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COCCIDIAN PARASITES (APICOMPLEXA: EIMERIIDAE) FROM INSECTIVORES. III. SEVEN NEW SPECIES IN SHREWS (SORICIDAE: SORICINAE) FROM CANADA, JAPAN, AND THE UNITED STATES

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ABSTRACT: Since May 1979, 458 shrews (*Blarina* sp. and *Sorex* spp.) representing 20 species collected in Canada, Japan, and the United States were examined for coccidia; 110 (24%) had oocysts in their feces, including 8 of 21 (38%) *B. brevicauda* from Massachusetts, Ohio, Pennsylvania, and Vermont; 2 of 7 (29%) *S. caecutiens* from Hokkaido and Honshu; 14 of 63 (22%) *S. cinereus* from Colorado, New Mexico, Pennsylvania, Vermont, Manitoba, and Ontario; 3 of 7 (43%) *S. fontinalis* from Pennsylvania; 11 of 16 (69%) *S. fumeus* from Massachusetts, Minnesota, Pennsylvania, Vermont, and Ontario; 1 of 4 (25%) *S. haydeni* from Minnesota; 6 of 8 (75%) *S. longirostris* from Florida and Virginia; 1 of 2 (50%) *S. ornatus* from California; 5 of 12 (42%) *S. pacificus* from California and Oregon; 13 of 41 (32%) *S. palustris* from California, Colorado, and New Mexico; 1 of 2 (50%) *S. tenellus* from California; 11 of 105 (10%) *S. trowbridgii* from California, Oregon, and Washington; 10 of 48 (21%) *S. unguiculatus* from Hokkaido; and 24 of 112 (21%) *S. vagrans* from Arizona, California, Colorado, New Mexico, Oregon, and Washington. The following coccidians were identified from infected shrews: *Eimeria brevicauda* n. sp. from *B. brevicauda*; *Eimeria fumeus* n. sp. from *S. fumeus*, *S. pacificus*, *S. unguiculatus*, and *S. vagrans*; *Eimeria inyoni* n. sp. from *S. tenellus*; *Eimeria palustris* n. sp. from *S. cinereus*, *S. fontinalis*, *S. fumeus*, *S. haydeni*, *S. longirostris*, *S. ornatus*, *S. pacificus*, *S. palustris*, *S. tenellus*, *S. trowbridgii*, and *S. vagrans*; *Eimeria vagrantis* n. sp. from *S. fumeus*, *S. trowbridgii*, and *S. vagrans*; *Isospora brevicauda* n. sp. from *B. brevicauda*; and *Isospora palustris* n. sp. from *S. pacificus*, *S. palustris*, *S. trowbridgii*, *S. unguiculatus*, and *S. vagrans*. The world literature on coccidian parasites of shrews (16 eimerians and 3 isosporans exclusive of the 7 new species described here) is reviewed.

The mammalian order Insectivora is a zoological catchall into which a number of ancient and seemingly distantly related taxa have been placed. However, the family Soricidae (shrews), the largest of the insectivore lines, is a rather homogeneous assemblage of small mammals which, although virtually unknown to nonscientists, is important to human agriculture in the control of insect, slug, and snail pests. At the University of New Mexico we have been collecting shrews and moles since 1979 and gathering skeletal, electrophoretic, karyotypic, and parasitic data to help understand the evolutionary relationship and zoogeographic distribution of these poorly studied groups. Here we review the literature on coccidians from members of the family Soricidae and report 7 new species found in *Blarina* sp. and *Sorex* spp. collected from Canada, Japan, and the United States.

MATERIALS AND METHODS

Fecal samples were collected from hosts live-trapped in the field using standard pitfall traps. The samples from Canada and the United States were stored in 2% (w/v) potassium dichromate ($K_2Cr_2O_7$) as previously

described (Duszynski et al., 1982), but the Japan samples were stored in 2% aqueous (v/v) H_2SO_4 . Methods for storing and processing fecal samples and for concentrating, measuring, and photographing oocysts have been described in detail (Duszynski et al., 1982; Stout and Duszynski, 1983). The type locality is that from which infected type hosts were collected. All measurements are in micrometers with size ranges in parentheses following the means.

RESULTS

The coccidians, the hosts they infected, and collection localities are presented in Table I.

COCCIDIANS

Eimeria brevicauda n. sp. (Figs. 1–3, 17)

Description

Oocyst usually spheroid to slightly subspheroid (Fig. 1), wall ≤ 1.5 , composed of 2 layers: inner layer membranous, colorless; outer layer sculptured (Fig. 3), colorless to pale yellow, $\sim 2/3$ of total thickness; micropyle and oocyst residuum absent; polar body sometimes present, but usually as 2–4 fragments of irregular size and shape; sporulated oocysts ($n = 50$) 20.3×19.7 ($18\text{--}23 \times 17\text{--}23$) with L:W ratio 1.03 (1.00–1.10); sporocysts ($n = 50$) ovoid, 11.3×7.6 ($10\text{--}14 \times 7\text{--}8$) with L:W ratio 1.50 (1.27–1.60); Stieda and substieda bodies present, with substieda body about same width as Stieda body or wider (Fig. 2); parastieda body absent; sporocyst residuum occasionally composed of a large

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TABLE I. *Eimeria* spp. and *Isospora* spp. recovered from *Blarina* sp. and *Sorex* spp. collected in the United States, Canada, and Japan.

Host spp.	Country: County, state, or island	No. hosts infected/no. examined (%)	Coccidia spp.
<i>B. brevicauda</i>	USA: Franklin Co., MA Ashtabula Co., OH Warren Co., PA Lamoille Co., VT	1/6 (17) 5/8 (63) 1/3 (33) 1/4 (25)	<i>E. brevicauda</i> <i>E. brevicauda</i> , <i>I. brevicauda</i> <i>E. brevicauda</i> <i>E. brevicauda</i>
<i>S. arcticus</i>	Canada: Reynolds Dist., Man.	0/2	—
<i>S. bendirii</i>	USA: Humbolt Co., CA	0/1	—
<i>S. caecutiens</i>	Japan: Hokkaido Honshu	0/2 2/5 (40)	— sp.*
<i>S. cinereus</i>	USA: Boulder Co., CO Mora Co., NM Santa Fe Co., NM Taos Co., NM Westmoreland Co., PA Lamoille Co., VT Canada: Piney Dist., Man. Reynolds Dist., Man. Hastings Co., Ont.	1/17 (6) 1/2 0/6 0/6 6/12 (50) 0/6 0/1 5/11 (45) 1/2	<i>E. palustris</i> <i>E. palustris</i> — — <i>E. palustris</i> , sp.* — — <i>E. palustris</i> , sp.* <i>E. palustris</i> , sp.*
<i>S. fontinalis</i>	USA: Cumberland Co., PA	3/7 (43)	<i>E. palustris</i> , sp.*
<i>S. fumeus</i>	USA: Franklin Co., MA Clay Co., MN Warren Co., PA Westmoreland Co., PA Lamoille Co., VT Canada: Hastings Co., Ont.	1/3 (33) 1/1 0/1 6/7 (86) 3/3 0/1	<i>E. fumeus</i> , <i>E. palustris</i> <i>E. palustris</i> — <i>E. palustris</i> , sp.* <i>E. fumeus</i> , <i>E. palustris</i> , <i>E. vagrantis</i> —
<i>S. haydeni</i>	USA: Clay Co., MN	1/4 (25)	<i>E. palustris</i>
<i>S. hosonoi</i>	Japan: Honshu	0/1	—
<i>S. hoyi</i>	USA: Cass Co., MN Canada: Piney Dist., Man.	0/2 0/1	— —
<i>S. longirostris</i>	USA: Leon Co., FL Suffolk Co., VA	3/3 3/5 (60)	<i>E. palustris</i> , sp.* <i>E. palustris</i>
<i>S. nanus</i>	USA: Santa Fe Co., NM	0/1	—
<i>S. ornatus</i>	USA: San Bernardino Co., CA	1/2	<i>E. palustris</i>
<i>S. pacificus</i>	USA: Humbolt Co., CA Benton Co., OR	4/11 (36) 1/1	<i>E. palustris</i> , <i>I. palustris</i> , spp.* <i>E. fumeus</i>
<i>S. palustris</i>	USA: Mono Co., CA Boulder Co., CO Mora Co., NM Sandoval Co., NM Santa Fe Co., NM Taos Co., NM	1/1 2/9 (22) 3/7 (43) 0/6 3/4 (75) 4/14 (29)	<i>E. palustris</i> <i>E. palustris</i> , sp.* <i>E. palustris</i> , spp.* — <i>E. palustris</i> , <i>I. palustris</i> <i>E. palustris</i> , sp.*
<i>S. preblei</i>	USA: Harney Co., OR	0/2	—
<i>S. tenellus</i>	USA: Mono Co., CA	1/2	<i>E. inyoni</i> , <i>E. palustris</i>

TABLE I. *Continued.*

Host spp.	Country: County, state, or island	No. hosts infected/no. examined (%)	Coccidia spp.
<i>S. trowbridgii</i>	USA:		
	Humbolt Co., CA	2/20 (10)	<i>E. palustris</i> , sp.*
	Benton Co., OR	5/46 (11)	<i>E. palustris</i> , <i>E. vagrantis</i> , <i>I. palustris</i> , sp.*
	Clallam Co., WA	2/13 (15)	<i>E. palustris</i> , sp.*
	Pierce Co., WA	2/26 (8)	<i>I. palustris</i>
<i>S. unguiculatus</i>	Japan:		
	Hokkaido	10/48 (21)	<i>E. fumeus</i> , <i>I. palustris</i> , sp.*
<i>S. vagrans</i>	USA:		
	Apache Co., AZ	2/11 (18)	<i>E. vagrantis</i> , <i>E. palustris</i>
	Cochise Co., AZ	1/17 (6)	sp.*
	Mono Co., CA	3/3	<i>E. palustris</i>
	Humbolt Co., CA	1/4 (25)	<i>E. palustris</i>
	Boulder Co., CO	0/2	—
	Catron Co., NM	1/12 (8)	<i>E. palustris</i>
	Mora Co., NM	1/1	<i>E. palustris</i>
	Otero Co., NM	2/16 (13)	<i>E. vagrantis</i> , sp.*
	Sandoval Co., NM	10/25 (40)	<i>E. palustris</i> , <i>E. vagrantis</i> , <i>I. palustris</i> , sp.*
	Santa Fe Co., NM	0/1	—
	Taos Co., NM	0/11	—
	Torrance Co., NM	2/4	<i>E. fumeus</i> , <i>E. palustris</i>
	Harney Co., OR	0/1	—
	Clallam Co., WA	0/1	—
	Kittitas Co., WA	0/1	—
	Pierce Co., WA	1/2	<i>E. vagrantis</i>
Totals: 20	33	110/458 (24)	7

* Unsporulated oocysts of 1 (sp.) or more (spp.) morphs; unable to identify.

homogeneous body (~4–5), but more often of scattered homogeneous globules (Fig. 17). Oocysts were 1,568 days old when measured.

Taxonomic summary

Diagnosis: Only *Eimeria blarinae* Todd, French, and Levine, 1986, from *B. brevicauda* in Illinois has been described from all *Blarina* spp. to date; although similar in size, it differs from *E. brevicauda* by having an oocyst residuum and lacking a substieda body. There are 35 *Eimeria* spp. described from other insectivore genera (Ahluwalia et al., 1979; Levine and Ivens, 1979; Sinha and Sinha, 1980; Dzerskinskii, 1982; Duszynski, 1985; Duszynski and Moore, 1986), but oocysts of *E. brevicauda* do not closely resemble any of them.

Type host: *Blarina brevicauda* (Say, 1823), short-tailed shrew, Museum of Southwestern Biology, Division of Mammalogy, NK 3110 (female), D. W. Moore #744, 27 June 1980, MSB 43414.

Type locality: USA. Ohio: Ashtabula Co.; 4 km W, 27.4 km S Ashtabula.

Prevalence: Found in 8 of 21 (38%) *B. brevicauda* collected in 4 states (Table I).

Site of infection: Unknown, oocysts recovered from feces.

Etymology: The nomen triviale is derived from the specific part of the scientific name of the host.

Eimeria fumeus n. sp.

(Figs. 4, 5, 16)

Description

Oocyst ellipsoid, with wall ~1.0, composed of 2 layers: outer layer rough, yellow, ~2/3 of total thickness; usually 1 polar body, but occasionally up to 4 fragments; micropyle and oocyst residuum absent; sporulated oocysts (n = 100) 27.6 × 22.4 (25–32 × 20–25) with L:W ratio 1.24 (1.09–1.49); sporocysts (n = 100) ovoid, 15.1 × 8.8 (13–17 × 8–12) with L:W ratio 1.73 (1.34–2.26); Stieda, sub- and parastieda bodies present (Figs. 4, 5), with substieda body about same width as

FIGURES 1–10. Photomicrographs of sporulated oocysts of coccidia recovered from the feces of shrews. ×1,911. NI—Nomarski interference. 1–3. *Eimeria brevicauda* n. sp. 1. Sporulated oocyst in optical cross section. 2. Sporocyst liberated from broken oocyst; note substieda body (arrow). 3 (NI). Sculptured nature of outer oocyst wall. 4, 5 (NI). *Eimeria fumeus* n. sp. showing small substieda body (4, arrow), parastieda body (5, arrow), and large sporocyst residuum (5, *). 6. *Eimeria inyoni* n. sp.; NI, note highly refractile polar body (horizontal arrow) and substieda body (vertical arrow). 7, 8 (NI). *Eimeria palustris* n. sp. 9, 10. *Eimeria vagrantis* n. sp.; note large substieda body (9, *).

Stieda body; sporocyst residuum a single large globule (Fig. 5), ~4.0, or composed of several globules. Oocysts were 725–1,171 days old when measured.

Taxonomic summary

Diagnosis: Oocysts of this eimerian do not resemble those from any species previously described from insectivores.

Type host: *Sorex fumeus* Miller, 1895, smokey shrew, Museum of Southwestern Biology, Division of Mammalogy, NK 3032 (sex undetermined), R. M. Sullivan #484, 14 June 1980, MSB 43318; NK 3041 (male), J. A. Cook #361, 15 June 1980, MSB 43319; NK 3042 (male), J. A. Cook #362, 15 June 1980, MSB 43320.

Type locality: USA. Vermont: Lamoille Co.; 6.4 km E, 3.2 km S Morrisville.

Other hosts and localities: See Table I.

Prevalence: Found in 4 of 16 (25%) *S. fumeus*, 1 of 12 (8%) *S. pacificus*, 2 of 48 (4%) *S. unguiculatus*, and 1 of 112 (<1%) *S. vagrans*.

Site of infection: Unknown, oocysts recovered from feces.

Etymology: The nomen triviale is derived from the specific part of the scientific name of the host in which this species was most prevalent.

Eimeria inyoni n. sp.

(Figs. 6, 14)

Description

Oocyst subspheroid, with thin, smooth wall ≤ 1.0 , composed of only 1 obvious layer; usually 1–2 polar bodies, but sometimes up to 7 highly refractile fragments (Fig. 6); oocyst residuum and micropyle absent; sporulated oocysts ($n = 100$) 21.6×19.3 ($19\text{--}24 \times 17\text{--}23$) with L:W ratio 1.12 (1.00–1.31); sporocysts ($n = 100$) ovoid 11.9×7.4 ($10\text{--}14 \times 6\text{--}9$) with L:W ratio 1.60 (1.30–1.86); Stieda and substieda bodies present (Fig. 6), with substieda body slightly wider than Stieda body; parastieda body absent; sporocyst residuum of dispersed granules; sporozoites with 1 obvious refractile body. Oocysts were 359 days old when measured.

Taxonomic summary

Diagnosis: This species most closely resembles *Eimeria suncus* Ahluwalia, Singh, Arora, Mandel, and Sarkar, 1979, from the common house shrew (*Suncus murinus*) from India, but differs by having larger oocysts (22×19 vs. 20×15) and by the presence of a substieda body, which *E. suncus* lacks.

Type host: *Sorex tenellus* Merriam, 1895, Inyo shrew, Museum of Southwestern Biology, Division of Mammalogy, NK 7991 (female), S. B. George #1059, 13 August 1983, MSB 53229.

Type locality: USA. California: Mono Co.; 22.5 km N, 4 km W Bridgeport.

Prevalence: Found in 1 of 2 (50%) *S. tenellus* from California.

Site of infection: Unknown, oocysts recovered from feces.

Etymology: The nomen triviale is derived from the common name of the host in which this species was found.

Eimeria palustris n. sp.

(Figs. 7, 8, 18)

Description

Oocyst usually spheroid to slightly subspheroid (Figs. 7, 8), with yellow, slightly sculptured wall that gives a striated appearance in optical cross section (Fig. 7), ≤ 1.0 , composed of only 1 obvious layer; 1–2 polar bodies present; oocyst residuum and micropyle absent; sporulated oocysts ($n = 306$) 17.1×16.6 ($12\text{--}22 \times 12\text{--}21$) with L:W ratio 1.03 (1.00–1.28); sporocysts ($n = 306$) ovoid, 10.8×6.5 ($6\text{--}14 \times 4\text{--}8$) with L:W ratio 1.66 (1.00–2.58); Stieda body present; sub- and parastieda bodies absent; sporocyst residuum composed of several dispersed granules; sporozoites contain 1 or 2 refractile bodies. Oocysts were 360–1,433 days old when measured.

Taxonomic summary

Diagnosis: Sporulated oocysts of *E. palustris* somewhat resemble those of *Eimeria bentongi* Colley and Mullin, 1971, from the lesser gymnure (*Hylomys suillus*) from Malaya (SE Asia), *Eimeria madagascariensis* Uilenberg, 1967, from the large Madagascar hedgehog (*Setifer setosus*), *Eimeria scapani* Henry, 1932, from the western American mole (*Scapanus latimanus*) from California, and *Eimeria suncus* Ahluwalia et al., 1979, from the common house shrew (*Suncus murinus*) in India. Six of the 11 *Sorex* spp. that harbored *E. palustris* share some of their host range with *S. latimanus* and at first we thought we might be seeing *E. scapani*. However Henry's photomicrograph of *E. scapani* clearly shows a thin, smooth oocyst wall that *E. palustris* lacks (see Figs. 7, 8). Another difference is that *E. palustris* is usually spheroid to slightly subspheroid (L:W = 1.03), whereas *E. scapani* is subspheroid to ellipsoid (L:W = 1.20). More subtle differences include the shape and size of their polar bodies and sporocyst residua, but these are structures that may change their appearance over time and thus may be less reliable in distinguishing oocysts of different species. Oocysts of *E. palustris* also resemble 3 species described from distant parts of the world. Although the structural distinctions between them are often subtle, we think it prudent to call our form a new species because the great geographic distance, different host species, and lack of overlap of host ranges make it unlikely these parasites belong to a single species complex. The oocysts we saw differ from those of *E. bentongi* by having a thinner oocyst wall (≤ 1.0 vs. 1.5) that is spheroid and sculptured (vs. ellipsoid and smooth), by the type of sporocyst residuum (a few scattered granules vs. compact mass), and by having sporozoites with 1–2 refractile bodies (vs. "comma-shaped, without clear globules"). They differ from oocysts of *E. madagascariensis* by having a rough outer oocyst wall, structure of the sporocyst residuum (few granules vs. many irregular granules), and by having sporozoites with refractile bodies that *E. madagascariensis* apparently lacks. Finally, they differ from *E. suncus* by having a single-layered, rough oocyst wall (vs. bilayered, smooth), in shape index (1.03 vs. 1.28), by lacking a micropyle cap, and by the presence of polar bodies.

Type host: *Sorex palustris* Richardson, 1828, northern water shrew, Museum of Southwestern Biology,

FIGURES 11–13. Photomicrographs of sporulated oocysts of coccidia recovered from the feces of shrews. $\times 1,911$. NI—Nomarski interference. 11, 12 (NI). *Isospora brevicauda* n. sp.; note substieda body (12, arrow). 13. *Isospora palustris* n. sp.; compare substieda body (arrow) with that of *I. brevicauda*.

Division of Mammalogy, NK 1027 (female), J. M. Evans #010, 8 July 1979, MSB 41120; NK 1002 (male), R. A. Hoyt #098, 6 July 1979, MSB 41122.

Type locality: USA. New Mexico: Santa Fe Co.; 8 km N, 12.9 km E Santa Fe.

Other hosts and localities: See Table I.

Prevalence: Found in 12 of 63 (19%) *S. cinereus*, 2 of 7 (29%) *S. fontinalis*, 5 of 16 (31%) *S. fumeus*, 1 of 4 (25%) *S. haydeni*, 5 of 8 (63%) *S. longirostris*, 1 of 2 (50%) *S. ornatus*, 1 of 12 (8%) *S. pacificus*, 8 of 41 (20%) *S. palustris*, 1 of 2 (50%) *S. tenellus*, 4 of 105 (4%) *S. trowbridgii*, and 14 of 112 (12.5%) *S. vagrans*.

Site of infection: Unknown, oocysts recovered from feces.

Etymology: The nomen triviale is derived from the specific part of the scientific name of the host in which the species was first seen.

Eimeria vagrantis n. sp.

(Figs. 9, 10, 15)

Description

Oocyst ellipsoid, with wall ~ 1.0 , composed of 2 layers: outer layer golden-yellow, rough, $\sim \frac{1}{4}$ of total thickness; 5–10 dispersed granules present in oocyst (oocyst residuum or polar fragments?); micropyle absent; sporulated oocysts ($n = 100$) 26.6×21.8 ($24\text{--}32 \times 20\text{--}25$) with L:W ratio 1.22 (1.07–1.52); sporocysts ($n = 100$) ovoid, 15.9×9.0 ($13\text{--}17 \times 7\text{--}10$) with L:W ratio 1.78 (1.54–2.22); Stieda and substieda bodies present (Figs. 9, 10), with substieda body about $2 \times$ wider than Stieda body; parastieda body absent; sporocyst residuum a cluster of 10–15 globules; sporozoites with single posterior refractile body. Oocysts were 932–1,354 days old when measured.

Taxonomic summary

Diagnosis: In size, this species resembles *Eimeria dissimilis* Yakimoff and Gousseff, 1935, from the Russian shrew (*S. araneus*), *Eimeria setosi* Uilenberg, 1967, from the large Madagascar hedgehog (*Setifer setosus*), and *E. fumeus* described above. It differs from *E. dissimilis* in oocyst L:W ratio (1.22 vs. 1.47), and by

having a coarse, granular sporocyst residuum, and Stieda and substieda bodies that *E. dissimilis* apparently lacks. It differs from *E. setosi* in oocyst wall thickness (≤ 1.0 vs. 2), the presence of a substieda body, and by having sporozoites with obvious refractile bodies. It differs from *E. fumeus* by lacking a parastieda body and by the size and shape of the substieda body (cf. Figs. 4, 5 and 9, 10).

Type host: *Sorex vagrans* Baird, 1858, vagrant shrew, Museum of Southwestern Biology, Division of Mammalogy, NK 1589 (female), D. J. Hafner #1671, 17 August 1979, MSB 40945.

Type locality: USA. New Mexico: Otero Co.; 8.8 km NE Cloudcroft.

Other hosts and localities: See Table I.

Prevalence: Found in 5 of 112 (4%) *S. vagrans*, 1 of 16 (6%) *S. fumeus*, and 1 of 105 ($\leq 1\%$) *S. trowbridgii*.

Site of infection: Unknown, oocysts recovered from feces.

Etymology: The nomen triviale is derived from the specific part of the scientific name of the host in which this species was first seen.

Isospora brevicauda n. sp.

(Figs. 11, 12, 19)

Description

Oocyst spheroid (Fig. 11) to slightly subspheroid (Fig. 12), wall ≤ 1.0 , probably composed of 2 layers of equal thickness: outermost layer generally with a few small bumps irregularly spaced, and with a striated appearance in optical cross section (Figs. 11, 12); micropyle and oocyst residuum absent; usually 4–6 polar body fragments of irregular shape; sporulated oocysts ($n = 50$) 16.5×16.2 ($15\text{--}18 \times 15\text{--}18$) with L:W ratio 1.02 (1.00–1.05); sporocysts ($n = 50$) ovoid, 11.6×7.6 ($10\text{--}12 \times 7\text{--}8$) with L:W ratio 1.52 (1.36–1.71); Stieda and substieda bodies present (Figs. 11, 12), with substieda body about $2 \times$ wider than Stieda body; parastieda body absent; sporocyst residuum of many lipid-like globules that obscure sporozoites (Figs. 11, 12). Oocysts were 1,568 days old when measured.

FIGURES 14-20. Line drawings of sporulated oocysts of coccidia recovered from the feces of shrews; bar = 10 μ m. 14. *Eimeria inyoni*. 15. *Eimeria vagrantis*. 16. *Eimeria fumeus*. 17. *Eimeria brevicauda*. 18. *Eimeria palustris*. 19. *Isospora brevicauda*. 20. *Isospora palustris*.

Taxonomic summary

Diagnosis: Thirteen isosporans have been described from all insectivores (Levine and Ivens, 1979; Duszyński, 1985; Duszyński and Moore, 1986) although none, as yet, have been found in *Blarina* spp. Oocysts and sporocysts of this species are similar in size to those of *Isoospora araneae* Golemansky, 1978, but differ by the striated nature of the oocyst wall and the presence of Stieda and substieda bodies (Figs. 12, 13) that *I. araneae* lacks. Other isosporans previously described from insectivores do not closely resemble *I. brevicauda*.

Type host: *Blarina brevicauda* (Say, 1823), short-tailed shrew, Museum of Southwestern Biology, Division of Mammalogy, NK 3122 (female), K. McBee #121, 29 June 1980, MSB 43415.

Type locality: USA. Ohio: Ashtabula Co.; 4 km W, 2.7 km S Ashtabula.

Prevalence: Found in 2 of 21 (10%) *B. brevicauda*.

Site of infection: Unknown, oocysts recovered from feces.

Etymology: The nomen triviale is derived from the specific part of the scientific name of the host in which we first saw it.

Isoospora palustris n. sp. (Figs. 13, 20)

Description

Oocyst subspheroid (Fig. 13), wall ≤ 1.0 , probably composed of 2 layers of equal thickness: outermost layer generally with a few small bumps irregularly spaced, and with a striated appearance in optical cross section (Fig. 20); micropyle and oocyst residuum absent; usually 1 polar body, but sometimes (30%) as 2–4 fragments of irregular size and shape; sporulated oocysts ($n = 100$) 17.6×16.7 ($16\text{--}19 \times 16\text{--}18$) with L:W ratio 1.06 (1.00–1.19); sporocysts ($n = 100$) ovoid, 12.8×8.3 ($12\text{--}14 \times 8\text{--}10$) with L:W ratio 1.56 (1.25–1.81); Stieda and substieda bodies present (Fig. 13), with spheroid substieda body same width as Stieda body; parastieda body absent; sporocyst residuum of many small granules (Fig. 20). Oocysts were 360–1,433 days old when measured.

Taxonomic summary

Diagnosis: Oocysts and sporocysts of this species are very similar to those of *I. brevicauda* (above) and, therefore, they are also similar to those of *I. araneae*. They differ from *I. araneae* in the same ways as did *I. brevicauda*. They differ from *I. brevicauda* in 2 ways: (1) oocyst length, oocyst width, sporocyst length, sporocyst width, and oocyst L:W ratio of *I. brevicauda* from *Blarina* sp. were highly significantly smaller ($P < 0.0001$, Student's *t*-distribution) than those of *I. palustris* from *Sorex* spp., even though the respective means and ranges appear similar, superficially; and (2) the width of the substieda body is about the same as that of the Stieda body in *I. palustris*, whereas it is about $2 \times$ wider than the Stieda body in *I. brevicauda* (cf. Figs. 12, 13); the shape of the substieda body is also different between the 2 species.

Type host: *Sorex palustris* Richardson, 1828, northern water shrew, Museum of Southwestern Biology, Division of Mammalogy, NK 1002 (male), R. A. Hoyt #098, 6 July 1979, MSB 41122; NK 1027 (female), J.

M. Evans #010, 8 July 1979, MSB 41120; NK 1028 (sex undetermined), J. M. Evans #000, 8 July 1979, specimen not deposited in MSB.

Type locality: USA. New Mexico: Santa Fe Co.; 8 km N, 12.9 km E Santa Fe.

Other hosts and localities: See Table 1.

Prevalence: Found in 1 of 12 (8%) *S. pacificus*, 3 of 41 (7%) *S. palustris*, 3 of 105 (3%) *S. townsendii*, 1 of 48 (2%) *S. unguiculatus*, and 1 of 112 (<1%) *S. vagrans*.

Site of infection: Unknown, oocysts recovered from feces.

Etymology: The nomen triviale is derived from the specific part of the scientific name of the host in which the oocysts were the most abundant.

HOSTS

Of those hosts with coccidia at the time they were collected, the following parasites or groups of parasites were seen.

Blarina brevicauda (Say, 1823). Six of 8 (75%) infected short-tailed shrews were singly infected with *E. brevicauda*; the other 2 were infected with both *E. brevicauda* and *I. brevicauda*.

Sorex caecutiens Laxmann, 1788. Both infected shrews contained a single morph of oocysts that failed to sporulate.

Sorex cinereus Kerr, 1792. Eleven of 14 (79%) infected masked shrews were singly infected with *E. palustris* (9) or a nonsporulated form (2); 3 shrews were doubly infected with *E. palustris* and a nonsporulated species.

Sorex fontinalis Hollister, 1911. Two of 3 (67%) infected Maryland shrews were singly infected with *E. palustris* and 1 shrew was infected with a nonsporulated species.

Sorex fumeus Miller, 1895. Eight of 11 (73%) infected smokey shrews were singly infected with *E. fumeus* (1), *E. palustris* (2), or a nonsporulated species (5); 2 shrews were doubly infected with *E. fumeus* and *E. palustris*; and 1 shrew was triply infected with *E. fumeus*, *E. palustris*, and *E. vagrans*.

Sorex haydeni Baird, 1858. The only infected shrew was singly infected with *E. palustris*.

Sorex longirostris Bachman, 1837. Five of 6 (83%) infected southeastern shrews were singly infected with *E. palustris*, and 1 was infected with a nonsporulated species.

Sorex ornatus Merriam, 1895. The only infected ornate shrew was singly infected with *E. palustris*.

Sorex pacificus Coues, 1877. Four of 5 (80%) infected Pacific shrews were singly infected with *E. palustris* (1), *I. palustris* (1), *E. fumeus* (1), or a nonsporulated species (1); 1 sample contained 2 types of nonsporulated oocysts.

Sorex palustris Richardson, 1828. Nine of 13 (69%) infected northern water shrews were singly infected with *E. palustris* (5) or a nonsporulated species (4); 3 shrews were doubly infected with *E. palustris* and *I. palustris*; and 1 sample contained 2 types of nonsporulated oocysts.

Sorex tenellus Merriam, 1895. The only infected Inyo shrew was doubly infected with *E. inyoensis* and *E. palustris*.

Sorex townsendii Baird, 1858. All of 11 infected Townsend shrews were singly infected with *E. palustris*.

TABLE II. *Eimeria* spp. and *Isospora* spp. described to date from oocysts recovered from fecal samples of the members of the family Soricidae.

Host	Coccidian spp.	Locality	Reference
<i>Blarina brevicauda</i>	<i>E. blarinae</i>	Illinois, USA	Todd et al., 1986
<i>B. brevicauda</i>	<i>E. brevicauda</i>	Massachusetts, Ohio, Pennsylvania, Vermont, USA	Present study
<i>B. brevicauda</i>	<i>I. brevicauda</i>	Ohio, USA	Present study
<i>Crocodyra leucodon</i>	<i>E. leucodontis</i>	Azerbaijan, USSR	Musaev and Veisov, 1961
	<i>E. chagasi</i> *	Bulgaria	Golemansky, 1978
<i>C. russula</i> †	<i>E. crocidurae</i>	Switzerland	Galli-Valerio, 1933
<i>C. schweitzeri</i>	<i>E. firestonei</i>	Liberia	Bray, 1958
	<i>E. milleri</i>	Liberia	Bray, 1958
<i>Neomys anomalus</i>	<i>E. chagasi</i> *	Bulgaria	Golemansky, 1978
	<i>I. neomyi</i>	Bulgaria	Golemansky, 1978
<i>N. fodiens</i>	<i>E. chagasi</i> *	Czechoslovakia	Černá, 1961
<i>Sorex araneus</i>	<i>E. chagasi</i> *	Gomel district, USSR	Yakimoff and Gousseff, 1935
		Czechoslovakia	Černá and Daniel, 1956
		Bulgaria	Golemansky and Yankova, 1973
	<i>E. dissimilis</i>	Gomel district, USSR	Yakimoff and Gousseff, 1935
	<i>E. soricinae</i>	Czechoslovakia	Galli-Valerio, 1927
	<i>I. araneae</i>	Bulgaria	Golemansky, 1978
	<i>I. soricis</i>	Bulgaria	Golemansky and Yankova, 1973
<i>S. asper</i>	<i>E. domashnevae</i>	Kazakhstan, USSR	Dzerskinskii, 1982
	<i>E. tedosevi</i>	Kazakhstan, USSR	Dzerskinskii, 1982
<i>S. californicus</i>	<i>E. soricis</i>	California, USA	Henry, 1932
<i>S. cinereus</i>	<i>E. palustris</i>	Colorado, New Mexico, Pennsylvania, Vermont, USA; Manitoba, Ontario, CAN	Present study
<i>S. fontinalis</i>	<i>E. palustris</i>	Pennsylvania, USA	Present study
<i>S. fumeus</i>	<i>E. fumeus</i>	Massachusetts, Vermont, USA	Present study
	<i>E. palustris</i>	Massachusetts, Minnesota, Pennsylvania, Vermont, USA	Present study
	<i>E. vagrantis</i>	Vermont, USA	Present study
<i>S. haydeni</i>	<i>E. palustris</i>	Minnesota, USA	Present study
<i>S. longirostris</i>	<i>E. palustris</i>	Florida, Virginia, USA	Present study
<i>S. ornatus</i>	<i>E. palustris</i>	California, USA	Present study
<i>S. pacificus</i>	<i>E. fumeus</i>	Oregon, USA	Present study
	<i>E. palustris</i>	California, USA	Present study
	<i>I. palustris</i>	California, USA	Present study
<i>S. palustris</i>	<i>E. palustris</i>	California, Colorado, New Mexico, USA	Present study
	<i>I. palustris</i>	New Mexico, USA	Present study
<i>S. tenellus</i>	<i>E. inyon</i>	California, USA	Present study
	<i>E. palustris</i>	California, USA	Present study
<i>S. trowbridgii</i>	<i>E. palustris</i>	California, Oregon, Washington, USA	Present study
	<i>E. vagrantis</i>	Oregon, USA	Present study
	<i>I. palustris</i>	Oregon, Washington, USA	Present study
<i>S. unguiculatus</i>	<i>E. fumeus</i>	Hokkaido, Japan	Present study
	<i>I. palustris</i>	Hokkaido, Japan	Present study
<i>S. vagrans</i>	<i>E. palustris</i>	Arizona, California, New Mexico, USA	Present study
	<i>E. fumeus</i>	New Mexico, USA	Present study
	<i>E. vagrantis</i>	Arizona, New Mexico, Washington, USA	Present study
	<i>I. palustris</i>	New Mexico, USA	Present study
<i>Suncus murinus</i>	<i>E. darjeelingensis</i>	West Bengal, India	Sinha and Sinha, 1980
	<i>E. suncus</i>	West Bengal, India	Ahluwalia et al., 1979

* Synonyms = *E. komarecki*, *E. neomyi*, *E. ropotomae*; see Discussion, p. 181.

† See Remarks, Levine and Ivens (1979), pp. 276–277.

tris (4), *I. palustris* (3), *E. vagrantis* (1), or a nonsporulated species (3).

Sorex unguiculatus Baird, 1858. Twenty-two of 24 (92%) infected shrews were singly infected with *E. fumeus* (1) or a nonsporulated species (8); 1 shrew was doubly infected with *I. palustris* and *E. fumeus*.

Sorex vagrans Baird, 1858. Twenty-two of 24 (92%) infected vagrant shrews were singly infected with *E. palustris* (13), *I. palustris* (1), *E. vagrantis* (3), *E. fumeus* (1), or a nonsporulated species (4); 2 shrews were doubly infected, 1 with *E. palustris* and *E. vagrantis*, the other with *E. vagrantis* and a nonsporulated species.

DISCUSSION

Shrews have a cosmopolitan distribution throughout the Holarctic, Africa, and Southeast Asia, being absent only from the polar regions, Australia, and South America below the equator (Eisenberg, 1981; Yates, 1984). The family has 2 extant groups, the Soricinae (11 genera, ca. 103 species), mainly Holarctic shrews, and the Crocidurinae (9 genera, ca. 189 species), those with

Palaearctic, Oriental, or Ethiopian distribution. Only 5 genera in the family (Soricinae: *Blarina*, *Neomys*, *Sorex*; Crocidurinae: *Crocidura*, *Suncus*) have been examined for coccidia and the majority of parasites described are from Asia and Europe (Table II). Prior to our study, only 2 eimerians, *E. soricis* in *S. californicus* from California and *E. blarinae* in *B. brevicauda* from Illinois, had been reported from North American shrews (Henry, 1932; Todd et al., 1986).

When one assembles the literature on the coccidia of any host group, the oocysts of several species often appear to be quite similar and this is true for several eimerians described from shrews (e.g., *E. chagasi*, *E. komareki*, *E. neomyi*, *E. ropotamae*). The problem that presents itself is that many original descriptions are incomplete and often (but not always) only line drawings are available for comparative purposes. In many ways, those who describe new species of coccidia are a century behind other descriptive disciplines because they are not required to provide type specimens of the species they describe. One reason for this is that no universal method has been developed to preserve type specimens of oocysts although 1 promising technique was published almost a decade ago (Marchiondo and Duszynski, 1978), and the oocysts in this preparation have remained unchanged for over 10 years (pers. obs.). In lieu of type specimens of oocysts for deposit with national museums, we suggest the next best thing; namely, that quality photomicrographs of representative oocysts should accompany each new species description. Additionally, as much qualitative and quantitative information as possible should be provided with every description of a new coccidium.

We stress these points because as we examine hundreds of host species for coccidia worldwide, we sometimes see sporulated oocysts that are identical even though they are found in different (but related, syntopic) host genera (e.g., *E. tamiasciuri*, see Hill and Duszynski, 1986) and in other instances we see oocysts that are nearly identical (e.g., *I. brevicauda* and *I. palustris*), but which can be separated by quantitative (=statistical) and qualitative differences. As an example of the latter, the size/shape of the Stieda/substieda body complex may help strengthen the case to distinguish between species, if these critical data are presented.

The coccidians we saw in this study were not shared between host genera, but this may be due as much to lack of geographic overlap between

the *Blarina* sp. and *Sorex* spp. we examined as to host specificity. On the other hand, there is considerable geographic overlap between many of the *Sorex* spp. we examined, and coccidians were shared freely between many host species: we found oocysts of *E. palustris* in 11 host species, *I. palustris* in 5 species, *E. fumeus* in 4 species, and *E. vagrantis* in 3 species. In almost every instance, the hosts that shared coccidians have geographic distributions that overlap (see Hall, 1981 for distribution maps). The only exception to our generalization is *S. longirostris*, found only in the southeastern USA and it was found to be infected only with *E. palustris*, the most ubiquitous of the shrew eimerians seen by us.

A similar sharing of eimerians may occur in European shrews. Yakimoff and Gousseff (1935) described *Eimeria chagasi* from *Sorex araneus* in the Gomel district of White Russia. In 1956, Černá and Daniel described similar oocysts that they named *E. komareki*, also from *S. araneus*, but collected from Czechoslovakia. Both descriptions are incomplete by today's measure, but their brief descriptions and respective line drawings are virtually identical; both pairs of authors were probably seeing the same species, *E. chagasi*. Černá (1961) said she saw *E. komareki* in *Neomys fodiens*, but later Golemansky (1978) named the form Černá (1961) saw *Eimeria neomyi*. In the same paper Golemansky (1978) also described *Eimeria ropotamae* from *Crocidura leucodon leucodon* in Bulgaria. The descriptions provided by Golemansky (1978) show that only a small size difference between the sporulated oocysts separate *E. neomyi* and *E. ropotamae*; his drawings of the 2 sporulated oocysts are indistinguishable. The difference in oocyst size may be attributed to the variability in host species discussed by Reduker et al. (1985), or to inherent individual variability in oocyst size over patency (Duszynski, 1971), or both. Based on this argument we suggest that *E. komareki*, *E. neomyi*, and *E. ropotamae* are junior synonyms of *E. chagasi*. This concurs with a view held by Levine and Ivens (1979).

Shrews are semifossorial and, as such, they inhabit environments (runways, tunnels) that could be conducive to the preservation of oocysts deposited there in host feces (adequate moisture, protection from UV radiation, etc.). In addition, they are reasonably gregarious and are known to share their tunnels with other shrews and to use tunnels/runways of other small mammals (e.g., voles), habits that should allow them access to

many different species of oocysts including their own. Under such circumstances, we expected that shrews, like shrew moles and moles, would have a high rate of infection by coccidia. For example, in recent surveys of moles (unpubl.) and shrew moles (Duszynski, 1985; Duszynski and Moore, 1986), 92% of the moles and 75% of the shrew moles had at least 1, but usually from 2 to 6 species of coccidian oocysts in their feces when examined. However, only 24% of the shrews we examined had coccidian oocysts in their feces and the majority (97%) of these, like most other mammalian groups thus far studied (Duszynski et al., 1982; Stout and Duszynski, 1983; Duszynski and Barkley, 1985; Hill and Best, 1985; Reduker and Duszynski, 1985; Reduker et al., 1985; Vance and Duszynski, 1985; Wash et al., 1985; Hill and Duszynski, 1986), had only single species infections. The factors responsible for these different infection patterns among related insectivores only can be speculated upon at present. The genetics, physiology, and ecology of insectivores, in general, and shrews, in particular, are poorly understood. Differences in metabolism, length of time spent on the surface, size of individual home range, defecation behavior, length of time available for coevolution between host and parasites, etc., probably all contribute to the distinctly different infection patterns seen between shrews, moles, and shrew moles. In the case of shrews, for example, nutritional state, age, season, and state of sexual maturity all seem to affect their physiological state (Gebczynski, 1977), weather (e.g., night rainfall, percent cloud cover, etc.) influences daily activity patterns (Vickery and Bider, 1977), and at least some shrews are known to maintain a midden separate from the nest area for deposit of excretory material (Maser and Hooven, 1974). Sorting out which factors may play the most important role in the patterns seen in naturally infected populations of small mammals should provide fertile ground for future research efforts.

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