Coccidian parasites of red squirrels (Sciurus vulgaris) and grey squirrels (Sciurus carolinensis) in England

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One hundred and ninety-three Eurasian red squirrels (Sciurus vulgaris) and 57 grey squirrels (Sciurus carolinensis) in England were examined for enteric coccidian parasites. Three species of the genus Eimeria were recovered from each host. The prevalences in S. vulgaris were Eimeria sciurorum 66%, Eimeria andrewsi 38% and Eimeria mira 2.6%; and in S. carolinensis they were Eimeria ascotensis 100%, Eimeria confusa 23% and Eimeria ontarioensis 7%.

Keywords: Sciurus vulgaris; Sciurus carolinensis; Eimeria spp; England

Introduction

The Eurasian red squirrel (Sciurus vulgaris Linnaeus, 1758), classed as native to the British Isles since the end of the last Ice Age (10,000 years ago), was once the only squirrel in Britain and widely distributed until about 100 years ago (Gurnell 1987). This species has now been replaced throughout much of its range in the British Isles by the invasive non-native North American grey squirrel, Sciurus carolinensis Gmelin, 1788 (Gurnell 1991). Apparently, the first release of grey squirrels in Britain was in Cheshire in 1876 but it is thought that they may have been present in 1830 Kenward and Holm 1989). In their review, Kenward and Holm (1989) noted that following a number of further introductions and translocations, the range of the grey squirrel rapidly increased during the middle of the twentieth century with a corresponding disappearance of the red squirrel. The grey squirrel has now spread to occupy almost all of England (Pepper and Patterson 2001). Sainsbury et al. (2008) consider the decline of the red squirrel to be the result of competition and reduced juvenile recruitment in the presence of grey squirrels. The grey squirrel is able to out-compete the red in almost every phase of its life history (Kenward and Holm 1989; Gurnell et al. 2004a, 2004b; Wauters et al. 2005). In addition, some infectious diseases have been suggested to play a part (Gurnell and Pepper 1988). Poxvirus is one agent suggested as a significant factor in the decline of red squirrel populations in East Anglia (Scott et al. 1981; Keymer 1983). When red squirrels become infected the probability of death within about 2 weeks is very high (Sainsbury and Gurnell 1995; Sainsbury and Ward 1996; Sainsbury et al. 2000; Tomkins et al. 2002). In contrast, poxvirus appears benign in grey squirrels. Coccidiosis, caused by species of Eimeria, has also been suggested as a cause of death in red squirrels (Keymer 1983). The site of infection of the Eimeria species so far studied in squirrels is the intestines (Carini

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and destruction of cells alone under some circumstances, such as stress or intercurrent infections, could be detrimental. There are only a few reports mentioning *Eimeria* species occurring in squirrels in England (Prasad 1960; Webster 1960; Jawdat 1975; Britt and Molyneux 1979; Ball and Snow 1984).

During the last three decades, especially in the late 1900s and early 2000s, we examined red and grey squirrels to identify the *Eimeria* species present and to evaluate the prevalence of infection.

**Material and methods**

The collection sites are indicated in Figure 1. Sites 1 and 2 had red squirrels only and site 3 had only grey squirrels. In contrast both squirrel species had been recorded in sites 4, 5 and 6. Samples from the colons of grey squirrels from Epping Forest, Essex were collected following culling by the forest keepers. Red squirrels from all other sites were obtained by trapping, and faecal samples were collected. Samples were stored in 2.5% (weight/volume) aqueous potassium dichromate at ambient temperature to allow oocyst sporulation. For consistency, each sample was placed in approximately twice its volume of dichromate solution, and within 6 months of collection the samples were examined by placing approximately 0.05 ml of the suspension under 22 × 22-mm coverslips on slides. The whole coverslip was viewed at × 400 magnification before a sample was recorded as negative. Oocysts were measured under oil at × 1000. Prevalence of eimerian infection was compared between male and female squirrels using Fisher’s exact test.

**Results**

A total of 193 faecal samples from *S. vulgaris* and 57 samples from *S. carolinensis* were examined (Tables 1 and 2). On the basis of morphology and size of the sporulated oocyst, three *Eimeria* species were identified from each species of squirrel. The dimensions of these, in micrometres, are given to allow comparison with the original descriptions. The measurements of oocysts from *S. vulgaris* were from hosts in the Isle of Wight and those from *S. carolinensis* were from Epping Forest.

**From *S. vulgaris***:

*Eimeria sciurorum* Galli-Valerio, 1922 measured 15.2 × 26.8 (range 12.5–17.5 × 19.5–32.5) (n = 100), SI (Shape Index = mean length/mean width) = 1.8

*Eimeria andrewsi* Yakimoff and Gousseff, 1935 measured 14.4 × 21.1 (12.5–17.5 × 17.5–25) (n = 100), SI = 1.5

*Eimeria mira* (Lubimov, 1934) Pellérdy, 1954 measured 23.1 × 32.5 (20–25 × 27.5–37.5) (n = 20), SI = 1.4; and had the characteristic pyriform shape with micropyle 4.6 in diameter (n = 6).

**From *S. carolinensis***:

*Eimeria ascotensis* Levine and Ivens, 1965 measured 17.5 × 29.5 (13–22 × 25–34) (n = 100), SI = 1.7
Eimeria confusa Joseph, 1969 measured 28.1 × 36.5 (24–34 × 30–42) ($n = 100$), $SI = 1.3$

Eimeria ontarioensis Lee and Dorney, 1971 measured 25.7 × 38.2 (22–28.6 × 30–46.2) ($n = 100$), $SI = 1.5$, and with a pyriform shape and a micropyle at the narrow end.

In samples from S. vulgaris of known sex, the prevalence of coccidians was marginally higher in males (23/25; 92%) than in females (37/42; 88%) but not

(Figure 1. Outline map of England indicating collection sites. 1. Isle of Wight; 2. Fursey Island; 3. Epping Forest; 4. Thetford Chase; 5. Formby; 6. Cumbria.)
significantly so \((p = 1.0)\). Also there was no significant difference between the prevalence of infection between male \((31/32)\) and female \((22/25)\) \textit{S. carolinensis} \((p = 0.85)\). Therefore the numbers of infected males and females of each host have been grouped together (Tables 1 and 2).

In the samples from \textit{S. vulgaris}, 34.7\% had one eimerian species, 19.6\% had two species and no squirrel was found to be infected by all three species simultaneously. In contrast, for the samples from \textit{S. carolinensis} from Epping Forest, 19\% of squirrels harboured one \textit{Eimeria} species, 44\% had two species and 14\% were infected with three species.

### Discussion

The populations of native red squirrels and introduced grey squirrels studied have a high prevalence of eimerian coccidia. Jawdat (1975) found that of 151 grey squirrels examined from an area near Reading, Berkshire, England all were infected with \textit{Eimeria} spp. Faecal samples from 12 grey squirrels examined by Britt and Molyneux (1979) from Cheshire all revealed eimerian oocysts, as did faecal samples from 44 grey squirrels from Northern Ireland (Scantlebury et al. 2010). These latter workers also reported that there were no differences in the prevalence of infection between sexes of the host; our results are in accord with these observations. Bertolino
et al. (2003) examined red squirrels from the Alps and found *E. sciuorum* in 111 of 143 (78%) and *E. andrewsi* in 61 of 143 (43%), which are 12% and 5%, respectively, greater than our findings.

The high prevalence of *E. sciuorum* and *E. andrewsi* suggests that a strong immunity does not develop and that hosts are either chronically infected or more likely being continually re-infected. Heavily infected young grey squirrels approximately 3 weeks old have been recovered from dreys, suggesting that infection is being passed from parents acting as carriers (Ball, S.J. and Withers, P., unpublished results).

In his review, Duszynski (1986) suggested that in mammals host specificity may not be as rigid as previously thought and gives examples of shared *Eimeria* species, especially in the Sciuridae. However it is not known whether *S. vulgaris* and *S. carolinensis* share coccidia but it would be interesting to determine whether the two species (*E. ontarioensis* and *E. mira*) could infect both hosts. Evidence from other squirrel species is scarce. Motriuk-Smith et al. (2009) identified *E. ontarioensis* and *Eimeria lancasterensis*, originally described from the grey squirrel, in the tree squirrel, *Sciurus niger*. In addition, *E. confusa* from the grey squirrel has been successfully transmitted to the fox squirrel (*S. niger rufiventris*) by Joseph (1975).

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**References**

Ball SJ, Snow KR. 1984. *Eimeria confusa* Joseph, 1969 and *E. ontarioensis* Lee and Dorney, 1971, from grey squirrels in England. J Parasitol. 70:390.

Bertolino S, Wauters LA, De Bruyn L, Canestri-Trotti G. 2003. Prevalence of coccidia parasites (Protozoon) in red squirrels (*Sciurus vulgaris*): effects of host phenotype and environmental factors. Oecologia. 137:286–295.

Britt D, Molyneux DH. 1979. Parasites of grey squirrels in Cheshire, England. J Parasitol. 65:408.

Carini A. 1932. Eimeriose intestinal de um serelepe por *Eimeria botelhoi* n.sp. Rev Biol Hyg. 3:80–82.

Duszynski DW. 1986. Host specificity in the coccidia of small mammals: fact or fiction. Symp Biol Hung. 33:325–337.

Gurnell J. 1987. The natural history of squirrels. London: Christopher Helm; xiii: + 201pp.

Gurnell J. 1991. Grey squirrel. The handbook of British mammals. Oxford: Blackwell Scientific p. 186–191.

Gurnell J, Lurz PWW, Shirley MDF, Cartmel S, Garson PJ, Magrish L, Steele J. 2004a. Monitoring red squirrels *Sciurus vulgaris* and grey squirrels *Scuirus carolinensis* in Britain. Mammal Rev. 34:51–74.

Gurnell J, Pepper H. 1988. Perspectives on the management of red and grey squirrels. In: Jardine DC, editor. Wildlife management in forests. Edinburgh: ICF p. 92–109.

Gurnell J, Wauters LA, Lurz PWW, Tosi G. 2004b. Alien species and interspecific competition: effects of introduced eastern grey squirrels on red squirrels population dynamics. J Anim Ecol. 73:26–35.

Jawdat SZ. 1975. Observations and studies on parasites of grey squirrels *Sciurus carolinensis* Gmelin, 1788. M Phil thesis. p. 1–151. University of Reading.
Joseph T. 1972a. *Eimeria lancasterensis* Joseph, 1969 and *E. confusa* Joseph, 1969 from the grey squirrel *Sciurus carolinensis*. J Protozool. 19:143–150.
Joseph T. 1972b. Observations on the endogenous stages of *Eimeria confusa* Joseph, 1969 from the grey squirrel *Sciurus carolinensis*. J Protozool. 19:408–413.
Joseph T. 1975. Experimental transmission of *Eimeria confusa* Joseph, 1969 to the fox squirrel. J Wild Dis. 11:402–403.
Kenward RE, Holm JL. 1989. What future for British red squirrels? Biol J Linn Soc. 38:83–89.
Keymer IF. 1983. Diseases of squirrels in Britain. Mammal Rev. 13:155–158.
Motriuk-Smith D, Seville RS, Oliver CE, Hofmann DL, Smit AW. 2009. Species of *Eimeria* (Apicomplexa: Eimeriidae) from tree squirrels (*Sciurus niger*) (Rodentia: Sciuridae) and analysis of the ITS, ITS2, and 5.8S rDNA. J Parasitol. 95:191–197.
Pellérdy L. 1954. Contribution to the knowledge of coccidia of the common squirrel (*Sciurus vulgaris*). Acta Vet Acad Sci Hung. 4:475–480.
Pepper H, Patterson G. 2001. Red squirrel conversation. Forestry Commission Practice Note 5 (revised). Edinburgh: Forestry Commission.
Prasad H. 1960. A new species of coccidian of the grey squirrel *Sciurus (Neoscurius) carolinensis*. J Protozool. 7:135–139.
Sainsbury AW, Deaville R, Lawson B, Cooley WA, Farelly SSJ, Stack MJ, Duff DP, McInnes CJ, Gurnell J, Russell PH, et al. 2008. Poxviral disease in red squirrels *Sciurus vulgaris* in the UK: spatial and temporal trends of an emerging threat. Ecohealth. 5:305–316.
Sainsbury AW, Gurnell J. 1995. An investigation into the health and welfare of red squirrels, (*Sciurus vulgaris*). Vet Rec. 137:367–370.
Sainsbury AW, Nettleton P, Gilray J, Gurnell J. 2000. Grey squirrels have a high seroprevalence to a parapoxvirus associated with deaths in red squirrels. Anim Conserv. 3:229–233.
Sainsbury AW, Ward L. 1996. Parapoxvirus infection in red squirrels. Vet Rec. 138:400.
Scantlebury M, Maher McWilliams M, Marks NJ, Dick JTA, Edgar H, Lutermann H. 2010. Effects of life-history traits on parasite load in grey squirrels. J Zool. 282:246–255.
Scott AC, Keymer IF, Labram J. 1981. Parapoxvirus infection of the red squirrel (*Sciurus vulgaris*). Vet Rec. 109:202.
Tomkins D, Sainsbury AW, Nettleton P, Buxton D, Gurnell J. 2002. Parapoxvirus causes a deleterious disease of red squirrels associated with UK population declines. P Roy Soc Lond B. 269:529–533.
Wauters LA, Tosi G, Gurnell J. 2005. A review of the competitive effects of alien grey squirrels on behaviour, activity and habitat use of red squirrels in mixed, deciduous woodland in Italy. Hystrix It J Mamm. 16:27–40.
Webster JM. 1960. Investigation into the coccidia of the grey squirrel *Sciurus carolinensis*, Gmelin. J Protozool. 7:139–146.