First Report of *Nematodirus battus* (Nematoda: Trichostrongyloidea) in North America: Redescription and Comparison to Other Species

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**ABSTRACT:** *Nematodirus battus* Crofton and Thomas, 1951 from sheep is reported for the first time in North America. Nematodes of this species were recovered from the small intestine of sheep born and raised in the Willamette Valley of western Oregon. Previously, *N. battus* was believed to have a geographic distribution limited to the British Isles and smaller foci in Europe where it is recognized as a significant pathogen in lambs. The presence of this nematode, exotic to North America, is consequently of great importance because of its potential negative economic impact. Specimens of *N. battus* can be distinguished from those of related species found in North America by the structure of the synlophes, in both sexes, the form of the copulatory burse and terminal portion of the spicules in males, and the form of the tail in females. It is likely that *N. battus* in sheep will most often occur in mixed infections with *N. filicollis* and *N. spathiger*.

Nematodes identified as *Nematodirus battus* Crofton and Thomas, 1951 were recovered from the small intestines of sheep (mixed breed), *Ovis aries* Linnaeus, at Oregon State University during a routine anthelmintic trial. Animals found to be infected had been locally raised in the Willamette Valley of western Oregon, thus establishing the endemic source of infection. Prior to the present study, *N. battus* had not been found outside of the western Palearctic. The presence of this species, exotic to North America and the Western Hemisphere, is notable and of significance beyond the apparent new geographic record.

*Nematodirus battus* was originally described from sheep, in Great Britain (Crofton and Thomas, 1951, 1954). Until 1969, it was thought that *N. battus* was restricted to the British Isles where it had been reported as a significant cause of disease and mortality in lambs (documented losses from 5 to 30%) (Kingsbury, 1953; Thomas and Stevens, 1956; Baxter, 1957; Dunn, 1978). Isolated populations of this nematode have since been recognized from several foci in Western Europe (Lepojev, 1963; Helle, 1969; Nardini et al., 1974a; Borgsteede et al., 1978). Foci in Norway and the Netherlands developed following the importation of infected sheep from Britain.

The pathogenicity of *N. battus* in lambs has been well documented (Thomas, 1959; Mapses and Coop, 1972; Coop et al., 1973; Dunn, 1978; Martin and Lee, 1980). The parasite is capable of causing serious clinical disease and death in lambs, and its presence in North America could pose a serious problem to the sheep production industry.

The present paper deals with several aspects concerning the occurrence of *N. battus* in North America. We present a redescription of the species based on North American material. Specimens from Oregon are compared with those reexamined by us from Weybridge, England, and are compared to previous redcriptions (Crofton and Thomas, 1954; Durette-Desset, 1979). Additionally, *N. battus* is distinguished from morphologically similar species, and from those known to occur in domestic and wild ruminants in North America. Aspects of potential epidemiology and future research are briefly discussed.

**Materials and Methods**

Specimens of *Nematodirus* spp., including *N. battus*, were recovered from the small intestine of sheep that were part of an anthelmintic trial. Thirty sheep purchased from a local producer in Philomath, Oregon on June 14, 1984, were maintained on pastures of the Veterinary Medical Animal Isolation Laboratory at Oregon State University until October 5, 1984, when they were transferred to indoor isolation stalls. On November 5, 20 of these sheep were treated with SCH 32481 (Schering Corporation) (10 at 7.5 mg/kg and 10 at 20 mg/kg) and the 10 untreated animals were utilized as controls. Necropsies were conducted on November 12 and 19 when equal numbers of animals were examined. Major sections of the gastrointestinal tract (abomasum, small intestine, large intestine, and caecum) were ligated in situ and later processed separately. Small
intestines were opened longitudinally and the mucosa was stripped, with all washings and contents being brought to a known volume from which two 5% aliquots were saved. Aliquots were sieved through a 400-mesh (37.5-µm) screen and all material retained, along with parasites, was preserved with 70% ethanol/iodine. In the laboratory, nematodes were removed from aliquots of intestinal contents for later identification.

Specimens of *Nematodirus* spp. were transferred to 70% ethanol/5% glycerin and later cleared in phenol-alcohol, glycerin, or glycerin jelly. The synlophie was studied using light and scanning electron microscopy. The description of the synlophie follows the methods and terminology described previously for the species of *Nematodirus* parasitic in domestic ruminants of North America (Lichtenfels and Pilitt, 1983). The redescription is based on 28 male and 21 female specimens. Fifteen male and five female specimens have been deposited in the National Parasite Collection, USDA, Beltsville, Maryland as USDA Par. Coll. No. 69984. All measurements are in micrometers unless stated otherwise; ranges are followed by mean values in parentheses and sample sizes for some measurements are given as (N =).

Other specimens examined: *Nematodirus battus* 12 males and 9 females from *Ovis aries*, representing the Weybridge strain, in Great Britain. USNM Helm. Coll. No. 69359, deposited by M. Lancaster.

**Results**

*Nematodirus* spp. were only found in the small intestine of control animals. *Nematodirus battus* was present in 4 of 10 sheep (range in intensity = 40–640; ẍ = 250 ± 268), whereas *N. filicollis* (Rudolphi, 1802) occurred in 9 of 10 (range = 40–1,560; ẍ = 400 ± 495) and *N. spathiger* (Railliet, 1896) was found in 7 of 10 (range = 40–200; ẍ = 80 ± 61). *N. battus* was always found in association with these species of *Nematodirus*.

*Nematodirus battus* Crofton and Thomas, 1951

(Figs. 1–17)

**Redescription:** Cephalic structures. Cephalic expansion with swelling anteriorly and transverse striations covering remaining portions. Six papillae of internal circle with sclerotized semicircular supports. Because of the poor condition of the specimens, papillae of the external circle were not seen. Perioral denticles number 37–40.

**Synlophie:** The synlophie of *N. battus* consists of an 18-ridge bilaterally symmetrical system in the region of the esophagus (Fig. 1). The ridges are numbered 1–9 in ventral and dorsal sets beginning at the right cervical papilla (Figs. 1–2). Ridges numbered 1 and 9 extend only slightly anterior to the cervical papillae and excretory pore (Fig. 10). In a few specimens ridges numbered 1–9 do not extend anterior to the cervical papilla but end just posterior to it. Ridges numbered 2 and 8 extend anteriorly to the level of the nerve ring and ridges numbered 3 and 7 extend almost to the cephalic expansion. The anterior portions of ridges 2, 3, 7, and 8 are thinner than more posterior portions of the same ridges or than the anterior portions of ridges 4, 5, and 6, which extend to the cephalic expansion.

A few additional irregular and discontinuous ridges are present in each lateral field between the pair of ridges numbered 1 and between the pair numbered 9 in the postcervical region. Usually a pair of discontinuous ridges are present in the lateral fields but one to three have been observed in the lateral postcervical region. Therefore, cross sections posterior to the esophagus may show 18–22 ridges (rarely 23 or 24 ridges). The ridges are continuous, except for those in the lateral fields, and they extend posteriorly to within about 190–220 µm anterior to the bursa in the male and about 1.0–1.10 mm posterior to the vulva in the female.


striations evident. Bosses generally oval, 4–18 in maximum diameter, distributed in three groups across lateral and ventral rays.

tail not attenuated, tapering to a blunt conical point followed by a whiplike ventral process with a sharp point. Vulva (N = 13) 5,010–6,940 (5,971) anterior to end of tail. Ovejectors well developed; anterior and posterior vestibula generally equal (N = 23), 184–253 (221) in length; anterior and posterior infundibula unequal, with latter generally greater in length, respectively (N = 8) 150–276 (221) and (N = 12) 219–253 (232) long. Sphincters strongly developed (N = 29), 46–69 (59) long by 62–83 (73) wide. Eggs thick-shelled (N = 40), 161–196 (179) long by 69–96 (82) wide, with irregular thickenings at each end.

Host: Ovis aries Linnaeus.

Locality: Willamette Valley, Oregon.

Habitat: Small intestine.

Voucher specimens: USDA Par. Coll. No. 69984.

Comparisons: Specimens of N. battus from Oregon, and those studied from England, did not differ in any major morphological characteristics (Table 1) from the original description and subsequent redescriptions (Crofton and Thomas, 1951, 1954; Dunn, 1978; Durette-Desset, 1979).

Type specimens of N. battus could not be located in England (David Gibson, pers. comm.). The bursa and spicules of males and the form of the female tail, ovejectors, and eggs were identical. Polar sculpturing, mentioned by Jansen (1973) and Dunn (1978), was observed only as irregular thickenings on an internal layer of the shells of eggs in utero in both lots of specimens that were studied. This agrees with observations of smooth-shelled eggs by Thomas (1959). The synlophae in specimens from Oregon, composed of 18–24 ridges was similar to the 18–22 ridges described by Durette-Desset (1979). However, photographs of specimens examined by Martin and Lee (1983), although not described, clearly show 25 ridges in the midbody region of female N. battus.

Among species of Nematodirus, N. battus is similar to N. urichi Cameron, 1935, and N. rosclidus Railliet, 1911 from cervids and N. triangularis Boughton, 1932 and N. arizonensis Dikmans, 1937 from lagomorphs. Females of N. battus differ from these and other species of Nematodirus, except N. urichi and possibly N. lamae Becklund, 1963, in having a conical, rather than attenuated tail with a single terminal spine (Crofton and Thomas, 1954; Becklund, 1963).

Eggs of both N. battus and N. rosclidus apparently have sculptured poles. Males of these four species, except for N. rosclidus, were adequately distinguished from N. battus by Crofton and Thomas (1954). They generally differ in the form of the bursa and terminal portion of the spicules (Boughton, 1932; Cameron, 1935; Dikmans, 1937; Crofton and Thomas, 1954). Males of N. battus most closely resemble those of N. rosclidus in having divergent lateral rays that approach the margin of the bursa. However, they can be distinguished by the synlophae (18–24 ridges in N. battus; 34 in N. rosclidus), number of perioral denticles (35–40 versus 46), length and form of the spicule tips (14–21 μm versus 48 μm), and distribution and size of bosses on the bursa (Kotrlá and Kotrly, 1973; Durette-Desset, 1979; Rossi, 1983). The morphology of the synlophae of species of Nematodirus from lagomorphs was found by Durette-Desset (1979) to differ from those in ruminants sufficiently to justify erection of a new genus, Rauschia Durette-Desset, 1979.

Host and geographic distributions further differentiate these species. Rauschia triangularis and R. arizonensis are apparently limited to lagomorphs in North America (Boughton, 1932; Dikmans, 1937). Nematodirus urichi may be restricted to Trinidad in Mazama americana (Erxleben) (=M. simpliciporina) (Cameron, 1935, 1936), whereas N. rosclidus has a broad host distribution in the western Palearctic, having been reported from Cervus elaphus Linnaeus, Cervus dama Linnaeus, Capreolus capreolus (Linnaeus), Ovis musimon Pallas, Rupicapra rupicapra (Linnaeus), and Cervus nippon Temminck but not apparently Ovis aries (Kotrlá and Kotrly, 1973; Rossi, 1983).

Additionally, N. battus can be distinguished from those species of Nematodirus known from domestic and wild ruminants in North America. In this geographic region six species, including N. filicollis, N. davtianii Grigorian, 1949, N. helveticus May, 1920, N. oiratianus interruptus Lichtenfels and Plitt, 1983, N. abnormalis May, 1920, and N. spathiger are characteristic of domestic hosts, particularly sheep and cattle (Becklund, 1964; Becklund and Walker, 1967a; Stringfellow, 1968; Knight and Vegors, 1970; Lichtenfels and Plitt, 1983; and others). These and an additional three species, including N. odocoilei Becklund and Walker, 1967, N. maculosus Becklund, 1965, and N. archari Sokolova, 1948 are found in wild ruminants, particularly deer, mountain sheep, and goats (Becklund, 1965; Becklund and Senger, 1967; Becklund and...
Figures 9–16. *Nematodirus battus* from Oregon sheep. Scale bars: 10 μm, Figure 9; 25 μm, Figures 10–16. 9. SEM of anterior extremity of male showing perioral denticles, six papillae of the internal circle (ic), and a lateral amphid (a). 10. SEM of synlophe at level of excretory pore (exp) and left cervical papilla (cp), showing ventral ridges numbered four through nine. 11. Interference-contrast light micrograph of synlophe, just posterior to region of esophagus showing left lateral view. 12. Eggs in uterus showing irregular polar thickenings in the shells. 13. Copulatory bursa of male, dorsolateral view, showing unique pattern of lateral bursal rays. 14. Spicule tip, dorsoventral view, showing heart-shaped tip. 15. Spicule tip, lateral view, showing delicate membrane (lower
Table 1. Comparison of *Nematodirus battus* Crofton and Thomas, 1951, from Oregon and localities in Britain.

<table>
<thead>
<tr>
<th></th>
<th>Oregon</th>
<th>Weybridge</th>
<th>Crofton and Thomas, 1954</th>
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<tbody>
<tr>
<td>Male: Total (length)</td>
<td>10.7–12.9 mm</td>
<td>7.4–12.6</td>
<td>10–16</td>
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<tr>
<td>Cephalic expansion (length)</td>
<td>94–108 (101)</td>
<td>90–108 (102)</td>
<td>(N = 10)</td>
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<td></td>
<td>41–60 (48)</td>
<td>41–48 (46)</td>
<td>120 × 60</td>
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<tr>
<td>Male: Total (width)</td>
<td>28–37 (33)</td>
<td>35–44 (37)</td>
<td>350–540</td>
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<td>Esophagus (length)</td>
<td>429–535 (486)</td>
<td>430–476 (449)</td>
<td>(N = 10)</td>
</tr>
<tr>
<td>(width)</td>
<td>11–14 (12)</td>
<td>11–14 (12)</td>
<td></td>
</tr>
<tr>
<td>Female: Total (length)</td>
<td>16.6–17.0 mm</td>
<td>12.8–17.2</td>
<td>15–24</td>
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<tr>
<td>Cephalic expansion (length)</td>
<td>81–104 (91)</td>
<td>99–115 (106)</td>
<td>(N = 9)</td>
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<tr>
<td></td>
<td>39–53 (46)</td>
<td>46–51 (49)</td>
<td></td>
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<tr>
<td>Female: Total (width)</td>
<td>496–610 (529)</td>
<td>483–541 (498)</td>
<td>(N = 9)</td>
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<tr>
<td>Esophagus (length)</td>
<td>32–55 (44)</td>
<td>39–48 (44)</td>
<td></td>
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<tr>
<td>(width)</td>
<td>320–504 (440)</td>
<td>389–564 (473)</td>
<td>(N = 9)</td>
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<tr>
<td>Female: Total (length)</td>
<td>209–297 (266)</td>
<td>236–299 (272)</td>
<td>(N = 6)</td>
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<td>Nerve ring†</td>
<td>145–207 (168)</td>
<td>127–156 (141)</td>
<td>90–140</td>
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<tr>
<td>Vulva-tail†</td>
<td>5,010–6,940 (5,971)</td>
<td>4,480–6,018 (5,367)</td>
<td>(N = 8)</td>
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<tr>
<td>Infundibula (length)</td>
<td>184–253 (221)</td>
<td>207–322 (262)</td>
<td>(N = 10)</td>
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<tr>
<td>P</td>
<td>150–276 (221)</td>
<td>230–239</td>
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<tr>
<td>Sphincters (length)</td>
<td>46–69 (59)</td>
<td>48–61 (56)</td>
<td></td>
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<tr>
<td>(width)</td>
<td>62–83 (73)</td>
<td>69–74 (71)</td>
<td>(N = 9)</td>
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<tr>
<td>Eggs (length)</td>
<td>161–196 (179)</td>
<td>143–196 (166)</td>
<td>(N = 50)</td>
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<tr>
<td>(width)</td>
<td>69–96 (82)</td>
<td>65–87 (75)</td>
<td>150–195</td>
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<tr>
<td>Cephalic:</td>
<td>37–40</td>
<td>—</td>
<td>80–95</td>
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<tr>
<td>No. denticles</td>
<td></td>
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* Distance from anterior extremity.
† Distance to tail.
‡ Anterior = A; posterior = P.
§ Overall length of ovejectors.

Walker, 1967b; Pursglove et al., 1976; and others). Differentiation of *N. battus* from these nine species is based on an array of characters including the synloph and number of perioral denticles in both sexes, the structure of the bursa (only in *N. battus* are the lateral rays divergent), distribution of bosses, and form of the fused portion and tip of the spicules in males, and the form of the tail in females (Skrjabin et al., 1954; Becklund, 1965; Becklund and Senger, 1967; Becklund and Walker 1967a, b; Stringfellow, 1968; Durette-Desset, 1979; Lichtenfels and Pilitt, 1983).

Host distribution: Host records for *N. battus* suggest that it is primarily a parasite of sheep (Crofton and Thomas, 1954; Thomas and Stevens, 1956; Thomas, 1959; Dunn, 1978; and others) although there have been several reports from cattle (Parfitt and Michel, 1958; Taylor and Cawthorne, 1972). Jansen (1973) suggested that sheep have only recently become a host for *N. battus* and that some species of wild ruminant or lagomorph may be the typical definitive host. This argument was supported by records of *N. battus* in roe deer (Dunn, 1965) and in wild rabbits (Boag, 1972). As previously mentioned, the arrow) that covers spicule just anterior to the tip, and one of two alae (upper arrow) with minute transverse striations. 16. Female tail, lateral view, showing anus (upper arrow), conical tail with a bluntly pointed tip (lower arrow) and a ventral terminal whiplike process with a sharp tip.
morphological attributes of *N. battus* suggest its greatest affinities are to species of *Nematodirus* from cervids (e.g., *N. rosidicus* and *N. urichi*) but the origin of *N. battus* remains a mystery.

**Geographic distribution:** Records indicate that *N. battus*, in domestic ruminants, originally may have been restricted to the British Isles (Crofton and Thomas, 1951, 1954; Baxter, 1957; Dunn, 1978; and others). Generally, *N. battus* is considered to have been present in Britain for a relatively long period prior to its recognition by Crofton and Thomas (1951). However, Jansen (1973) has suggested that *N. battus* did not occur in Britain prior to 1940.

Apparently *N. battus* has become established only recently in several limited foci in western Europe. The introduction and subsequent development of isolated populations of *N. battus* in Norway (Helle, 1969) and the Netherlands (Borgsteede et al., 1978; Borgsteede and König, 1979) can be attributed to the importation of infected sheep from Britain. In Italy, *N. battus* has been present since at least 1954 (Nardi et al., 1974a, b) and may also occur in Yugoslavia (Lepejov, 1963; Cvetkovic et al., 1963).

**Discussion**

Prior to the present study, *Nematodirus battus* was not known from domestic or wild ruminants in North America, or the Western Hemisphere. The extent of its geographic distribution and mode of introduction into North America has yet to be elucidated. This species may have been: (1) present in North America but not previously recognized; (2) imported recently with animals brought into the United States from an area where the parasite is endemic; or (3) introduced via fomites. Currently, we can only speculate about the potential source of infection.

It is possible that *N. battus* was only recently introduced to North America. The morphological attributes that characterize this nematode clearly distinguish it from other *Nematodirus* spp. Therefore, it is unlikely that specimens of such a distinctive species would have been misidentified during the relatively extensive surveys of parasites in domestic sheep over the past 50 years (Becklund, 1964). Detailed studies in systematics of nematodes from both domestic and wild ruminants further suggest that *N. battus* has not previously been present for an extended period in North America (Becklund, 1966; Becklund and Walker, 1967a; Samson, 1968; Stringfellow, 1968; Lichtenfels and Pilitt, 1983; and others).

In other areas where *N. battus* has been introduced, it became the most prominent species in lambs and apparently displaced *N. filicollis* and *N. spathiger* (Kingsbury, 1953; Thomas and Stevens, 1956; Helle, 1969). In our studies *N. filicollis* was the most abundant species in sheep, followed by *N. spathiger* and *N. battus*. Clinical disease associated with infections of *N. battus* had not been confirmed in Oregon at the time the present redescriptions was prepared. However, on May 29, 1985, a lamb of 12–16 weeks in age (from a farm adjacent to the original source of infected sheep) and exhibiting some clinical signs of the disease (see Dunn, 1978) was necropsied by us (GLZ and EPH) following death. Upon examination, 1,552 specimens of *Nematodirus* spp. were found in the small intestine, in addition to a few *Ostertagia* spp., *Cooperia* spp., and numerous *Moniezia expansa* Rudolphi, 1810. Specimens of *N. battus* accounted for 95% of the *Nematodirus* spp. present (6% represented by fourth-stage larvae and immature adults; 89% represented by mature males and gravid females). In more typical cases of nematodiasis the proportion of larvae and immature adult *N. battus* was generally greater than mature and gravid adults, and infections were often of greater intensity than that observed by us (Kingsbury, 1953; Thomas and Stevens, 1956; Baxter, 1957; Dunn, 1978).
It has been shown that \textit{N. battus} must accumulate on a given pasture over several years, be coincidental with the presence of susceptible lambs, and an optimum climatological regime which promotes survival of eggs and hatching of larvae, for severe outbreaks to occur (Thomas and Stevens, 1960; Helle, 1969; Smith and Thomas, 1972; Boag and Thomas, 1975; Gibson and Everett, 1981; Borgsteede, 1983; and others). The potential for spread of this nematode in North America, analogous to the situation in the British Isles, warrants concern and indicates the need to elucidate the current geographic distribution and epidemiology of \textit{N. battus} in Oregon. The development of monospecific isolates of \textit{N. battus} would allow detailed studies of pathogenesis in sheep, and may provide a means to determine the degree to which populations of \textit{N. battus} in Europe and North America are related.

\textbf{Literature Cited}


\textbf{Kotrýa B., and A. Kotrý.} 1973. First finding of
DISTINGUISHED VETERINARY PARASITOLOGIST AWARD

Request for Nominations

The American Association of Veterinary Parasitologists is seeking nominations of outstanding scientists for its annual Distinguished Veterinary Parasitologist Award. This is an international award that seeks to honor an individual whose contributions to veterinary parasitology are widely recognized as significant and important to the understanding and control of parasitic diseases of animals. The 1986 recipient will be honored at the annual meeting of AAVP in Atlanta, Georgia, July 1986; all expenses of the recipient will be paid. Nominations should include a curriculum vitae, list of publications, and letters of support and should be sent by February 1, 1986 to Dr. K. D. Murrell, Animal Parasitology Institute, Bldg. 1040, Room 2, BARC-East, Beltsville, Maryland 20705. Members of the Awards Committee are Drs. G. Conder, J. Hansen, P. Klesius, D. Murrell, and J. C. Williams.