Epidemiological and postmortem findings in 262 red squirrels (*Sciurus vulgaris*) in Scotland, 2005 to 2009

J. P. LaRose, A. L. Meredith, D. J. Everest, C. Fiegna, C. J. McInnes, D. J. Shaw, E. M. Milne

Postmortem and virological examinations for squirrelpox virus (SQPV) were carried out on 262 red squirrels (*Sciurus vulgaris*) found dead or moribund in Scotland between September 2005 and July 2009, to determine the likely causes of death and highlight factors that might be threats to the red squirrel population. Most of the squirrels were submitted from Dumfries and Galloway, and 71 per cent of them were adults. Road traffic accidents, squirrelpox, trauma or starvation were responsible for death in a large proportion (73 per cent) of the squirrels. Thin or emaciated body condition was associated with deaths resulting from pneumonia SQPV infection and starvation, and with the presence of external parasites. There were differences between age groups with regard to the cause of death; a large proportion of juveniles died of starvation, whereas a large proportion of subadults and adults died in road traffic accidents. SQPV infection was associated with the presence of external parasites, but was not associated with the sex of the animals.

The red squirrel (*Sciurus vulgaris*) is considered a vulnerable species in the UK and is included as a priority species in the UK government's conservation initiative, the UK Biodiversity Action Plan. Red squirrels are no longer present in many parts of England and Wales, and many of the existing populations are declining (Harris and others 1995). The published estimate of the size of the red squirrel population in Great Britain is 161,000 animals, comprising approximately 30,000 in England, 10,000 in Wales and 121,000 in Scotland; the red squirrels in Scotland therefore represent 70 to 75 per cent of the surviving population of the species in Great Britain (Harris and others 1995). The protection of this last remaining substantial red squirrel population is a priority if the species is not to become extinct on the UK mainland.

The red squirrel’s demise has been attributed mainly to the presence of the American grey squirrel (*Sciurus carolinensis*), a non-native species first introduced into the UK in the late 19th century (Usher and others 1992, Kenward and Holm 1993). Direct competition between red and grey squirrels for resources may partly account for the decline in the red squirrel population, with grey squirrels tending to outcompete red squirrels in some types of habitat (Kenward and Holm 1993, Kenward and others 1998). However, the most significant factor in this relationship between the decline in the number of red squirrels and the presence of grey squirrels is now believed to be squirrelpox virus (SQPV) (Tomkins and others 2002, Rushton and others 2006). SQPV, which belongs to the Poxviridae subfamily Chordopoxviridae (McInnes and others 2006), infects grey squirrels with no apparent adverse effects on their health, but causes a severe, usually lethal, disease in red squirrels (Tomkins and others 2002). There is only one reported case of clinically evident naturally occurring SQPV disease in a grey squirrel (Duff and others 1996). In red squirrels, the disease is characterised by severe, erythematous, exudative dermatitis around the face, feet and ventrum. Ulceration and infection of these lesions, along with lethargy, may lead to the death of infected red squirrels in the wild (Tomkins and others 2002), although the existence of seropositive red squirrels suggests that some may recover (Sainsbury and others 2008). SQPV is blamed for the extinction of many red squirrel populations in England and Wales, and the grey squirrel is likely to be the reservoir host for the virus (Sainsbury and others 2008). Indirect evidence for the likely existence of SQPV in Scotland was not recorded until 2005, when grey squirrels seropositive for the virus were first identified there. Two years later, the first affected red squirrels were detected (McInnes and others 2009), demonstrating that SQPV now presents a serious threat to red squirrels in Scotland.

Although SQPV appears to have contributed significantly to the decline in the red squirrel population in Great Britain, it is not the only cause of death associated with this decline, especially in Scotland, where squirrelpox is not yet widespread. Other previously reported causes of mortality in red squirrels include predation, starvation, extreme cold weather, parasitic disease, failure to thrive after weaning, stress after relocation, neoplasia, nutritional disease and human activities (road traffic casualties) (Keymer 1983, Kenward and Hodder...
A full postmortem examination was undertaken where the condition of the carcase permitted this, and all macroscopic lesions were recorded. In most squirrels, a PCR for SQPV was carried out on the eyelid, forefoot digital skin and lip skin. In cases where blood or body cavity fluid was obtainable, an ELISA for SQPV antibody was also performed, as described by McInnes and others (2009). When SQPV infection was suspected, confirmation was obtained by electron microscopy of scabs to demonstrate the characteristic virus particles (McInnes and others 2009). In two cases, histopathological examination, were used to assess and, in the two cases specified, histopathological examination, were used to determine, where possible, the predominant cause of death (or cause of signs that led to euthanasia) for each of the 262 squirrels.

Data analysis
Minitab 15 was used for statistical analysis of the data. Associations between categorical variables were examined using chi-squared analysis where appropriate. Fisher’s exact test was performed if expected counts were less than five. In all cases P<0.05 was taken to indicate statistical significance.

Results
Sample population
The dead red squirrels submitted for examination were from various regions...
Throughout Scotland, however, a majority (175 of 262, 66.8 per cent) came from Dumfries and Galloway. The precise locations, based upon grid reference numbers, were known for 247 of the squirrels (Fig 1); the majority of the squirrels were found associated with the road network (data not shown).

The month of discovery was known for 246 of the 262 squirrels. The numbers of squirrels submitted for examination increased overall throughout the study period (Fig 2).

### TABLE 1: Numbers of red squirrel carcasses found in Scotland, categorised by age group and sex, which were submitted for postmortem examination between September 2005 and July 2009

<table>
<thead>
<tr>
<th>Age group</th>
<th>Juvenile</th>
<th>Subadult</th>
<th>Adult</th>
<th>Age group unknown</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>14</td>
<td>17</td>
<td>91</td>
<td>1</td>
<td>123</td>
</tr>
<tr>
<td>Male</td>
<td>20</td>
<td>21</td>
<td>92</td>
<td>3</td>
<td>136</td>
</tr>
<tr>
<td>Sex unknown</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>34</td>
<td>40</td>
<td>183</td>
<td>5</td>
<td>262</td>
</tr>
</tbody>
</table>

Information with regard to the exact location of the animal was available for 154 of the 262 squirrels. Of these, 41 per cent were known to have been found on or near a road, 18 per cent in a garden, 12 per cent within a wooded area, 9 per cent at the base of a tree and 4 per cent in or near a feeder; 16 per cent had been found in a variety of other locations. Information on whether the squirrel was found dead, died after being found ill or injured, or was euthanased after being found ill or injured was available for 226 of the 262 squirrels. Seventy per cent of these 226 squirrels had been found dead, 15 per cent had died after being found ill or injured, and 15 per cent had been euthanased as a result of illness or injury.

The age groups of 257 of the squirrels and the sex of 259 of them could be determined. The majority of the squirrels were adult (71 per cent) and 48 per cent were female (Table 1); six of the females were pregnant. Among the carcasses examined, there was no statistically significant association between age group and sex (P=0.603). Body condition was determined in 259 of the 262 squirrels. Of these, most were in normal body condition (60 per cent), and 38 per cent were either thin or emaciated; emaciated animals were mainly found from May to October (Fig 3a). There was a statistically significant association between age group and body condition (P<0.001) (Fig 3b), with a higher proportion of juvenile and subadult squirrels being thin or emaciated (88 per cent), and a much lower proportion of adults in these categories (25 per cent).

### Assigned causes of death

On the basis of the gross postmortem findings, and in two cases histopathological examination, it was possible to assign a likely predominant cause of death in 245 (94 per cent) of the 262 squirrels. Of the remaining 17 carcasses, two were in too poor a condition for a predominant cause of death to be determined, and 15 appeared healthy with no significant abnormalities found at postmortem examination. The assigned causes of death are shown in Table 2 and Fig 4a; road traffic

### TABLE 2: Summary of the causes of death of 245 red squirrels for which a predominant cause of death could be assigned

<table>
<thead>
<tr>
<th>Assigned cause of death</th>
<th>Description</th>
<th>Number (%) of squirrels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road traffic accident</td>
<td>Clear evidence of trauma and found on or near a road</td>
<td>105 (42.9)</td>
</tr>
<tr>
<td>Squirrelpox virus infection</td>
<td>Typical skin ulceration and scab formation, confirmed by electron microscopy</td>
<td>35 (14.3)</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>Consolidation of lung lobes with or without pleuritis</td>
<td>27 (11.0)</td>
</tr>
<tr>
<td>Abscess</td>
<td>Digit (1); kidney (1); submandibular (1); intrathoracic (2)</td>
<td>5 (2.0)</td>
</tr>
<tr>
<td>Septicemia</td>
<td>Enlarged lymph nodes and spleen, epicardial haemorrhages</td>
<td>4 (1.6)</td>
</tr>
<tr>
<td>Small intestinal foreign body</td>
<td>Vegetable foreign body penetrating the intestinal wall</td>
<td>1 (0.4)</td>
</tr>
<tr>
<td>Unspecified</td>
<td>Accumulation of fluid ingesta or gas in the intestine without congestion or diarrhoea</td>
<td>2 (0.8)</td>
</tr>
<tr>
<td>Pyometra</td>
<td>Severe loose intestine with grossly evident anaemia</td>
<td>4 (1.6)</td>
</tr>
<tr>
<td>Carcinosis</td>
<td>Severe conjunctivitis with keratitis in one eye and bilateral purulent ocular discharge</td>
<td>1 (0.4)</td>
</tr>
<tr>
<td>Septic attraction</td>
<td>Enlarged lymph nodes and spleen, epicardial haemorrhages</td>
<td>1 (0.4)</td>
</tr>
<tr>
<td>Died/euthanased for other reasons</td>
<td>Suspected soft tissue sarcoma with pulmonary metastases, multicentric lymphoma</td>
<td>11 (4.5)</td>
</tr>
<tr>
<td>Neoplasia</td>
<td>Found under powerline with subcutaneous haemorrhages/oedema and internal haemorrhage</td>
<td>2 (0.8)</td>
</tr>
<tr>
<td>Electrocardiogram</td>
<td>Cardiomyopathy with left ventricular hypertrophy, cardiomegaly with atrial dilatation</td>
<td>2 (0.8)</td>
</tr>
<tr>
<td>Heart failure</td>
<td>Severe subcutaneous oedema of pinnae, muzzle, eyelids, limbs, scrotum and tail</td>
<td>1 (0.4)</td>
</tr>
<tr>
<td>Peritonitis</td>
<td>Severe bladder distension and apparent urethral obstruction</td>
<td>1 (0.4)</td>
</tr>
<tr>
<td>Staphylococcal infection</td>
<td>Partially contracted hindlimbs with abnormal angulation</td>
<td>1 (0.4)</td>
</tr>
<tr>
<td>Suspected anticoagulant rodenticide poisoning</td>
<td>Multiple internal and external haemorrhages, history of possible access to rodenticide</td>
<td>1 (0.4)</td>
</tr>
</tbody>
</table>
Among the 262 squirrels examined, external parasites (fleas, ticks and lice) were observed in 49 per cent. Fifty-six per cent of the squirrels with external parasites were found to have fleas alone, 12 per cent had ticks alone, and 12 per cent had lice alone; 15 per cent had both fleas and ticks, 4 per cent had both ticks and lice, and 1 per cent had both fleas and lice. There was a statistically significant association between body condition and the presence of external parasites ($P=0.027$), with 38 per cent of thin or emaciated squirrels having external parasites, compared with 25 per cent of normal/fat squirrels. In only four cases was ectoparasitism considered the likely cause of death; all four were juveniles with many hundreds of lice and severe pallor of the carcase, consistent with anaemia.

**SQPV**

No squirrelpox cases were seen from the start of the study period (September 2005) until May 2007, when two cases were submitted. In July 2007 there was one case, in March 2008 and June 2008 there were two cases each, and in August 2008 there was one case. In 2009 there was at least one case every month, with one case each month from January through to April, then seven cases in May, 13 cases in June, and three cases in July. Of the 35 squirrels confirmed positive for SQPV infection, 33 had shown obvious clinical or postmortem signs of the disease. There was no statistically significant association between SQPV infection and sex ($P=0.340$). However, there was a statistically significant association between the presence of SQPV infection and age group ($P=0.015$), with 86 per cent of confirmed squirrelpox cases being adults and no cases in juveniles. In addition, there was also a statistically significant association between SQPV infection and body condition ($P=0.011$), with 57 per cent of SQPV-infected squirrels being thin or emaciated. There was a statistically significant association between SQPV infection and the presence of external parasites ($P=0.007$), with 49 per cent of SQPV-infected squirrels carrying external parasites, compared with only 26 per cent of uninfected squirrels. Specifically, there was a statistically significant association between SQPV infection and the presence of fleas ($P=0.001$), with 43 per cent of SQPV-infected squirrels having external parasites, compared with only 26 per cent of uninfected squirrels. There was a statistically significant association between SQPV infection and body condition ($P=0.007$), with 86 per cent of confirmed squirrelpox cases being adults and no cases in juveniles. In addition, there was also a statistically significant association between SQPV infection and body condition ($P=0.011$), with 57 per cent of SQPV-infected squirrels being thin or emaciated. There was a statistically significant association between SQPV infection and the presence of external parasites ($P=0.007$), with 49 per cent of SQPV-infected squirrels carrying external parasites, compared with only 26 per cent of uninfected squirrels. Specifically, there was a statistically significant association between SQPV infection and the presence of fleas ($P=0.001$), with 43 per cent of SQPV-infected squirrels having external parasites, compared with only 26 per cent of uninfected squirrels; however, there was no significant association between SQPV infection and the presence of ticks or lice ($P>0.226$).

**Discussion**

Convenience sampling was the only practical way to obtain the squirrels examined in this study. As a consequence, the results are unlikely to be representative of the whole Scottish red squirrel population. Bias was undoubtedly introduced in the way in which the squirrels were collected, because squirrels that had died within areas visible to the public were more likely to be discovered. Similarly, more squirrels are likely to be submitted during times of the year when members of the public are more active outdoors. Therefore the numbers of squirrels submitted by month do not necessarily reflect actual fluctuations in mortality. In addition, the majority of the squirrel carcases were submitted from Dumfries and Galloway. This is most likely because of the greater concern about SQPV infection among the public and countryside rangers in this region. Nevertheless, this study is the first to document a (non-exhaustive) list of likely causes of death from a large sample size of red squirrels in Scotland, and to indicate how some of these causes relate to the

**FIG 4:** Predominant assigned causes of death in red squirrel carcases found in Scotland between September 2005 and July 2009 and submitted for postmortem examination. (a) All squirrels in the study ($n=262$), (b) juveniles ($n=34$), (c) subadults ($n=40$), (d) adults ($n=183$).
ever, increased population density also has the potential to support adaption to independent life. Starvation of this type does not apply to subadults or adults because they have long since been weaned, and this may result in them crossing roads, whereas juveniles are more predominant cause of death. Adults and subadults range more widely, and this may result in them crossing roads, whereas juveniles are more likely to be found near the nest area. Efforts to decrease the number of red squirrel road casualties have been incorporated into conservation efforts in some areas; for example, aerial squirrel crossings have been built over roads on the island of Jersey; however, the true impact of these crossings on the squirrel population is not known (Gurnell and Magris 2002). The majority of the juveniles that had apparently died of starvation were found during the late summer or early autumn, corresponding to the season in which summer-born young are weaned (Lurz and others 2005). This newly weaned status was frequently corroborated by postmortem examination, and presumably reflects failed adaption to independent life. Starvation of this type does not apply to subadults or adults because they have long since been weaned, and therefore an apparent inability to use food sources, rather than any actual shortage of food sources, could explain why starvation was one of the more significant causes of death. Provision of supplementary food has been shown in some cases to increase the population density of squirrels in a given area (Gurnell and Magris 2002); however, increased population density also has the potential to support a higher level of disease and spread of parasites. Since the spread of SQPV in particular is known to be a threat to red squirrel populations (Tomkins and others 2002, Rushton and others 2006), any attempt to increase squirrel population density through food supplementation may be detrimental rather than helpful in areas where there is a risk of SQPV being present.

A higher than expected proportion of thin or emaciated squirrels was found to have died, apparently from pneumonia, squirrelpox or starvation. By definition, any squirrel that had died of starvation would have been in poor body condition at the time of death. Squirrels that died of debilitating disease conditions, such as squirrelpox or severe ectoparasitism, would reasonably be expected to have lost body condition before death. The possibility also exists that squirrels in thin or emaciated condition are more susceptible to disease. Demas and others (2005) found that a decrease in total body fat can reduce humoral immunity in Siberian hamsters (Phodopus sungorus) and prairie voles (Microtus ochrogaster); a later study of Siberian hamsters (Demas and Sakaria 2005) found this change in immunity to be regulated through levels of leptin, an adipose tissue hormone. In the present study, it was not known whether the squirrels that died of disease were in poor body condition before or after succumbing to disease, but poor body condition is likely to have been a predisposing factor to disease in at least some of the squirrels.

There was also an association between body condition and the presence of external parasites, with more thin or emaciated animals having external parasites compared with animals in normal or fat body condition. It is not known what proportion of these squirrels were in poor body condition before becoming infested with external parasites, and what proportion lost body condition as a result of already established ectoparasitism. Depression of immunity as a result of poor body condition may have contributed to the establishment of ectoparasitism in some of these squirrels; however, the infestation was severe enough to be the suspected cause of death only in four of the animals.

The presence of SQPV disease was first detected during the present study in May 2007; there had been no previous reported cases of SQPV in red squirrels in Scotland before that date (McInnes and others 2009). It is notable that, since the study period described by McInnes and others (2009), SQPV has increased in importance as a cause of mortality among red squirrels in Scotland. Nearly all of the squirrels that were confirmed as infected with SQPV had clearly visible pox lesions at postmortem examination, although in two cases SQPV infection was not suspected on postmortem examination. These two cases were considered to be early cases, and highlight the fact that infection may be overlooked in the absence of laboratory investigation. There was a significant association between SQPV infection and thin or emaciated body condition. It has been shown that affected red squirrels can lose weight as a result of SQPV disease (Tomkins and others 2002). However, it is not yet known whether squirrels in poor body condition when they come into contact with the virus are more susceptible to squirrelpox disease than squirrels in normal body condition.

It is still uncertain whether SQPV can be carried by vectors such as fleas, ticks or lice; Sainsbury and others (2008) concluded that epidemiological patterns of SQPV infection in red squirrels did not indicate that the disease was vectorborne. In the present study, SQPV-infected squirrels were more likely to have external parasites, specifically fleas. However, the converse was not true; that is, squirrels with parasitic infestation were not more likely to be infected with SQPV. This could suggest that SQPV infection might predispose squirrels to external parasitism, rather than that the presence of external parasites predisposes to SQPV infection. However, the association between fleas and squirrelpox must be treated with caution because it is possible that more squirrels with squirrelpox were euthanased by veterinary surgeons and immediately placed in a bag, preventing loss of fleas from the carcasses.

Finally, there was no statistically significant association between sex and SQPV infection. This finding is contrary to findings of a previous study which examined past squirrelpox epidemics outside Scotland, and concluded that males may be more likely than females to be infected (Sainsbury and others 2008).
In conclusion, this study brings to light many different causes of mortality in red squirrels in Scotland, and the demographic factors associated with these. It demonstrates the value of schemes that gather information about causes of red squirrel mortality, some of which may not be as obvious as SQPV disease. Information gathered from wildlife submission schemes and studies such as this have the potential to aid in the detection of new disease patterns or other threats to populations, and may ultimately help to direct conservation efforts.

Acknowledgements

The authors are grateful to all of the red squirrel conservation groups, ranger services, veterinary surgeons and members of the public who submitted squirrel carcasses, including Richard Wales, Stephanie Johnstone and Ann-Marie McMaster of Red Squirrels in South Scotland, the Buccleuch Ranger Service, Tayside Red Squirrel Forum, Nithsdale Veterinary Surgeons, the Bard Veterinary Group and Elly Hamilton. The authors are also grateful to the Wellcome Trust for a Wellcome Vets vacation scholarship (J. LaRose) and to Scottish Natural Heritage for providing part of the funding for this project.

References


KENWARD, R. E., HODDER, K. H., ROSE, R. J. & WALLS, C. A. (1998) Comparative demography of red squirrels (Sciurus vulgaris) and grey squirrels (Sciurus carolinensis) in deciduous and coniferous woodland. *Journal of Zoology* 244, 7-21


Epidemiological and postmortem findings in 262 red squirrels (Sciurus vulgaris) in Scotland, 2005 to 2009

J. P. LaRose, A. L. Meredith, D. J. Everest, et al.

Veterinary Record 2010 167: 297-302
doi: 10.1136/vr.c4196

Updated information and services can be found at:
http://veterinaryrecord.bmj.com/content/167/8/297.full.html

These include:

References
This article cites 19 articles, 9 of which can be accessed free at:
http://veterinaryrecord.bmj.com/content/167/8/297.full.html#ref-list-1

Article cited in:
http://veterinaryrecord.bmj.com/content/167/8/297.full.html#related-urls

Email alerting service
Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

Notes

To request permissions go to:
http://group.bmj.com/group/rights-licensing/permissions

To order reprints go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to BMJ go to:
http://group.bmj.com/subscribe/