity of the *Severianoia* sp. discovered in the Galápagos Islands is also now considered to be *S. annamensis*.

Materials and methods

Cockroaches used in this study were euthanized and the posterior intestine dissected to recover nematodes. Specimens of *D. punctata* were examined from the colony maintained in the Ohio State University insectary (Columbus, Ohio, U.S.A.) from 2007 to 2011. Specimens of *P. australasiae* and *P. surinamensis* were collected in the Moore greenhouse, Ohio Wesleyan University, Delaware, Ohio, U.S.A., and searched for pinworms. From additional field collected cockroaches including *P. surinamensis* and *P. australasiae*, nematodes belonging to the genus *Blattophila* were recovered (geographic localities given below). Nematodes were preserved in 5% formalin or in 90% ethanol, the latter for DNA extraction and PCR. Several specimens preserved in formalin were measured and then prepared for scanning electron microscopy (SEM) by dehydrating the specimens in a graded ethanol series. The specimens were critical point dried using an Autosamdri 795 Supercritical Point Dryer (Tousimis, Rockville, Maryland). A Leo 435 VP scanning electron microscope as well as a Zeiss EVO LS10 SEM were used for imaging. Pinworms were examined either in a 0.9% NaCl solution or were cleared in lactic acid as wet mounts. A Nikon E600 microscope with both bright field and differential interference contrast microscopy was used for light microscopical observations. Measurements are provided as mean values with standard deviation followed by range in parentheses (Tables 1–3). Type and paratype specimens have been deposited into the Harold W. Manter Laboratory of Parasitology collection (HWML) at the University of Nebraska, Lincoln, Nebraska, U.S.A. (see collection numbers below). Voucher DNA sequences were acquired for both of the new species. These included SSU rDNA and partial LSU rDNA, the latter containing the D2 and D3 domains. DNA extraction, polymerase chain reaction, and sequencing followed the methodology used in Carreno & Nadler (2003). For SSU rDNA, two overlapping regions were amplified using primers 47, 112, 135, and 136, and primers 391 and 501 were used for LSU rDNA sequences (see Carreno & Nadler, 2003, for primer sequences).

Descriptions

Hammerschmidtiella keeneyi n.sp.
(Figs. 1A–F, 3A–D; Table 1)

Description (based on 16 males, 41 females). **Male**: Body with thin anterior half, prominent expansion of midbody, and slender posterior and tail region (Fig. 1E). Narrow lateral alae present, extending from corpus to precloacal region. Esophagus with base of corpus slightly expanded, thin isthmus, and elongate bulb. Nerve ring posterior to base of corpus. Excretory pore posterior to esophagus. Three pairs of caudal papillae present, including one pair subventral precloacal, one pair lateral postcloacal papillae, both pairs slightly raised from the body surface, and one pair on base of tail appendage (Figs. 1F, 3B). Phasmids situated on cuticular expansion immediately posterior to cloaca. Spicule present. Gubernaculum absent. Tail ending long, filiform.

Female: Oral opening surrounded by eight oblong-quadrate myolabia (Figs 1C, 3C, D). Inner lining of oral opening (cheilostom) with three small projections of tridentate structures, one on each lobe of the esophagus (Fig. 3D). Amphids semicircular with rounded portion facing outward. Oral annule small, circular, followed by 5–9 prominent cuticular annules (Fig. 3A); subsequent cuticular annules less distinct. Narrow lateral alae present, arising from a point immediately anterior to the vulva and extending to anus. Esophageal corpus with slight rounded expansion at distal end and with wide base. Nerve ring anterior to broad portion of corpus (Fig. 1B). Isthmus cylindrical. Basal bulb spherical with valvular apparatus. Excretory pore posterior to esophageal bulb. Intestine slightly dilated at anterior end, but not forming a prominent cardia. Vulva located at anterior third of body, consisting of a crescent-shaped opening with a slight, smooth cuticular extension; vagina directed posteriorly (Fig. 1A). Uterus branches into two ovaries usually terminating in anterior portion of body. Didelphic, prodelphic. Rectal glands present. Tail subulate (Fig. 1D). Eggs long, oval, slightly flattened on one side. Measurements in Table 1.
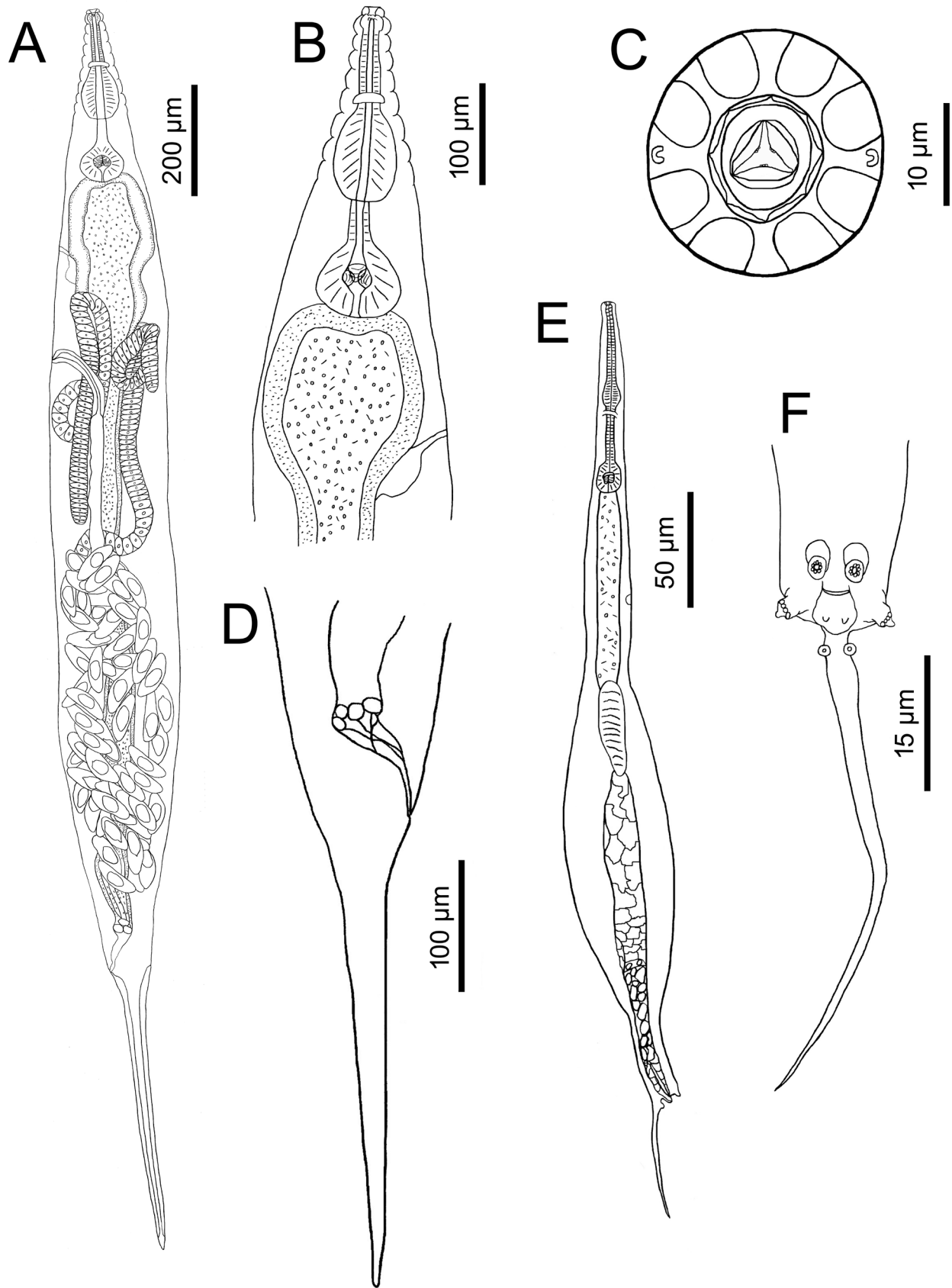
FIGURE 1. *Hammerschmidtiella keeneyi* **n. sp.** A. Female whole worm. B. Female anterior end. C. Female, *en face*. D. Female tail, lateral. E. Male, whole worm, lateral. F. Male caudal end, ventral.

TABLE 1. Morphometric measurements (in micrometers) for *Hammerschmidtiella keeneyi* **n. sp.** The mean and standard deviation are followed by range for paratype measurements.

Character	Holotype female	Paratype females (n=40)	Allotype male	Paratype males (n=15)
Body length	2225	2214 ± 224 (1733–2750)	419	436 ± 70 (335–573)
Maximum width	200	222 ±34 (164–300)	49	47 ± 10 (30–69)
Buccal cavity (length)	13	13 ± 3 (8–9)	-	3
Oral annule length	6	6 ± 2 (4–9)	-	-
Oral annule width	23	24 ± 2 (20–26)	-	-
Second annule length	18	16 ± 2 (13–18)	-	-
Second annule width	34	35 ± 3 (23–39)	-	-
Nerve ring	98	103 ± 8 (90–120)	64	52 ± 9 (41–64)
Excretory pore	Not observed	422 ± 12 (410–438)	Not observed	132.5
Distance from base of esophagus to excretory pore	105	98 ± 25 (78–130)	Not observed	32
Esophagus	304	307 ± 20 (262–350)	87	90 ± 7 (77–100)
Corpus length	193	192 ± 15 (158–230)	47	47 ± 4 (43–50)
Corpus maximum width	70	66 ± 5 (56–74)	8	7 ± 1 (7–8)
Width of anterior expansion of corpus	21	23 ± 1 (20–25)	-	-
Isthmus length	48	45 ± 8 (30–60)	26	26
Bulb length	65	71 ± 8 (57–96)	14	15 ± 1 (13–17)
Bulb width	87.5	84 ± 8 (71–105)	11	14 ± 2 (11–15)
Vulva from anterior end	640	669 ± 66 (570–800)	-	-
Vulva from posterior end	1585	1568 ± 150 (1300–1950)	-	-
Vagina length	155	166 ± 15 (155–176)	-	-
Tail length	505	410 ± 57 (325–535)	54	59 ± 6 (45–70)
Egg length	83–90 (n=4)	87 ± 5 (77–98)	-	-
Egg width	30–35 (n=4)	30 ± 3 (25–38)	-	-
a	11	10 ± 2 (7–14)	8.55	10 ± 2 (8–16)
b	7	7 ± 1 (6–8)	4.82	5 ± 1 (4–6)
c	4	5 ± 1 (4–7)	7.76	8 ± 1 (5–9)
V	29	30 ± 2 (26–32)	-	-
Spicule length	-	-	22	21 ± 3 (17–27)

Taxonomic summary

Type host: *Diploptera punctata* (Eschscholtz, 1822) (Blattaria: Blaberidae)

Type locality: captive host colony, insectary, Department of Evolution, Ecology, and Organismal Biology, Ohio State University, Columbus, Ohio, U.S.A.

Site of infection: hindgut

Prevalence: 82%; mean intensity = 2.8; ratio of males to females = 1:1.69.

Specimens deposited: holotype female, HWML 99914; allotype male HWML 99915; paratype two males HWML 99916; paratypes, 12 females HWML 99917.

Voucher DNA sequences: 18S small subunit ribosomal RNA gene, partial sequence GenBank accession number KX752429. The 28S ribosomal RNA gene, partial sequence, GenBank accession number KX752430.

Etymology. This species is named in honor of George Keeney, entomologist, director of the Ohio State University insectary, and valued colleague.

Remarks. *Hammerschmidtiella keeneyi* **n. sp.** differs from the type species, *H. diesingi* (Hammerschmidt,

1838) Chitwood, 1932, in having several smaller body proportions such as male body length, distance of nerve ring to anterior end, esophageal length, corpus length, and corpus width, spicule length, and tail length (males), and tail length and De Man ratio b in females (see Chitwood, 1932, Lee, 1958, Shah, 2007, and Blanco *et al.*, 2012, for descriptions of *H. diesingi*). There is slight overlap in reported female tail length (Blanco *et al.*, 2012). However, the measurement for *H. keeneyi* **n. sp.** (325–535 μm, mean = 410 μm vs 479.4–1132.2 μm, mean = 871.6 μm provided for *H. diesingi* by Blanco *et al.*, 2012) clearly shows a longer tail length for *H. diesingi*. Furthermore, the female tail of *H. keeneyi* **n.sp.** is not filiform as in *H. diesingi* and De Man ratio c (body length/tail length) is higher in *H. keeneyi* **n. sp.** (range 4–7 vs. 2.6–4 in Blanco *et al.*, 2012). Similarly, ratio b (body length/esophageal length) is smaller (range 6–8 vs 9.5–16) and does not overlap with that of *H. diesingi*. Although there is slight overlap in male length, the males of *H. keeneyi* **n. sp.** are generally smaller than those of *H. diesingi* (mean length 436 μm vs. 701 μm) and have a shorter tail length (mean 59 μm vs. 101.3 μm) and esophageal length (mean 90 μm vs. 124.7 μm). *Hammerschmidtiella basiri* Singh & Kaur, 1988 also has females with longer tails (900–1000 μm) and differs in having the excretory pore anterior to the esophageal bulb rather than posterior to the esophagus (Singh & Kaur, 1988). Cuticular plates covering the vulva in *H. basiri* are absent in *H. keeneyi* **n. sp.** Interestingly, tooth-like projections similar to those observed for *H. keeneyi* **n. sp.** were noted for *H. basiri* but not illustrated (Singh & Kaur, 1988). *Hammerschmidtiella aspiculus* Biswas & Chakravarty, 1963 also included mention of three tooth-like projections in the mouth cavity. However, this species also has a longer female tail (920–960 μm), an excretory pore situated at the level of the esophagus, and smaller eggs (length 74–78 μm vs. 77–98 μm). Male caudal structures were not described in *H. aspiculus* (Biswas and Chakravarty, 1963). *Hammerschmidtiella acreana* Kloss, 1966 has a shorter female tail whose reported length (482–567 μm) slightly overlaps with that of *H. keeneyi* **n. sp.** However, eggs of *H. acreana* are smaller (length 75–78 μm) and male proportions (body length 590–710 μm; esophagus length 107–117 μm; tail 78–135 μm) are larger than in *H. keeneyi* **n. sp.** (Kloss, 1966).

Hammerschmidtiella indicus Singh & Malti, 2003 has a longer female tail (960–980 μm) and much smaller eggs (length 55–56 μm). Both sexes in this species lack lateral alae. In *Hammerschmidtiella mackenziei* (Zervos, 1987) Adamson & Van Waerebeke, 1992 both female (250–290 μm) and male (28 μm) tail lengths are shorter than in *H. keeneyi* **n. sp.**, male body shape does not have a mid-body expansion, and the caudal region has four pairs of caudal papillae rather than three (Zervos, 1987). Female tail lengths of *Hammerschmidtiella manohari* Rao, 1958 (780 μm) and *Hammerschmidtiella singhi* Rao & Rao, 1965 (658 μm) are longer than that of *H. keeneyi* **n. sp.**, and males are longer (830 μm for *H. singhi*, 810–960 μm for *H. manohari*). In addition, the males of both *H. manohari* and *H. singhi* are slenderer in shape. *Hammerschmidtiella keeneyi* **n. sp.** differs from *Hammerschmidtiella andersoni* Adamson & Nasher, 1987 in lacking a gubernaculum, having a wide mid-body region in males, and in having a shorter female tail (tail length for *H. andersoni* 579–679 μm). *Hammerschmidtiella andersoni* was reported from a diplopod in Saudi Arabia (Adamson & Nasher, 1987).

Hammerschmidtiella cristata Spiridonov, 1984 is distinguished from other species of the genus in having a comb-like structure on the anterior end of the cloaca lip of the male, as observed from a recent redescription of the species from the cockroach *Gromphadorhina portentosa* (Schaum, 1853) by Guzeeva & Spiridonov (2009). This structure was not observed on males of *H. keeneyi* **n. sp.** The tail of *H. cristata* females is filiform and there is only slight overlap with the longer length range reported for *H. cristata* (450–660 μm). In *Hammerschmidtiella poinari* (Gupta & Kaur, 1978) Adamson & Van Waerebeke, 1992, the tail length, estimated to be approximately 400 μm based on the illustration of the female tail, falls within the range of that of *H. keeneyi* **n. sp.** (Gupta & Kaur, 1978). However, in *H. poinari* the vulva is in the mid-region of the body rather than in the anterior third, and the excretory pore is closer to the esophageal bulb.

Hammerschmidtiella keeneyi **n. sp.** resembles *Hammerschmidtiella neyrai* Serrano Sanchez, 1945. The shorter female tail length of *H. neyrai* (400 μm) falls within the range of *H. keeneyi* **n. sp.,** and other female body proportions are consistent with the description of *H. neyrai* (Serrano Sánchez, 1947). However, female body length is slightly greater in *H. neyrai* (2800 μm, no range available, vs 1733–2750 in *H. keeneyi* **n. sp.**), egg length is shorter in *H. neyrai* (78 μm), and male body length (1270 μm), width (80 μm), esophagus (146 μm), and spicule length (28 μm) are greater. Lateral alae are absent in *H. neyrai*. *Hammerschmidtiella hochi* Jex, Schneider, Rose, & Cribb, 2005 differs in lacking lateral alae and having the female excretory pore at the level of the bulb, and in having ovoid, pear-shaped eggs.

***Blattophila peregrinata* n. sp.**
(Figs. 2A–F; 3E–H; Table 2)

Description (based on 16 males, 70 females). **Male**: Small worms. Narrow lateral alae present, extending from point of esophageal corpus to precloacal region (Fig. 3F). Head region slightly expanded. Esophagus with base of corpus slightly expanded, thin isthmus, and elongate bulb (Fig. 2E). Nerve ring posterior to base of corpus. Excretory pore posterior to esophagus. Four pairs of caudal papillae present, including one larger pair subventral precloacal, one smaller pair postcloacal papillae spaced closely together, one adanal pair, and one small pair at base of filiform tail appendage (Fig. 2F). Spicule present. Gubernaculum absent.

Female: Oral opening triangular, 8 weakly developed myolabia present, each with a rounded distal end and linear elevated cuticular division between the two borders of each myolabium (Figs. 2C, 3E). Amphids circular. Second annule longer and markedly wider than oral annule, base delineated from rest of body (Fig. 2B). Lateral alae absent. Esophageal corpus with slightly rounded, expanded anterior portion surrounding the stoma. Posterior of corpus expanded, gradually narrowing toward anterior end (Fig. 2B). Nerve ring near posterior end of corpus, at point where corpus expands basally (Fig. 2B). Isthmus short, straight. Basal bulb spherical with valvular apparatus. Excretory pore posterior to esophageal bulb. Didelphic, opisthodelphic. Vulva opening in anterior third of body, vagina posteriorly directed (Fig. 2A). Vulva opening crescent-shaped, lacking prominent extension of cuticle. Common uterus branching posterior to mid body, ovaries reflexed anteriorly. Tail subulate, slightly filiform (Fig. 2D). Rectal glands present. Eggs oval, with operculum (Figs. 3G, H).

Taxonomic Summary

Type host: *Periplaneta australasiae* (Fabricius, 1775) (Blattaria: Blattidae)

Type locality: Moore Greenhouse, campus of Ohio Wesleyan University, Delaware, Ohio, USA. (40˚17'43.1"N 83˚03'55.3"W).

Prevalence = 79.5%; mean intensity = 6.43

Other localities (from *P. surinamensis* only): John Pennecamp Coral Reef State Park, Key Largo, Florida, USA (25˚7'38.3"N, 80˚24'31.2"W); Prevalence = 79%; mean intensity = 2.15; Galápagos Islands, Ecuador (locality information for specific islands in Sinnott *et al.*, 2015). Prevalence (in Galápagos *P. surinamensis*) = 16%; mean intensity = 1.5

Site of infection: hindgut

Specimens deposited: From *P. australasiae*: holotype female, HWML 99918; allotype male HWML 99919; paratypes, 20 females HWML 99921.

From *P. surinamensis*: vouchers, four females HWML 99920, 1 male HWML 99922 from John Pennecamp Coral Reef State Park, Key Largo, Florida, USA.

Voucher DNA sequences: 18S small subunit ribosomal RNA gene, partial sequence GenBank accession number KX752427. 28S ribosomal RNA gene, partial sequence GenBank accession number KX752428.

Etymology. The name "*peregrinata*", or "traveler", refers to the widespread distribution of this species.

Remarks. Based on keys to the genus *Blattophila* by Farooqui (1967), Ali *et al.* (1970), and an updated key by Jex *et al.*,(2005), *Blattophila peregrinata* **n. sp.** differs from *Blattophila suppelaima* Basir, 1941, *Blattophila singhi* Farooqui, 1967, *Blattophila indica* Rao & Rao, 1965, *Blattophila farooquii* (Farooqui, 1967) Adamson & Van Waerebeke, 1992, and *Blattophila bryostriae* Farooqui, 1967 in having a posteriorly directed vagina. In each of these species, as well as in *Blattophila basiri* (Ahmed & Jabin, 1966) Adamson & Van Waerebeke, 1992, a species not included in published keys, the vagina is anteriorly directed. Females of *B. basiri*, *B. bryostriae*, and *B. farooquii* have lateral alae and males of these species differ, being larger (970–1000 µm in *B. bryostriae*, 1030–1200 µm in *B. farooquii* and 1800–2100 µm in *B. basiri* vs. 275–510 µm in *B. peregrinata* **n. sp.**) and having only a single postcloacal papilla at the base of the tail (Ahmed & Jabin, 1966; Farooqui, 1967). The male tail appendage is shorter in these species (19–29 µm in *B. basiri* vs. 28–43 µm in *B. peregrinata* **n. sp.**). Females of *B. singhi* also have lateral alae and a laterally tilted cephalic region. Females of *B. supellaima* lack a well delineated second annule and do not have as broad a corpus base (17–40 µm vs. 38–58 µm) as in *B. peregrinata* **n. sp.** (Basir, 1941). The eggs of *B. supellaima* lack an operculum. Females of *B. indica* also have a narrower corpus base (33 µm) and lack operculate eggs, and males are larger (1016 µm). The posterior tail shape of males differs from that of *B. peregrinata* **n. sp.** in being rounded rather than gradually tapering (Rao & Rao, 1965).

Of the remaining species, *Blattophila narayani* Farooqui, 1967, and *Blattophila javanica* Chitwood &

Chitwood, 1934 have the vulva located near the midbody rather than at its anterior third. *Blattophila narayani* females have lateral alae, and the male tail appendage extends from an abruptly ending, rounded tail tip. *Blattophila javanica* has a longer esophagus (length 410–610 µm) and tail length (590–670 µm). Based on the illustrations of the female by Chitwood and Chitwood (1934), the base of the corpus is also wider (estimated as 70 µm from Fig. 2 in Chitwood & Chitwood, 1934) than in *B. peregrinata* **n. sp.**
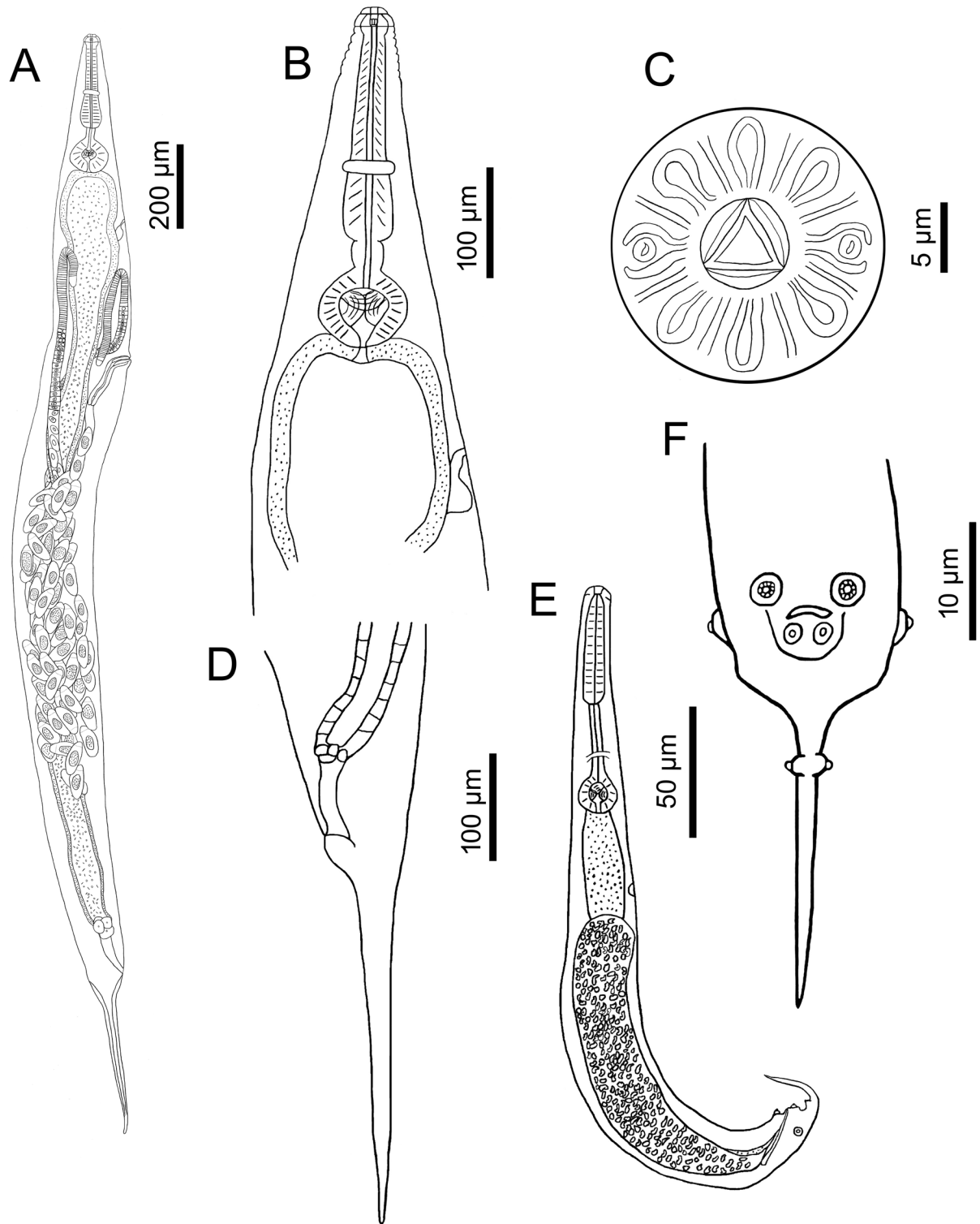

FIGURE 2. *Blattophila peregrinata* **n. sp.** A. Female whole worm. B. Female anterior end. C. Female, *en face*. D. Female tail, lateral. E. Male worm, lateral. F. Male caudal end, ventral.
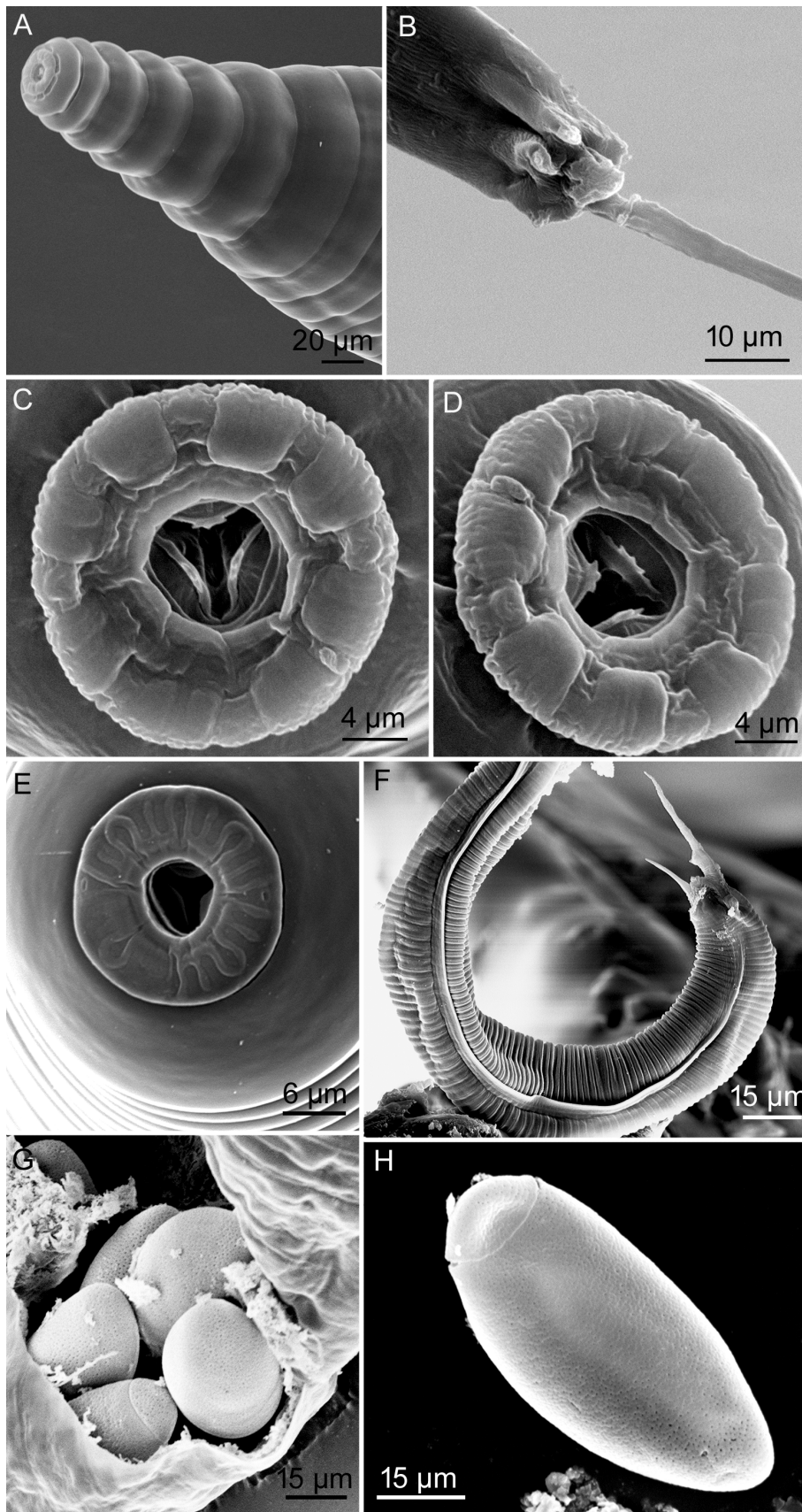
FIGURE 3. Scanning electron micrographs. *Hammerschmidtiella keeneyi* **n. sp.** A. Female anterior end, lateral. B. Male, tail region, ventral. C, D. En face, female. *Blattophila peregrinata* **n. sp.** E. Female, *en face*. F. Male, lateral view showing lateral alae. G. Eggs in utero. H. Egg showing operculum.

TABLE 2. Morphometric measurements (in micrometers) for *Blattophila peregrinata* **n. sp.** The mean and standard deviation are followed by range for paratype measurements.

Character	Holotype female	Paratype females (n=70)	Allotype male	Paratype males (n= 16)
Body length	3000	2378 ± 348 (1725–3225)	388	381 ± 72 (275–510)
Maximum width	270	220 ±38 (150–305)	46	35 ± 6 (26–46)
Buccal cavity (length)	10	11 ± 2 (8–15)	3	3 ± 1 (2–3)
Oral annule length	3	5 ± 1 (3–5)	4	-
Oral annule width	20	20 ± 2 (18–23)	8	-
second annule length	10	12 ± 2 (8–15)	-	-
Second annule width	35	35 ± 3 (30–40)	-	-
Nerve ring	143	127 ± 11 (108–150)	64	68 ± 12 (55–79)
Excretory pore	-	450 ± 33 (396–500)	130	116 ± 12 (109–130)
Distance from base of esophagus to excretory pore	102	148 ± 29 101–213	38	27 ± 16 15–38
Esophagus	343	296 ± 18 (265–343)	89	89 ± 8 (73–101)
Corpus length	228	201 ± 14 (170–231)	43	41 ± 4 (35–46)
Corpus maximum width	50	46 ± 4 (38–58)	8	8 ± 1 (8–9)
Width of anterior expansion of corpus	25	22 ± 2 (20–25)	-	-
Isthmus length	25	23 ± 4 (18–30)	23	18 ± 4 (11–23)
Bulb length	88	73 ± 6 (63–88)	20	24 ± 4 (20–30)
Bulb width	95	83 ± 8 (70–101)	14	14 ± 2 (11–16)
Vulva from anterior end	860	689 ± 83 (550–880)	-	-
Vulva from posterior end	2140	1653 ± 256 (1163–2220)	-	-
Vagina length	-	132 ± 14 (105–145)	-	-
Tail length	440	365 ± 42 (290–440)	30	34 ± 4 (28–43)
Egg length	73–79 (n=4)	74 ± 4 (65–83)	-	-
Egg width	25–28 (n=4)	29 ± 2 (25–35)	-	-
a	11	11 ± 2 (8–15)	8	11 ± 2 (8–14)
b	9	8 ± 1 (6–10)	4	5 ± 1 (3–5)
c	7	7 ± 1 (5–8)	13	12 ± 2 (10–16)
V	29	30 ± 2 (28–35)	-	-
Spicule length	-	-	23	20 ± 3 (15–23)

Three additional species, *Blattophila perisphoeriai* Ali, Farooqui, & Shrisunder, 1970, *Blattophila aurangabadensis* Ali & Shrisunder, 1971, and the type species, *Blattophila sphaerolaima* Cobb, 1920 have the vulva located in the anterior third of the body, as in *B. peregrinata* **n. sp.** *Blattophila perisphoeriai* differs in lacking cephalic annules and *B. aurangabadensis* has eggs without an operculum. *Blattophila peregrinata* **n. sp.** has prominent cephalic annules and has operculate eggs. Measurements for many characters of *B. perisphoeriai* females (body length, width, esophagus, excretory pore, distance of vulva from anterior end, and egg length) are similar to those of *B. peregrinata* **n. sp.**, and the base of the corpus is not prominently rounded (Ali *et al.*, 1970). However, the tail of *B. peregrinata* **n. sp.** is longer than that of *B. perisphoeriai* (200–240 μm in the latter) and tapers somewhat gradually rather than abruptly narrowing from the end of the body. There is not a prominent second cephalic annule in *B. perisphoeriai*. *Blattophila sphaerolaima* resembles *B. peregrinata* **n. sp.** in having an enlarged second annule, a slightly expanded distal portion of the corpus surrounding the buccal cavity, and operculate eggs (Jex *et al.*, 2005). However, the eggs are larger (84–100 μm) and there are two polar opercula in *B. sphaerolaima*, and the female has lateral alae. Tail length (800 – 1140 μm) is also considerably larger than in *B. peregrinata* **n. sp.**

The most recently described species, *B. praelongicauda* Jex, Schneider, Rose, & Cribb, 2006, another species with operculate eggs, has a much longer tail (seen by actual length 800–820 µm and De Man ratio c 2.3–2.4) and has a corpus whose base is more rounded than that of *B. peregrinata* **n. sp.**

Severianoia annamensis Van Luc and Spiridonov, 1993
(Table 3)

Several specimens of *P. surinamensis* collected in southern Florida were infected with *S. annamensis* (Table 3).

Taxonomic Summary

Host: *Pycnoscelus surinamensis* (Linnaeus, 1758)

Locality: John Pennecamp Coral Reef State Park, Key Largo, Florida (25˚7'38.3"N, 80˚24'31.2"W).

Prevalence = 15%; mean intensity = 2.8

Site of infection: hindgut

Specimens deposited: Vouchers HWML 99923 1 male, 1 female; HWML 99924, three females, John Pennecamp Coral Reef State Park, Key Largo, Florida.

Voucher DNA sequence: 18S small subunit ribosomal RNA gene, partial sequence Genbank accession number KX752431.

TABLE 3. Morphometric measurements (in micrometers) for *Severianoia annamensis* Van Luc and Spiridonov, 1993. The mean and standard deviation are followed by range.

Character	Females (n = 6)	Males (n = 5)
Body length	3302 ± 383 (2750–3875)	735 ± 100 (600–840)
Maximum width	272 ± 21 (250–305)	94 ± 17 (75–110)
Buccal cavity (length)	15 ± 3 (13–21)	6 ± 1 (5–8)
Oral annule length	6 ± 2 (5–9)	-
Oral annule width	24 ± 2 (21–26)	-
Second annule length	17 ± 2 (15–18)	-
Second annule width	48 ± 2 (47–51)	-
Nerve ring	173 ± 12 (162–190)	101 ± 2 (100–103)
Excretory pore	Not observed	300
Esophagus	450 ± 29 (415–503)	160 ± 19 (139–182)
Corpus length	306 ± 17 (288–338)	92 ± 13 (79–109)
Corpus maximum width	56 ± 3 (53–60)	17 ± 2 (14–19)
Isthmus length	25 ± 5 (18–30)	25 ± 2 (23–28)
Bulb length	117 ± 8 (110–130)	45 ± 6 (38–50)
Bulb width	123 ± 7 (113–132)	36 ± 4 (30–41)
Vulva from anterior end	2265 ± 50 (2230–2300)	-
Vulva from posterior end	1191 ± 543 (808–1575)	-
Vagina length	115	-
Tail length	152 ± 8 (141–159)	50 ± 1 (48–51)
Egg length	80 ± 4 (74–83)	-
Egg width	30 ± 2 (27–31)	-
a	12 ± 2 (10–15)	8 (7–8)
b	7 ± 1 (6–9)	5 ± 1 (4–6)
c	23 ± 3 (19–28)	15 ± 2 (12–17)
V	66 ± 10 (59–73)	-
Spicule length	-	28 ± 4 (23–33)

General observations of *S. annamensis* from Florida. Although esophageal proportions are slightly larger (with overlap) in the Florida specimens (415–503 µm in Florida specimens vs. 320–460 µm in original description), other measurements overlapped more broadly with those provided for *S. annamensis*, and the specimens were determined to be morphologically indistinguishable. The type species, *Severianoia severianoi* (Schwenck, 1926) Travassos, 1929 has much larger esophageal length (525–706 µm in original description by Schwenck and redescription by Kloss, 1966). Female body length (3000–4366 µm) is also greater in *S. severianoi*. A report of a single female originally identified by Chitwood (1932) as *S. severianoi* from *P. surinamensis* in southern Florida (Paradise Key, Everglades National Park) included measurements that are more consistent with *S. annamensis* (Van Luc & Spiridonov, 1993). The tail length of Chitwood's female (110 µm) fell well out of the range of the Key Largo specimens (141–159 µm). However, tail length in the original description of *S. severianoi* (100–200 µm) overlaps with both species (Schwenck, 1926; Van Luc and Spiridonov, 1993), and re-measurement of Chitwood's specimen (US National Parasite Collection code USNPC 31893) yielded a tail length of 147 µm. The *Severianoia* sp. documented from the Galápagos Islands also yielded overlapping measurements of both males and females of *S. annamensis* and more closely resembles *S. annamensis* than *S. severianoi* (Sinnott *et al.*, 2015).

Discussion

The discovery of *Hammerschmidtiella keeneyi* **n. sp.** in a laboratory colony of *D. punctata* raises the question of the origin of this species. One hypothesis, namely that of the existence of *H. keeneyi* **n. sp.** originating in wild populations of *D. punctata* and subsequently cycling in lab-reared colonies of the host must be explored with collection of wild hosts. This appears to be the case for another thelastomatid, *Leidynema portentosae* Van Waerebeke, 1978, which was described from wild populations of the host, *G. portentosa* but which is also widespread in laboratory, zoo, and pet populations of this host, commonly known as the Madagascar hissing cockroach (van Waerebeke, 1978; Reif et al, 2005). *Diploptera punctata* is found in Hawaii and other areas of the South Pacific, southeast Asia, and southeast China, and it has been used in endocrinology studies due to its unique status as a viviparous species (Li & Wang, 2015). We did not recover *H. keeneyi* **n. sp.** in other laboratory blattarians where the colony of *D. punctata* is kept. Although the distribution of pinworms in wild blattarians is poorly documented relative to that of common laboratory cockroaches such as *Periplaneta americana* (Linnaeus, 1758), there is a need for careful examination of other laboratory hosts. Species such as *Thelastoma periplaneticola* Leibersperger, 1960 (*P. americana*), *Thelastoma blabericola* Leibersperger, 1960 (*Blaberus cranifer* Burmeister, 1838 and *Blaptica dubia* Serville, 1838) and *Severianoia blapticola* Guzeeva, 2009 (*Blaptica dubia*) have been described from laboratory hosts. It is possible that additional species of thelastomatoids await discovery from laboratory cockroach colonies.

The majority of wild species of *Blattaria* have not been sampled and many species undoubtedly await discovery. In some cases, multispecies infections are seen in single host species (e.g. Carreno & Tuhela, 2011; Jex *et al.*, 2007). In others, there are patterns of single species infections that may reflect host specificity or interspecies competition (e.g. Dale, 1966). A strong pattern of single species infections was observed in pinworms from the Galápagos Islands, one in which no two species of pinworms occurred in a single host despite infection of single host species with different species of pinworms (Sinnott *et al.*, 2015). The sample of *P. surinamensis* collected in Florida is too small to permit us to draw meaningful conclusions. However, no specimens hosting *S. annamensis* also hosted *B. peregrinata* **n. sp.** Similarly, the Ohio greenhouse population of *P. australasiae* and *P. surinamensis* did not host other thelastomatoid nematodes. Together, these preliminary patterns are indicative of a possible competitive advantage of *B. peregrinata* **n. sp.** over other thelastomatoid nematodes in the hosts from which it has been documented, resulting in exclusion of other species in the hindgut.

Females of a *Blattophila* sp. and males and females of a species originally identified as *Severianoia* sp. were recovered from *P. surinamensis* in the Galápagos Islands (Sinnott *et al.*, 2015). The measurements provided in that study were from a small sample size from specimens which had been preserved in situ in ethanol. However, the morphology of the *Blattophila* sp. is consistent with that of *B. peregrinata* **n. sp.** Measurements are, overall, smaller for the Galápagos specimens, especially in esophageal proportions (female esophagus length 218–296 µm vs. 265–343 µm in *B. peregrinata* **n. sp.**; corpus length 145–203 µm vs. 170–231 µm in *B. peregrinata* **n. sp.**; bulb length 50–70 µm vs. 63–88 µm in *B. peregrinata* **n. sp.**). However, we consider the Galápagos specimens to be *B.*

peregrinata **n. sp.** The *Severianoia* sp. from the Galápagos Islands which was originally determined to be *S. severianoi* is actually more consistent in measurements with *S. annamensis*. Thus, we identify three greatly separated geographic localities for both of these pinworms from *P. surinamensis*.

The finding of *B. peregrinata* **n. sp.** and *S. annamensis* in three different localities (Florida, Ohio, Ecuador for the former; Viet Nam, Florida, and Ecuador for the latter) indicates that they have a broad distribution that, subject to sampling in other regions, may approach a cosmopolitan range similar to those of *H. diesingi* and *Leidynema appendiculata* (Leidy, 1850) Chitwood, 1932. The latter are widespread in *P. americana* and other blattarian hosts. Other species recently discovered far from their type localities, such as *Cephalobellus ovumglutinosus* Van Waerebeke, 1978 (first described in Madagascar and recently recovered from various blattarian hosts in the Galápagos islands—see Sinnott *et al.*, 2015), are indicative of a broad global distribution for these species.

The finding of *C. ovumglutinosus* in multiple blattarian hosts may indicate that low host specificity has allowed for a widespread distribution of the parasite. Host biology may also enhance spread of both organisms. *Pycnoscelus surinamensis* is the most widely distributed species of the genus and has been widely introduced into the New World (Roth, 1998). This species, because of its parthenogenetic, thelytokous capability, can be spread and established by a single nymph or female in tropical or subtropical regions (Roth, 1998). *Pycnoscelus surinamensis*, like many others, has spread around the world through human activities. Little is known of the global distribution of most thelastomatoid nematodes, and more sampling around the world will provide additional opportunities to uncover interesting biogeographical patterns for these parasites that include varying degrees of host specificity, interspecific competition, host colonization capabilities, and other factors.

Acknowledgements

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