Edinburgh Research Explorer

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

Citation for published version:
LaRose, JP, Meredith, AL, Everest, DJ, Fiegna, C, McInnes, CJ, Shaw, DJ & Milne, EM 2010, 'Epidemiological and postmortem findings in 262 red squirrels (Sciurus vulgaris) in Scotland, 2005 to 2009' Veterinary Record, vol. 167, no. 8, pp. 297-302. DOI: 10.1136/vr.c4196

Digital Object Identifier (DOI):
10.1136/vr.c4196

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Early version, also known as pre-print

Published In:
Veterinary Record

General rights
Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.
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.
Two hundred and sixty-six dead red squirrels, found in Scotland between September 2005 and July 2009, were submitted to the Veterinary Pathology Unit at the University of Edinburgh for postmortem examination. This is the first paper to use some of the parameters assessed. The carcases were frozen at –20°C on arrival if the postmortem examination was not scheduled to be carried out immediately. Decomposition limited the completeness of the postmortem examination in some cases, and therefore the number of animals differs for some of the parameters assessed.

Materials and methods

Study population and pathological examination

Two hundred and sixty-six dead red squirrels, found in Scotland between September 29, 2005 and July 24, 2009, were submitted to the Veterinary Pathology Unit at the University of Edinburgh by members of the public, red squirrel conservation organisations, ranger services and veterinary surgeries, for postmortem examination. Four of these carcases were omitted from the data set because their condition was too poor to allow meaningful assessment, leaving 262 squirrels.

The administrative region and Ordnance Survey grid reference where each squirrel was found were recorded, if known. The specific location information were assumed to have come from the area around the sender’s address. For some of the squirrel carcases there was incomplete or no information regarding the date of finding, location and/or situation in which they were found; squirrel carcases with no specific location information were assumed to have come from the area around the sender’s address.

The dead red squirrels submitted for postmortem examination between September 2005 and July 2009, categorised by the date on which they were found. Un Month of submission was unknown.

Results

Sample population

The dead red squirrels submitted for examination were from various regions of Scotland. There was a significant difference in the number of squirrels found in different months (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.

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.
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 carcases 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 carcases, 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 accidents were the leading cause of death (Table 2).

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

### 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>Trauma</td>
<td>Clear evidence of trauma but not found near a road</td>
<td>27 (11 0)</td>
</tr>
<tr>
<td>Starvation</td>
<td>Emaciated body condition and no other predominant cause of death</td>
<td>24 (9 8)</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>Consolidation of lung lobes with or without pleuritis</td>
<td>18 (7 3)</td>
</tr>
<tr>
<td>Entropathy</td>
<td>12 (4 9)</td>
<td></td>
</tr>
<tr>
<td>Intussusception</td>
<td>Colonic or colorectal intussusception</td>
<td>5 (2 0)</td>
</tr>
<tr>
<td>Entitis</td>
<td>Mucosal congestion and/or accumulation of fluid ingesta or gas in the intestine. In some cases, diarrhoea present</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>Abscess</td>
<td>Digit (1), kidney (1), submandibular (1), intrathoracic (2)</td>
<td>5 (2 0)</td>
</tr>
<tr>
<td>Ectoparasitism</td>
<td>Severe louse infestation with grossly evident anaemia</td>
<td>4 (1 6)</td>
</tr>
<tr>
<td>Other infections</td>
<td>4 (1 6)</td>
<td></td>
</tr>
<tr>
<td>Balantiditis</td>
<td>Prepuce severely inflamed with purulent discharge</td>
<td>1 (0 4)</td>
</tr>
<tr>
<td>Pyometra</td>
<td>1 (0 4)</td>
<td></td>
</tr>
<tr>
<td>Septic peritonitis</td>
<td>Peritonitis with septicaemia</td>
<td>1 (0 4)</td>
</tr>
<tr>
<td>Septic peritonitis</td>
<td>1 (0 4)</td>
<td></td>
</tr>
<tr>
<td>Septic peritonitis</td>
<td>1 (0 4)</td>
<td></td>
</tr>
<tr>
<td>Sepsis</td>
<td>1 (0 4)</td>
<td></td>
</tr>
<tr>
<td>Diel/euthanased for other reasons</td>
<td>11 (4 5)</td>
<td></td>
</tr>
<tr>
<td>Neoplasia</td>
<td>Suspected soft tissue sarcoma with pulmonary metastases, multicentric lymphoma</td>
<td>2 (0 8)</td>
</tr>
<tr>
<td>Electrocardiograph</td>
<td>Found under powerline with subcutaneous haemorrhages/oedema and internal haemorrhage</td>
<td>2 (0 8)</td>
</tr>
<tr>
<td>Cardiac failure</td>
<td>Cardiomegaly with left ventricular hypertrophy, cardiomegaly with atrial dilatation</td>
<td>2 (0 8)</td>
</tr>
<tr>
<td>Suspected fatal allergic reaction</td>
<td>Severe subcutaneous oedema of pinnae, muzzle, eyelids, limbs, scrotum and tail</td>
<td>1 (0 4)</td>
</tr>
<tr>
<td>Stress</td>
<td>No gross abnormalities but squirrel recently caught for translocation</td>
<td>1 (0 4)</td>
</tr>
<tr>
<td>Urethral obstruction</td>
<td>Severe bladder distension and apparent urethral obstruction</td>
<td>1 (0 4)</td>
</tr>
<tr>
<td>Congenital hindlimb contracture</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>
accidents, squirlpox, trauma and starvation together represented 78 per cent of the assigned causes of death.

There was a statistically significant association between age group and predominant cause of death (P<0.001). Road traffic accidents were rare in the juvenile group (Fig 4b), and no juveniles had died of squirlpox. Starvation was the most common cause of death in juveniles, followed by pneumonia and trauma (Fig 4b). This difference was less marked between subadults (Fig 4c) and adults (Fig 4d), with road traffic accidents being the most common in both age groups, followed by trauma, squirlpox and pneumonia in the subadults, and squirlpox and trauma in the adults (Fig 4d). There was a statistically significant association between body condition and predominant cause of death (P<0.001); 77 per cent of thin or emaciated squirrels died from pneumonia, squirlpox or starvation, compared with 17 per cent of normal/fat squirrels, whereas 83 per cent of normal/fat squirrels died from road traffic accidents or trauma.

The number of submissions per region (Fig 1) was a confounding factor, and the predominant cause of death varied according to the location in which they had been found (Fig 5). No S OPPV-associated disease was reported outside Dumfries and Galloway, and the majority of submissions from central Scotland related to road traffic accidents. Road traffic accidents were also the largest grouping in the animals submitted from the Borders and Dumfries and Galloway.

External parasites
Among the 262 squirrels examined, external parasites (fleas, ticks and/or lice) were observed on 29 per cent. Fifty-six per cent of the squirlpox-infected squirrels being thin or emaciated. There was a statistically significant association between S OPPV infection and the presence of external parasites (P=0.007), with 49 per cent of S OPPV-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 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=0.027), 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 squirlpox 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 S OPPV infection, 33 had shown obvious clinical or postmortem signs of the disease.

There was no statistically significant association between S OPPV infection and sex (P=0.340). However, there was a statistically significant association between the presence of S OPPV infection and age group (P=0.015), with 86 per cent of confirmed squirlpox cases being adults and no cases in juveniles. In addition, there was also a statistically significant association between S OPPV infection and body condition (P=0.011), with 57 per cent of S OPPV-infected squirrels being thin or emaciated. There was a statistically significant association between S OPPV infection and the presence of fleas (P=0.001), with 43 per cent of uninfected squirrels; 12 per cent had ticks alone, 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. There was a statistically significant association between SQPV infection and body condition (P=0.001), with 57 per cent of SQPV-infected squirrels being thin or emaciated. There was a statistically significant association between body condition and predominant cause of death (P=0.011); 77 per cent of thin or emaciated squirrels died from pneumonia, squirlpox or starvation, compared with 17 per cent of normal/fat squirrels, whereas 83 per cent of normal/fat squirrels died from road traffic accidents or trauma.

The number of submissions per region (Fig 1) was a confounding factor, and the predominant cause of death varied according to the location in which they had been found (Fig 5). No S OPPV-associated disease was reported outside Dumfries and Galloway, and the majority of submissions from central Scotland related to road traffic accidents. Road traffic accidents were also the largest grouping in the animals submitted from the Borders and Dumfries and Galloway.

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 carcasses were submitted from Dumfries and Galloway.

This is most likely because of the greater concern about S OPPV 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 5: Cause of death, assigned from findings at postmortem examination of 258 red squirrels found between September 2005 and July 2009, categorised according to the county from which the submissions came. The size of each pie chart represents the number of squirrels submitted from that county, and the location of the county is the average location for squirrels submitted from that county. Crown Copyright/database right 2009. An Ordnance Survey/EDINA supplied service

Figure legend:
- Abscess
- Ectoparasitism
- Enteropathy
- Infection
- Pneumonia
- SQPV
- Road traffic accident
- Starvation
- Trauma
- Other
- Too decomposed
- Apparently healthy

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 (Tompkins 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 (Tompkins 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


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

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/