Description of 3 New Species of *Eimeria* (Apicomplexa: Eimeriidae) from Springbok (*Antidorcas marsupialis*) in Namibia

**WENDY C. TURNER,** 1,6 **BAREND L. PENZHORN,** 2,3 **AND WAYNE M. GETZ** 4,5

1 Department of Biological Sciences, State University of New York, Albany, New York 12222, U.S.A. (e-mail: wcturner@albany.edu),
2 Faculty of Veterinary Science, Department of Veterinary Tropical Diseases, University of Pretoria, Private Bag X04, Onderstepoort 0110, South Africa (e-mail: banie.penzhorn@up.ca.za),
3 National Zoological Gardens of South Africa, 232 Boom Street, Pretoria 0001, South Africa,
4 Department of Environmental Science, Policy and Management, University of California-Berkeley, 137 Mulford Hall, Berkeley, California 94720-3112, U.S.A. (e-mail:wgetz@berkeley.edu), and
5 School of Mathematical Sciences, University of KwaZulu-Natal, Private Bag X54001, Durban 4000, South Africa

**ABSTRACT:** We document morphological descriptions for 3 newly described *Eimeria* spp. that infect springbok (*Antidorcas marsupialis*). *Eimeria antidorcas* n. sp. oocysts are ovoid, with average size (n = 346) 26.2 × 18.8 (19.2–33.5 × 13.1–26.5) μm, a length/width ratio of 1.4 (1.2–2.0), a microcylpe, and a polar granule sometimes present. Sporocysts are ovoid (n = 336), 11.3 × 7.3 (6.0–14.6 × 5.2–9.8) μm, with a length/width ratio of 1.5 (1.1–2.0), a Stieda body, a prominent, ovoid sporocyst residuum, and one refractile body per sporozoite. *Eimeria versfeldi* n. sp. oocysts are ellipsoid (n = 136), 38.9 × 26.6 (27.8–48.2 × 21.2–31.0) μm, with a length/width ratio of 1.5 (1.2–2.0), a microcyle cap with submicrulary material, and 2–4 polar granules. Sporocysts are elongate-ovoid (n = 132), 18.3 × 9.2 (13.2–22.8 × 6.8–11.2) μm, with a length/width ratio of 2.0 (1.3–2.5), a Stieda body, a small sporocyst residuum present, and an evident nucleus and two refractile bodies per sporozoite. *Eimeria gasawayi* n. sp. oocysts are subspheroïd (n = 87), 14.8 × 13.6 (11.5–20.0 × 11.1–18.2) μm, with a length/width ratio of 1.1 (1.0–1.2), and no microcylpe. Sporocysts are elongate-ovoid (n = 82), 9.0 × 4.6 (5.5–12.5 × 3.6–6.4) μm, with a length/width ratio of 2.0 (1.3–2.4), a small Stieda body, and an irregularly shaped sporocyst residuum present. These are the first *Eimeria* spp. described from springbok.

**KEY WORDS:** *Antidorcas marsupialis*, Antilopini, Bovidae, coccidia, *Eimeria*, Eimeriidae, Etosha National Park, Namibia, springbok, taxonomy.

The genus *Eimeria* Schneider, 1875 (Apicomplexa: Eimeriidae) is a speciose group of single-celled parasitic organisms, with over 1,800 known species (Duszynski, 2011). Given that most vertebrate species examined thus far are parasitized by *Eimeria*, estimates put the number of described species in this genus at only 2–4% of its total diversity (Tenter et al., 2002; Duszynski, 2011). This study focuses on describing 3 new species of *Eimeria* observed in springbok (*Antidorcas marsupialis* Zimmermann, 1780). Springbok are a medium-sized, mixed-feeding herbivore in the family Bovidae, and they are a commercially important game species located in the more arid regions of southern Africa (Skinner and Chimimba, 2005). *Antidorcas* means “not gazelle” and is used to distinguish this species (the only member of *Antidorcas*) from other species in the tribe Antilopini due to its unique dentition and unusual back skin-flap (the source of the specific epithet *marsupialis*) (Lutley and Oldfield, 1900).

In general, *Eimeria* species are described as being host-specific parasites, at least to the level of host genus (Zhao and Duszynski, 2001). However, there are also examples of eimerians able to infect hosts from several closely related genera (e.g., *Eimeria alabamensis*, *Eimeria auburnensis*, *Eimeria bovis*, *Eimeria brasiliensis*, *Eimeria bukidnonensis*, *Eimeria canadensis*, *Eimeria cylindrica*, *Eimeria bovis*, *Eimeria wyomingensis*, and *Eimeria zuerini* infect 2–4 host genera within the tribe Bovini; Levine and Ivens, 1986) or even from different host families (e.g., *Eimeria dispersa* and *Eimeria innocua* infect gallinaceous birds within the families Phasianidae and Odontophoridae; Vrba and Michal, 2015). Thus, it is important to investigate known *Eimeria* species from beyond the host genus when describing new species of *Eimeria*.

To our knowledge, no descriptions of *Eimeria* in springbok have been published, although an older abstract attributed the mortality of several springbok on a game farm in South Africa to coccidiosis caused by an unidentified *Eimeria* infection (Lopez-Rebollar et al., 1997). These authors isolated oocysts from the feces of one carcass and found lesions in the intestine that were
consistent with pathology caused by *Eimeria*. However, no other information was provided to detail the size or shape of the oocysts. Moreover, a survey of gastrointestinal parasites conducted from 2005 to 2008 in ungulates of Etosha National Park, Namibia, showed distinct differences in the morphology of *Eimeria* individuals recovered from springbok feces as compared to other sympatric bovid species (Turner, 2009). Turner et al. (2012) documented the prevalence, shedding intensity, seasonality, and demographic patterns of infection for 2 springbok *Eimeria* morphotypes. When characterizing these morphotypes based on phenotypic descriptions of the sporulated oocysts, we discovered a third, smaller morphotype of *Eimeria*. Here, we provide a morphological description of these 3 springbok *Eimeria* morphotypes, and we discuss how they compare with known *Eimeria* species from related host species.

**MATERIALS AND METHODS**

**Study area**

Etosha National Park is a 22,915 km² semiarid reserve in northern Namibia between 18°30′–19°30′S and 14°15′–17°10′E. Etosha contains a 4,760 km² salt pan, a dominant geological feature that is the remnant of a paleolake (Hipondoka et al., 2006). Grasslands and dwarf shrub savanna dominate the plains habitats surrounding the Etosha salt pan (le Roux et al., 1988). These open habitats are home to the "plains ungulates," including springbok, plains zebra (*Equus quagga* Boddart, 1785), gemsbok (*Oryx gazella* Linnaeus, 1758), and blue wildebeest (*Connochaetes taurinus* Burchell, 1823) (Gasaway et al., 1996). The only perennial water in Etosha comes from boreholes and artesian or contact springs (Auer, 1997), around which animals congregate in large numbers during dry conditions. Rainfall is strongly seasonal, mainly falling between November and April, with the greatest monthly rainfall in January and February (Engert, 1997). These rainfall patterns lead to strong seasonality in gastrointestinal parasite infections (Turner and Getz, 2010; Turner et al., 2012).

**Oocyst descriptions in springbok**

A prior study recognizing 2 morphotypes of *Eimeria* in springbok (Turner et al., 2012) showed that oocyst shedding was highest in the wet season after the year’s lamb crop was born, that the intensity or prevalence of shedding decreased with age, and that 2 of the 3 morphotypes were relatively rare. To maximize the number of oocysts recovered and to increase the chances of isolating the rarer morphotypes, we sampled in the wet season, selectively collecting feces from young animals (juveniles and yearlings), and we pooled several samples into one for isolation. As a result, we were not able to determine the prevalence of these species, and we instead rely on numbers from Turner et al. (2012).

Fecal samples for morphological descriptions of oocysts were collected in April 2007, February 2008, February 2010, and April 2011, representing >100 individual hosts sampled. Samples were initially screened for oocyst presence using fecal flotation. For samples that contained oocysts, these were isolated from fecal matter via straining to remove larger debris and then processed with a series of washes, centrifugation with distilled water, suspension in saturated salt solution, recovery of the surface solution containing the oocysts, and a final wash to remove the salt solution. Oocysts were stored in a 2% (w/v) potassium dichromate (K₂Cr₂O₇) solution at room temperature for 2–3 wk to allow sporulation and then stored in a refrigerator. All oocysts were characterized and photographed within 5 mo of sampling (the 2011 samples, which represent all photomicrographs of the new species, were analyzed within 30–58 d of sampling).

Isolated oocysts from 2007–2010 were studied at the University of Pretoria, while isolates from 2011 were studied at the Biological Imaging Facility, University of California, Berkeley, using a Zeiss AxioImager microscope. A drop of precipitated oocysts was placed on a slide, covered with a coverslip, and sealed with nail polish to prevent drying out during observations. In total, 569 oocysts were measured and characterized for this study.

Descriptions of the sporulated oocysts followed the guidelines of Duszynski and Wilber (1997) and used their abbreviations. These included oocyst shape, oocyst length (L) and width (W), length/width ratio (L/W ratio), wall characteristics, and presence/absence of the micropyle (M), micropyte cap (MC), oocyst residuum (OR), and polar granule (PG). Description of the sporocyst included shape, length (SL), width (SW), SL/SW ratio, the presence/absence of a Stieda body (SB) and sporocyst residuum (SR), and observation of sporozoites (SP), sporozoite refractile bodies (SRB), as well as, when evident, the nucleus (N). Measurements presented are the mean, standard deviation, and range of values, and all units are in μm.

Comparisons among *Eimeria* oocysts from springbok and other host species were done by evaluating morphological features of *Eimeria* oocysts from bovids in the tribe Antilopini, and from additional species in the family Bovidae that occur in the study area. The species in Antilopini were based upon the phylogeny of Bärmann et al. (2013) and include the genera Antidorcas, Antilope, Ammodorcas, Dorcatragus, Endorcas, Gazella, Lithocranius, Madoqua, Nager, Ourebia, Procaphra, Raphicerus, and Saiga. However, *Eimeria* species have only been described from species within Antidorcas (this study), Antilope, Gazella, Lithocranius, Procaphra, and Saiga. Comparisons among *Eimeria* spp. were based upon morphological information in the following references: Mohammed et al. (2012); Mohammed and Hussein (1992); Omer et al. (2011); Hussein and Mohammed (1992); Levine and Ivens (1986); Sugär (1981–1982); results are summarized in Table 1, which includes the taxonomic authority for each *Eimeria* species.

**RESULTS**

**Species descriptions of *Eimeria* from springbok**

 Morphological examination of sporulated oocysts showed evidence of 3 different morphotypes of *Eimeria* from springbok hosts based on size, shape, and the presence or absence of a micropyte and micropyte cap. These are described here as new species.
Table 1. Morphological features of described *Eimeria* species infecting hosts from the tribe Antilopini, and from other host species from the family Bovidae that occur in Etosha National Park, Namibia.

<table>
<thead>
<tr>
<th>Tribe Antilopini</th>
<th><em>Eimeria</em> species</th>
<th>Oocysts</th>
<th>Shape</th>
<th>Mean size (range) (µm)</th>
<th>M*</th>
<th>MC*</th>
<th>OR*</th>
<th>PG* (no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antidorcas marsupialis</td>
<td><em>E. antidorcasi</em> n. sp.</td>
<td>Ovoid</td>
<td>26.2 × 18.8 (19.34–13.27)</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>± (1)</td>
<td></td>
</tr>
<tr>
<td>Antilocapra americana</td>
<td><em>E. mostelii</em> n. sp.</td>
<td>Ellipsoid</td>
<td>39 × 27 (28.48–21.31)</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>+ (2–4)</td>
<td></td>
</tr>
<tr>
<td>Antilope cervicapra</td>
<td><em>E. antilopatet</em> Ray and Mandal, 1960</td>
<td>Subspheroid</td>
<td>15 × 14 (12.20–11.38)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td><em>Eimeria</em> species</td>
<td><em>E. antilopatet</em> Ray and Mandal, 1960</td>
<td>Cylindrical</td>
<td>(28.34–12.16)</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Antilope cervicapra</td>
<td><em>E. mirage</em> Pande, Chauhan, Bhata and Arora, 1972</td>
<td>Ovoid</td>
<td>49 × 30 (39.55–26.32)</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Gazella dorcas</td>
<td><em>E. dorcadis</em> Mantovani, 1966</td>
<td>Cylindrical</td>
<td>32 × 19 (27.36–16.24)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Gazella gazella</td>
<td><em>E. chinikari</em> Pande, Bhata, Chauhan and Garg, 1970</td>
<td>Subspheroid</td>
<td>25 × 22 (24.27–19.26)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Gazella gazella</td>
<td><em>E. idmi</em> Mohammed and Hussein, 1992</td>
<td>Ellipsoid</td>
<td>42 × 30 (36.48–27.37)</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Gazella gazella</td>
<td><em>E. farsamii</em> Omer, Apio, Wronski and Mohammed, 2011</td>
<td>Spherical-subsphe</td>
<td>21 × 20 (19.25–18.23)</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Gazella gazella</td>
<td><em>E. abenovi</em> Svanbaev, 1960</td>
<td>Ellongate ovoid</td>
<td>(23.45–16.25)</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>±</td>
<td></td>
</tr>
<tr>
<td>Gazella gazella</td>
<td><em>E. elegany</em> Yakimoff, Gousseff and Rastegaieff, 1932</td>
<td>Ovoid</td>
<td>32 × 23 (23.40–19.26)</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Gazella gazella</td>
<td><em>E. gazella</em> Musaev, 1970 emend. Svanbaev, 1979</td>
<td>Ovoid or spherical</td>
<td>24 × 20 (20.28–17.25)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Gazella gazella</td>
<td><em>E. rugosa</em> Mohammed and Hussein, 1992</td>
<td>Spherical or ovoid</td>
<td>25 × 21 (20.34–18.30)</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Gazella marica</td>
<td><em>E. rugosa</em> Mohammed and Hussein, 1992</td>
<td>Roughly ovoid</td>
<td>29 × 23 (27.30–22.25)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Procupra gautana</td>
<td><em>E. gautnanii</em> de Vos, 1970</td>
<td>Subspheroid</td>
<td>36 × 33 (32.38–31.34)</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Saiga tatarica</td>
<td><em>E. sarangii</em> Musaev, 1970</td>
<td>Spherical or ovoid</td>
<td>28 × 24 (21.33–18.28)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Saiga tatarica</td>
<td><em>E. saiga</em> Svanbaev, 1958</td>
<td>Spherical or short-o</td>
<td>31 × 30 (28.34–27.32)</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>±</td>
<td></td>
</tr>
<tr>
<td>Saiga tatarica</td>
<td><em>E. sajanica</em> Machul’skii, 1947</td>
<td>Ovoid or spherical</td>
<td>21 × 18 (18.23–16.20)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Saiga tatarica</td>
<td><em>E. tatarica</em> Musaev, 1970</td>
<td>Ovoid</td>
<td>30 × 24 (25.35–19.30)</td>
<td>+</td>
<td>–</td>
<td>(rarely)</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Saiga tatarica</td>
<td><em>E. tekenni</em> Svanbaev, 1979</td>
<td>Ovoid or ellipsoid</td>
<td>29 × 22 (23.33–18.24)</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Other Bovidae species that occur in Etosha National Park</td>
<td><em>E. impalae</em> Prasad and Narayan, 1963</td>
<td>Ellipsoid</td>
<td>33 × 22 (30.36–20.24)</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Aepyceros melampus</td>
<td><em>E. melampus</em> Prasad and Narayan, 1963</td>
<td>Spherical-subsphe</td>
<td>32 × 30 (29.34–28.33)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>±</td>
<td></td>
</tr>
<tr>
<td>Alcelaphus buselaphus</td>
<td><em>E. talbotii</em> Prasad and Narayan, 1963</td>
<td>Ovoid and asymmetrical</td>
<td>36 × 25 (35.38–22.28)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Connochaetes taurinus</td>
<td><em>E. connochaetii</em> Levine and Ivens, 1970</td>
<td>Ellipsoid</td>
<td>22 × 14 (20.27–13.15)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Connochaetes taurinus</td>
<td><em>E. gorgoni</em> Prasad, 1960</td>
<td>Ellipsoid</td>
<td>23 × 17 (20.26–15.18)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Taurotragus oryx</td>
<td><em>E. canna</em> Trufllet, 1924</td>
<td>Ovoid</td>
<td>23 (23.24–16.20)</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Taurotragus oryx</td>
<td><em>E. triflora</em> Yakimoff, 1934</td>
<td>Ellipsoid</td>
<td>21 × 18 (21.24–15.19)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

* M, microple; MC, microple cap; OR, oocyst residuum; PG, polar granule; SB, Stieda body; SRB, sporozoite refractile bodies; SR, sporocyst residuum; +, present; −, absent; ±, sometimes present or absent; blank cells indicate the description had no information about that character.

† The “clear globules” described in sporozoites by Levine and Ivens (1986) are interpreted to be refractile bodies based on drawings of sporulated oocysts.

**TAXONOMIC DESCRIPTIONS**

*Eimeria antidorcasi* n. sp. (Figs. 1–4, 13)

**Description**

*Sporulated oocysts:* Oocyst shape: ovoid; wall characteristics: smooth; L × W (n = 346): 26.2 × 18.8 (SD = 3.2 × 2.1; range 19.2–33.5 × 13.1–26.5); L/W ratio: 1.4 (SD = 1.1; 1.2–2.0); M: present at the narrow end of the oocyst; PG: sometimes present as a single PG (Fig. 2), sometimes not visible, and oocyst interior looks granular, as if the PG disintegrated (Figs. 3, 4); MC: absent; OR: absent.

*Sporulated sporocysts and sporozoites:* Sporocyst shape: ovoid; SL × SW (n = 336): 11.3 × 7.3
Table 1. Extended.

<table>
<thead>
<tr>
<th>Shape</th>
<th>Mean size (range) (μm)</th>
<th>SB*</th>
<th>SRB** (no.)</th>
<th>SR*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ovoid</td>
<td>11 × 7 (6–15 × 5–10)</td>
<td>+</td>
<td>(1)</td>
<td>+</td>
</tr>
<tr>
<td>Elongate-ovoid</td>
<td>18 × 9 (13–23 × 7–11)</td>
<td>+</td>
<td>(2)</td>
<td>+</td>
</tr>
<tr>
<td>Elongate-ovoid</td>
<td>9 × 5 (6–13 × 4–6)</td>
<td>+</td>
<td>(1)</td>
<td>+</td>
</tr>
<tr>
<td>Piniform</td>
<td>11 × 7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ellipsoid</td>
<td>21 × 10 (19–23 × 9–10)</td>
<td>+</td>
<td>(2–3)</td>
<td>+</td>
</tr>
<tr>
<td>Elongate-ellipsoid</td>
<td>14 × 8 (12–17 × 6–9)</td>
<td>+</td>
<td>(2)</td>
<td>+</td>
</tr>
<tr>
<td>Almond-shaped</td>
<td>14 × 8 (13–14 × 8–9)</td>
<td>+</td>
<td>(2)</td>
<td>+</td>
</tr>
<tr>
<td>Elongate-ovoid</td>
<td>18 × 10 (10–23 × 8–13)</td>
<td>+</td>
<td>(2)</td>
<td>+</td>
</tr>
<tr>
<td>Elongate</td>
<td>8 × 3 (7–10 × 2–5)</td>
<td>+</td>
<td>(1)</td>
<td>+</td>
</tr>
<tr>
<td>Ellipsoid</td>
<td>11 × 7 (8–14 × 6–9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ovoid</td>
<td>(10–14 × 6–12)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ovoid to broad ovoid</td>
<td>9 × 6 (6–11 × 5–8)</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ovoid</td>
<td>10 × 8 (6–15 × 5–10)</td>
<td>+</td>
<td>(1)</td>
<td>+</td>
</tr>
<tr>
<td>Broadly ovoid</td>
<td>(8–13 × 5–8)</td>
<td>+</td>
<td>(1)</td>
<td>+</td>
</tr>
<tr>
<td>Ovoid</td>
<td>18 × 10 (17–19 × 9–11)</td>
<td>+</td>
<td>(3)</td>
<td>+</td>
</tr>
<tr>
<td>Ovoid or spherical</td>
<td>10 × 9 (7–12 × 7–11)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ellipsoid to spherical</td>
<td>12 × 8 (11–13 × 6–11)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spherical or short-ovoid</td>
<td>10 × 8 (7–12 × 7–9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ovoid</td>
<td>(5–10 × 3–5)</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ovoid</td>
<td>10 × 8 (9–13 × 6–8)</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ellipsoid</td>
<td>11 × 7 (9–13 × 6–9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ovoid</td>
<td>11 × 8 (8–14 × 7–9)</td>
<td>±</td>
<td>(1)</td>
<td>–</td>
</tr>
<tr>
<td>Ellipsoid</td>
<td>17 × 7 (16–19 × 6–8)</td>
<td>+</td>
<td>(1)</td>
<td>+</td>
</tr>
<tr>
<td>Piniform</td>
<td>14 × 10 (12–15 × 9–10)</td>
<td></td>
<td>(1)</td>
<td>–</td>
</tr>
<tr>
<td>Ovoid</td>
<td>4.5 × 1.5</td>
<td>+</td>
<td>(1)</td>
<td>+</td>
</tr>
<tr>
<td>Lemon-shaped</td>
<td>(12–15 × 4–6)</td>
<td>+</td>
<td>(1)</td>
<td>+</td>
</tr>
<tr>
<td>Ovoid</td>
<td>(12–17 × 5–7)</td>
<td>+</td>
<td>(1–2)</td>
<td>+</td>
</tr>
<tr>
<td>Elongate</td>
<td>9 × 4.6</td>
<td></td>
<td></td>
<td>–</td>
</tr>
</tbody>
</table>

(SD = 1.5 × 0.8; 6.0–14.6 × 5.2–9.8); L/W: 1.5 (SD = 0.14; 1.1–2.0). SR: present, prominent, with coarse granules, appears membrane-bound maintaining the residuum in an ovoid packet; SB: present, small; SRB: present, 1/SP, not always evident.

Taxonomic summary

Symbiotype host: Antidorcas marsupialis Zimmermann, 1780.

Type locality: Okaukuejo, Etosha National Park, Namibia; 19°10’S; 15°55’E.

Material deposited: Photosyntypes of sporulated oocysts, HWML #101984.

Prevalence: Unknown from this study. This species was identified in Turner et al. (2012) as “Eimeria morphotype A” and, based on fecal flotation of unsporulated oocysts, had a prevalence of 61.0% (n = 726) averaged across seasons and demographic groups (2005–2008). Infections were highly seasonal, with the monthly prevalence ranging from 10 to 96% from dry to wet season months (Turner et al., 2012).
Site of infection: Unknown. Oocysts collected from fecal specimens.

Endogenous stages: Unknown.

Etymology: The specific epithet antidorcasi is derived from the genus of the type host (the only species within this genus), because this was by far the most commonly observed oocyst in the host species. Since Antidorcas means “not gazelle,” we extend this terminology from the host to its parasite, and in the spirit of the host’s genus name, we note that E. antidorcasi is also not a gazelle.

Remarks
Based on oocyst length and width measurements, presence of M, absence of MC, and presence of SR, this species is similar to Eimeria elegans and Eimeria rheemi from Gazella subgutturosa Güldenstädt, 1780, Eimeria dorcadis from Gazella dorcas Linnaeus, 1758, and Eimeria canna from Taurotragus oryx Pallas, 1766 (Table 1). However, oocyst shape distinguishes E. antidorcasi from all 4 of these species. Eimeria dorcadis and E. elegans oocysts are nearly cylindrical (Levine and Ivens, 1986; Mohammed et al., 2012), E. rheemi oocysts are nearly spherical (Hussein and Mohammed, 1992), and, although E. canna oocysts are also ovoid, the end with the M does not narrow as it does in E. antidorcasi. In additional, E. canna oocysts have a pronounced SB, and the SR is linearly arranged along the long axis of the sporocyst (Levine and Ivens, 1970), while E. antidorcasi has a more subtle SB and an ovoid SR.

Eimeria versfeldi n. sp.
(Figs. 5–8, 14)

Description
Sporulated oocysts: Oocyst shape: ovoid; wall characteristics: smooth; L × W (n = 136): 38.9 × 26.6 (SD = 4.8 × 2.2; range 27.8–48.2 × 21.2–31.0); L/W ratio: 1.5 (SD = 0.11; 1.2–2.0); M: present; MC: present and prominent, can be torn off during processing; MC depth (n = 65): 3.2 (SD = 0.59; 2.2–4.9); sub-micropylar material is evident beneath the MC (Figs. 5, 7), which is centrally placed, nongranular, nonrefractile, and irregularly shaped; PG: 2–4 present; OR: absent.

Sporulated sporocysts and sporozoites: Sporocyst shape: elongate-ovoid; SL × SW (n = 132): 18.3 × 9.2 (SD = 2.2 × 0.9; 13.2–22.8 × 6.8–11.2); L/W: 2.0 (SD = 0.21; 1.3–2.5); SR: present, small, centrally located, with fine granules, and appears to be attached to the sporocyst wall (Fig. 7); SRB: 2/SP, 1 large one at either end of the sporocyst, I smaller one toward the middle; rarely, a second smaller SRB is visible, for a total of 3 SRB/SP; N: evident, located between the two SRBs (and intermediate in size to the SRBs; Fig. 8); SB: present, flattened.

Taxonomic summary
Symbiotype host: Antidorcas marsupialis Zimmermann, 1780.

Type locality: Okaukuejo, Etosha National Park, Namibia; 19°10’S; 15°55’E.

Material deposited: Photosyntypes of sporulated oocysts, HWML #101985.

Prevalence: Unknown from this study. This species was identified in Turner et al. (2012) as “Eimeria morphotype B” and, based on fecal flotation of unsporulated oocysts, had a prevalence of 16.5% (n = 726) averaged across seasons and demographic groups (2005–2008). The monthly prevalence for E. versfeldi ranged from 4 to 44% throughout the year, but it did not have the strong seasonality exhibited by E. antidorcasi (Turner et al., 2012).

Site of infection: Unknown. Oocysts collected from fecal specimens.

Endogenous stages: Unknown.

Etymology: The specific epithet versfeldi is for Wilfred Versfeld of the Etosha Ecological Institute, the “institutional memory” of Etosha National Park. He retired from the Ministry of Environment and Tourism after 35 y of service in March 2016. His many duties over the years included monitoring the ecology and demographics of the springbok population, which are among his favorite species.

Remarks
These large oocysts often ruptured under the pressure of the 100 × oil immersion objective, making them initially very difficult to measure. This problem was solved by placing two partial strands of human hair under the cover slip to elevate it slightly.

Based on the presence of MC (described as an unusual feature in Eimeria species from antelope and their relatives; Mohammed and Hussein, 1992), E. versfeldi is similar to Eimeria idmii from Gazella Pallass, 1766, Eimeria mrigai from Antilope cervicapra, and Eimeria tekenovi from Saiga tatarica Linnaeus,
Eimeria tekenovi is smaller than E. versfeldi, while E. idmii is similarly sized (Table 1); however, E. idmii and E. tekenovi both lack a PG (Levine and Ivens, 1986; Mohammed and Hussein, 1992), and E. versfeldi has 2–4 present. Eimeria mrigai shares with E. versfeldi the presence of sub-microplar material, but E. mrigai oocysts are larger, and the SR is dispersed throughout the sporocyst (Levine and Ivens, 1986), whereas the SR of E. versfeldi is centrally placed in the sporocyst.

Eimeria gasawayi n. sp.

(Figs. 9–12, 15)

Description

Sporulated oocysts: Oocyst shape: subspheroid; wall characteristics: smooth; L × W (n = 87): 14.8 × 13.6 (SD = 2.5 × 2.1; range 11.5–20.0 × 11.1–18.2); L/W: 1.1 (SD = 0.05; 1.0–1.2); M: absent; MC: absent; PG: absent; OR: absent.

Figures 1–12. Photomicrographs of sporulated oocysts. 1. Eimeria antidorcasi, showing the micropyle (M). 2. E. antidorcasi, showing the polar granule (PG; not always present) and sporocyst residuum (SR). 3. E. antidorcasi, showing the granular interior of the oocyst (and no PG). 4. E. antidorcasi, showing a single refractile body per sporozoite (SRB), Stieda body (SB), and SR. 5. Eimeria versfeldi, showing the oocyst with prominent micropyle cap (MC). 6. E. versfeldi, showing two PGs, the flattened SB, and in a sporozoite, the nucleus (N) and the large posterior SRB. 7. E. versfeldi sporocyst, showing the SR and the large SRB. 8. E. versfeldi sporocyst, showing the large and small SRBs and the N. 9–12. Eimeria gasawayi oocysts, showing a SB and SR.
Sporulated sporocysts and sporozoites: Sporocyst shape: elongate-ovoid; SL × SW (n = 82): 9.0 × 4.6 (SD = 1.5 × 0.6; 5.5–12.5 × 3.6–6.4); SL/SW ratio: 2.0 (SD = 0.22; 1.3–2.4); SR: present, granular, generally located off-center to the long axis of the sporocyst and of variable shape, from elongate-ovoid to irregular; SB: present, small; individual SP often not evident; SRB: absent.

**Taxonomic summary**

**Symbiotype host:** Antidorcas marsupialis Zimmermann, 1780.

**Type locality:** Okaukuejo, Etosha National Park, Namibia; 19°10′S; 15°55′E.

**Material deposited:** Photosyntypes of sporulated oocysts, HWML #101986.

**Prevalence:** Unknown, described from pooled fecal samples; rarer than *E. antidorcasi* and *E. versfeldi*.

**Site of infection:** Unknown. Oocysts collected from fecal specimens.

**Endogenous stages:** Unknown.

**Etymology:** The specific epithet gasawayi is named after the late William C. Gasaway, who studied springbok and other plains herbivores in Etosha National Park from the late 1970s to the early 1990s, and who obtained funds from the U.S. Agency for International Development (USAID) and the Zoological Society of San Diego to build Okaukuejo’s research camp, the William Gasaway Memorial Research Camp.

**Remarks**

*Eimeria gasawayi* has similar features (oocyst shape; absence of M, MC, OR, and PG; sporocyst shape; presence of SB and SR) to *Eimeria sajanica* in *S. tatarica*, *Eimeria chinkari* in *G. gazella*, *Eimeria neitzi* in *Aepyceros melampus* Lichtenstein, 1812, and *Eimeria gazella* in *G. subgutturosa* (Levine and Ivens, 1986). However, *E. gasawayi* is smaller than all of these species, with the mean oocyst length and width outside the ranges reported for all 4 of these species (Table 1).

**Eimeria of sympatric hosts in Etosha National Park**

Turner (2009) did a survey of gastrointestinal parasites of 13 different ungulate species in Etosha National Park. Of these species, *Eimeria* species were observed only from species in the family Bovidae, including springbok, black-faced impala (*Aepyceros melampus petersi* Bocage, 1879), red hartebeest (*Alcelaphus busephalus caama* É. Geoffroy Saint-Hilaire, 1803), blue wildebeest (*C. taurinus*), gemsbok (*O. gazella*), and greater kudu (*Tragelaphus strepsiceros* Pallas, 1766). These parasites were only examined as unsporulated oocysts, but the size, shape, and M characteristics suggest they all differ from the springbok *Eimeria* species (Turner, 2009). Among the bovid species from Etosha that were also infected with *Eimeria*, the following species are recognized: in hartebeest (*Alcelaphus busephalus cokii*, not *A. b. caama*), *Eimeria talboti*; in impala (from common, not black-faced impala), *Eimeria impalae* and *E. neitzi*; and in wildebeest, *Eimeria connochaetii* and *Eimeria gorgonis* (Levine and Ivens, 1986). It is interesting to note that no *Eimeria* samples were recovered from the feces of nonbovid ungulate species examined, including *Loxodonta africana* Blumenbach, 1797, and *Dicerorhinus birorhinus* Linnaeus, 1758 (n = 100), *Diceros bicornis* Linnaeus, 1758, or *Equus zebra hartmannae* Matschie, 1898. However, *Eimeria* species were observed in *Phacocherus africanus* Gmelin, 1788, or *Giraffa camelopardalis* Linnaeus, 1758 (n = 55) (Turner, 2009; Turner and Getz, 2010).

In 2010, we further examined a few pooled fecal samples from blue wildebeest and from gemsbok to observe the diversity of *Eimeria* species recovered in these species, which share the grassland habitat with springbok. No *Eimeria* species have been described from gemsbok, and 2 have been described for blue wildebeest, *E. gorgonis*, Prasad 1960 and *E. connochaetii* (Prasad, 1960) Levine and Ivens, 1970, although the description and history of *E. connochaetii* are somewhat unclear. These 2 wildebeest *Eimeria* species were identified by Prasad (1960), who described *E. gorgonis* as a new species and labeled the other observed morphotype as *E. ellipsoidalis* Becker and Frye, 1929, based on morphological similarities to this species, which was originally described from *Bos taurus* (Levine and Ivens, 1986). Prasad (1960) erroneously labeled the host of these *Eimeria*
Figures 16–21. Eimeria observed in 2 bovid species sympatric with springbok in Etosha National Park, Namibia. 16–17. Two examples of a smaller morphotype found in blue wildebeest, Connochaetes taurinus. These oocysts have a micropyre and average size of 21.4 × 18.1 (19.7–23.5 × 17.9–18.3) μm (n = 3). 18–19. Two examples of a larger morphotype found in C. taurinus. These oocysts have an asymmetrically placed micropyre cap and average size of 31.2 × 23.2 (27.8–34.5 × 21.5–25.4) μm (n = 6). 20–21. Two examples of the morphotype found in gemsbok, Oryx gazella. These oocysts have a micropyre cap and an average size of 44.0 × 32.4 (38.8–52.3 × 29.1–34.9) μm (n = 6).

as black wildebeest (Connochaetes gnu Zimmermann, 1780), a species that only occurs in southern Africa, yet stated that the samples were collected from wildebeest in East Africa. Using the data published in Prasad (1960), Levine and Ivens (1970) described this morphotype as a new species, E. connochaetei (correcting the host record to C. taurinus), because the sporocysts were smaller than E. ellipsoidalis and because the phylogenetic distance between host species would suggest the 2 Eimeria morphotypes are different.

We observed 2 morphotypes of Eimeria from blue wildebeest (Figs. 16–17, 18–19), and 1 morphotype of Eimeria from gemsbok (Figs. 20–21). Our smaller wildebeest morphotype (Figs. 16–17) resembles E. Connochaetei in size, shape, and other features, except it was described in Levine and Ivens, (1970) as lacking a M, which is evident in our morphotype. The larger wildebeest morphotype (Figs. 18–19) has a MC and hence differs from both known species (Levine and Ivens, 1986). Thus, these morphotypes may each represent novel species. However, since only a few oocysts were examined (3–6 per morphotype), we do not attempt a description, but we rather use them as a comparison to springbok Eimeria.

The smaller morphotype from wildebeest does not look like the springbok Eimeria species based on its shape and size (Figs. 16–17), while the larger wildebeest morphotype and the gemsbok morphotype both superficially resemble E. versfeldi, with the presence of a MC (Figs. 18–21). Eimeria versfeldi is smaller than the gemsbok morphotype, with an average oocyst size of 38.9 × 26.6 versus 44.0 × 32.4, respectively. The gemsbok morphotype also has 2 large SRBs centrally located in the sporocyst, giving it the appearance of eyes in an elongate face, whereas E. versfeldi has large SRBs at the ends of the sporocysts. Compared with the bigger of the 2 wildebeest morphotypes (Figs. 18–19), E. versfeldi has a broader, more symmetrical MC and is a larger oocyst, with an average size of 38.9 × 26.6 versus 31.2 × 23.2, respectively. Thus, the Eimeria species described from springbok also seem unique when compared with Eimeria species infecting sympatric, if more distantly related, bovid species. Our results from this study are consistent with the pattern suggested by Zhao and Duszynski (2001), i.e., that Eimeria infecting artiodactyl hosts lack an OR (although we note that Eimeria saiga and Eimeria canagdzeeri both have an OR; Table 1).

**DISCUSSION**

Springbok are the only extant species in the genus Antidorcas, and there have been no Eimeria species described from this species or its closest relative, Anmordorcas clarkei Thomas, 1891 (Clarke’s gazelle) from Ethiopia and Somalia. Within the tribe Antilopini, which consists of 13 genera (Bärmann et al., 2013), Eimeria have been described from only 7 species: Antilope cervicapra Linnaeus, 1758 (Eimeria antilocervi and E. mirgai), G. dorcas (E. dorcadis), G. gazella (E. chinkari, E. idmint, Eimeria farasanium), G. subgutturosa (Eimeria abenoui, E. elegans, E. gazella, and E. rheemi), Litocranius walleri Brooke, 1879 (Eimeria walleri), ProcaprUTURN ET AL.—EIMERIA OF SPRINGBOK 209

Eimeria abenoui, E. elegans, E. gazella, and E. rheemi), ProcaprUTURN ET AL.—EIMERIA OF SPRINGBOK 209

Eimeria abenoui, E. elegans, E. gazella, and E. rheemi), ProcaprUTURN ET AL.—EIMERIA OF SPRINGBOK 209

Eimeria abenoui, E. elegans, E. gazella, and E. rheemi), ProcaprUTURN ET AL.—EIMERIA OF SPRINGBOK 209

Eimeria abenoui, E. elegans, E. gazella, and E. rheemi), ProcaprUTURN ET AL.—EIMERIA OF SPRINGBOK 209

Eimeria abenoui, E. elegans, E. gazella, and E. rheemi), ProcaprUTURN ET AL.—EIMERIA OF SPRINGBOK 209

Eimeria abenoui, E. elegans, E. gazella, and E. rheemi), ProcaprUTURN ET AL.—EIMERIA OF SPRINGBOK 209

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Eimeria abenoui, E. elegans, E. gazella, and E. rheemi), ProcaprUTURN ET AL.—EIMERIA OF SPRINGBOK 209

Eimeria abenoui, E. elegans, E. gazella, and E. rheemi), ProcaprUTURN ET AL.—EIMERIA OF SPRINGBOK 209

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Eimeria abenoui, E. elegans, E. gazella, and E. rheemi), ProcaprUTURN ET AL.—EIMERIA OF SPRINGBOK 209

Eimeria abenoui, E. elegans, E. gazella, and E. rheem
Indian subcontinent (*A. cervicapra*). Based on morphology, the springbok *Eimeria* species differ from all of these known species (Table 1).

We broadened the taxonomic group of hosts considered beyond Antilopini to include other members of the family Bovidae that co-occur with springbok in Etosha National Park for comparison. Of these additional host species, *Eimeria* species have been described in 4 species: *A. melampus* (*E. impalae* and *E. neitzi*), *A. buseilaphus* (*E. talboti*), *C. taurinus* (*E. connochaetiae* and *E. gorgonis*), and *T. oryx* (*E. canna* and *E. triffittae*). Again, based on morphology, the *Eimeria* species from springbok differ from each of these species (Table 1). We further assessed if the springbok *Eimeria* species seem locally species specific by evaluating oocysts infecting hosts that share the grassland habitats with springbok (Figs. 16–21) and found the *Eimeria* spp. infecting *C. taurinus* and *O. gazella* are clearly different from the species infecting springbok.

In summary, none of the known *Eimeria* spp. considered shares all the features of the *Eimeria* described here from springbok. In addition, the 3 *Eimeria* spp. described here are clearly different from each other in the size, shape, and phenotypic characteristics of the oocysts. Therefore, we feel confident that *E. antidorcas*, *E. versfeldi*, and *E. gasawayi* represent 3 distinct species, each of which is new to science.

**ACKNOWLEDGMENTS**

We thank the Namibian Ministry of Environment and Tourism for permission to conduct research in Etosha National Park. We give a special thanks to the staff of the Etosha Ecological Institute for logistical support and assistance. Werner Kilian, Wilferd Versfeld, Shayne and Birgit Köting, and Gabriel Shatumbu were vital to the success of this research program, and Martina Küsters assisted with data collection. Yathin Krishnappa provided the oocyst line drawings. Milana Troskie and Ruhani Nkuna helped with early isolation and measurement of oocysts, and Holly Ganz provided moral support. Species descriptions were improved through discussions with Don Duszynski and Scott Gardner. This research was conducted as part of a Ph.D. dissertation at the University of California, Berkeley, and was supported by a Fulbright fellowship, Andrew and Mary Thompson Rocca Scholarships, the Professor Earl Storie Memorial Scholarship, the G. Fitzgarald Martin Scholarship, and a grant from the Department of Environmental Science, Policy and Management to W.C.T., and National Institutes of Health grant GM83863 to W.M.G.

**LITERATURE CITED**


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