<table>
<thead>
<tr>
<th><strong>Title</strong></th>
<th>Post-release Monitoring of Two Translocated Red Squirrel (Sciurus vulgaris L.) Populations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author(s)</strong></td>
<td>Waters, Catherine</td>
</tr>
<tr>
<td><strong>Publication Date</strong></td>
<td>2012-10-24</td>
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<td><strong>Item record</strong></td>
<td><a href="http://hdl.handle.net/10379/3041">http://hdl.handle.net/10379/3041</a></td>
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</tbody>
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Post-release Monitoring of Two Translocated Red Squirrel (*Sciurus vulgaris* L.) Populations

A thesis submitted for the degree of Ph.D. to the National University of Ireland, Galway by:

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October 2012
# Table of Contents

Abstract vi 
Acknowledgements viii 
List of Figures x 
List of Tables xiii 
List of Plates xvi 

## 1 General Introduction

1.1 Squirrel taxonomy 1  
1.2 Red squirrel biology 5  
1.3 History of squirrels in Ireland 7  
1.4 The distribution of squirrels in Ireland 7  
1.5 Competition 9  
1.6 Legislation and conservation 11  
1.7 Translocation 12  
1.8 Post-release monitoring 13  
1.9 Project Aims 14  

## 2 Translocation and early post-release settlement of a red squirrel population in the west of Ireland

2.1 Introduction 15  
2.1.1 Considerations for translocation 15  
2.1.2 History of red squirrel translocation in Europe 16  
2.1.3 Background to Belleek Forest Park translocation 18  
2.1.4 Aims and Objectives 20  
2.2 Materials and Methods 21  
2.2.1 Target site 21  
2.2.2 Translocation procedure 23  
2.2.3 Radio telemetry 26  
2.2.4 Live trapping 27
3.3 Results (Belleek Forest Park) 95
3.3.7 Population estimates and density 95
3.3.8 Recruitment 97
3.3.9 Individual fitness and breeding status 98
3.3.10 Dispersal of red squirrels from Belleek Forest Park 105
3.3.11 Habitat quality and seed crop 106
3.4 Discussion 108
3.4.1 Red squirrel population abundance 108
3.4.2 Population demographics 110
3.4.3 Red squirrel dispersal 113
3.4.4 Habitat quality and seed crop analysis 115
3.5 Summary and Conclusion 119

4. The Impact of Habitat Loss on Red Squirrel Populations
4.1 Introduction 121
4.1.1 Planned and unplanned events and forestry 121
4.1.2 Forest management and policy 123
4.1.3 Background to habitat loss at Derryclare wood 125
4.1.4 Aims and Objectives 127
4.2 Materials and Methods 128
4.2.1 Study site 128
4.2.2 Live trapping 134
4.2.3 Carrying capacity 136
4.2.4 Habitat quality 136
4.2.5 Work and event schedule 137
4.3 Results 138
4.3.1 Population and density estimates 138
4.3.2 Recruitment 139
4.3.3 Individual fitness 140
4.3.4 Carrying capacity 142
4.3.5 Habitat quality 147
4.4 Discussion 149
4.4.1 Impact of clear-felling on squirrel populations 149
4.4.2 Impact of forest fire on squirrel populations 151
4.4.3 Derryclare wood as a sustainable habitat 152
4.4.4 Mapping the future of Derryclare wood for the red squirrel population 153
4.5 Summary and Conclusion 155

5 The Potential Threat of Grey Squirrel Infiltration into Belleek Forest Park
5.1 Introduction 157
5.1.1 Habitat fragmentation and its effects on squirrel populations 157
5.1.2 Squirrel habitat in the west of Ireland 158
5.1.3 Grey squirrel management and control methods 159
5.1.4 Modelling the spread of an invasive species 162
5.1.5 Background to this section of the study 162
5.1.6 Aims and Objectives 163
5.2 Materials and Methods 164
5.2.1 Study area 164
5.2.2 Survey work 166
5.2.3 Squirrel habitat suitability 166
5.2.4 Least Cost Pathway model 168
5.3 Results 170
5.3.1 Survey responses 170
5.3.2 Land-use in the western region of Ireland 172
5.3.3 Least Cost Pathway analysis 173
5.4 Discussion 177
5.4.1 Survey results 177
5.4.2 Land-use and its impact on squirrel dispersal 178
5.4.3 Least Cost Pathways 180
5.4.4 Implementation of grey squirrel monitoring and control 182
<table>
<thead>
<tr>
<th>5.5</th>
<th>Summary and Conclusion</th>
<th>184</th>
</tr>
</thead>
</table>

6 **General Discussion**

6.1 Overview of red squirrel populations at Belleek Forest Park and Derrycclare wood 186

6.2 Post-translocation management: What role does it play? 188

6.3 Translocation and its role in the conservation of the red squirrel in Ireland 191

6.4 Translocation and its role as a conservation tool for animal populations in general 193

6.5 Conclusions 195

7 **References** 196

8 **Appendices** 226
Abstract

The red squirrel (*Sciurus vulgaris*) has suffered a 20% decline in its range in Ireland since the introduction of the grey squirrel (*Sciurus carolinensis*) mainly through competition. Translocation (the intentional movement of a living organism from one area to another) of red squirrels was conducted in Derrycclare wood, Connemara between July and October 2005. This project has investigated the fate of this red squirrel population through post-release monitoring techniques. A second translocation to Belleek Forest Park, Co Mayo was also conducted and the establishment and subsequent well-being of this population was also investigated.

The second translocation of red squirrels to Belleek was conducted in a three phase programme in 2007 and 2008. Fifteen individuals were translocated in what was designed as a soft release procedure, although there were some problems of squirrels escaping from the enclosure during the second and third phase of the translocation. A fourth phase of translocation was deemed unnecessary as the population began to breed and recruit new individuals. Initial success was recorded using short-term monitoring. Settlement patterns investigated by radio telemetry displayed a priority for locating food initially after release; individuals tracked were found to include the release enclosure and supplementary feeders within home ranges. Not all squirrels established core areas initially using their home range uniformly. However, during a second tracking session, conducted 18 months later, a pattern more in keeping with that of established squirrel populations was shown; individuals were utilising other areas of the wood including parts without supplementary feeders and all had preferred core areas within their home range.

Post-release monitoring in Derrycclare was mainly conducted through live trapping, between June 2008 and March 2011. It was found that the population had dispersed further into the woodland since work had finished there in 2007 and were utilising new areas. Six of the originally translocated stock were captured near to or within the Nature Reserve in which the release enclosures had been based.

Both red squirrel populations at Belleek Forest Park and Derrycclare wood were monitored to investigate establishment of each population and their demographics in the medium-term. Comparison between the populations in each wood showed that spread of the red squirrels was influenced by difference in habitat type. The red squirrel population at Belleek were found to have inhabited all available habitat and then increased in density, whereas, the population at Derrycclare were found to have spread through the woodland as their density increased. Recruitment of individuals was high at both sites, these new squirrels were the progeny of translocated stock as both areas were isolated from the possible immigration of other red squirrels. Over the course of the study both populations showed an increase in abundance year on year. Habitat quality was also monitored at both sites.
The future success of both translocations was considered and the potential threats to the populations analysed, in order to investigate the long-term prospects of both populations. At Derryclare wood, the potential impact of habitat loss was investigated. This was achieved by examining the changing squirrel carrying capacity of the woodland due to planned clear-felling procedures. It was found that if felling was conducted as planned by land-owners, then a sufficient sustainable habitat would be available for the red squirrel population in the future. However, in April 2011, 150 hectares of forest were impacted by a forest fire. The actual detrimental effects of the fire were investigated; it was found that as the fire remained on the ground, mature trees were only scorched at their base which did not affect their survival. A small area of immature trees did suffer fatally from the fire but not enough was damaged to impact upon the sustainability of the red squirrel population.

At Belleek Forest Park, the potential infiltration of grey squirrels to the area was investigated. A distribution survey of red and grey squirrels in the region separating Belleek from known grey squirrel inhabited areas of the northwest of Ireland was undertaken. It was found that the red squirrel was widespread throughout the area surveyed. Only five reports of grey squirrels were received by the survey, each report was more than a year old and in each case only one squirrel had been witnessed. Although the authenticity of these grey squirrel sightings was questioned, the potential invasion of greys from these possible nearest sources of grey squirrels to Belleek was analysed. This was achieved by using a GIS based model Least Cost Pathway (LCP) from the source location to Belleek Forest Park. The LCPs were examined to determine whether such routes were viable. It was found that there was potential for grey squirrels to reach Belleek from these locations, but that the grey squirrel would have to establish itself in habitat along the way. LCP analysis also provided the potential locations of sentry posts (areas which can be observed to detect grey squirrel presence and progress towards Belleek) to use in on-going monitoring and where necessary control programmes, that will protect the area from the invasion of the grey squirrel.

Overall, the project found that translocation is a feasible option for conserving the red squirrel in Ireland. It found that red squirrels can establish themselves in uninhabited woodland successfully. A recommendation from the study suggests that long-term prospects and monitoring programmes in target sites must be incorporated into feasibility plans in the preliminary stages of translocation. This includes investigation into forest sustainability and where possible models such as the LCP to assess the sites isolation from grey squirrels.
Acknowledgements

First and foremost I would like to thank my supervisor Dr Colin Lawton for giving me the opportunity to do this PhD. Throughout my PhD he has shown great patience, knowledge and guidance, as well as a bit of banter over Manchester City and United matches!

A big thank you to Professor Wallace Arthur and Dr Grace McCormack, as Heads of Department, for their support and assistance.

I would like to thank my family and dedicate this thesis to my mum and dad. For always being there when I needed them with; advice, patience and optimism as well as dinner and cups of tea! Words cannot express my true gratitude. To my brother Richard for making me a desk from which this was written and to my brother Justyn, Rita and Liam for their kind support. To my dog Star for keeping me company throughout the write-up!

To the original Elder Lemon, Dr Alan Poole, who inspired me to do my best in zoology in my final year as an undergraduate. Your work has been the foundation of my PhD, thank you. To Dr Laura Finnegan and Nicola Condell whose hard work got this project off the ground. To the National Parks and Wildlife Service for funding the project, especially Ferdia Marnell and relevant rangers (Ger O’Donnell and James Kilroy). To Coillte Teoranta namely Dermott Tiernan and Barry Rintoul for their accommodation and consultation. To the Belleek Forest Park Enhancement Committee, especially Cyril Collins, thank you for always being around to help me out, you’re an inspiration to the local community and I will always remember your dedication and interest in the red squirrels.

A massive thank you to the three amigos; John Galvin, Albert Lawless and last but not least Eoin Macloughlin who helped me up muddy hills, over barbed-wire fences, out of bogs and away from the dreaded midges!! I will be forever grateful to all of you for your support and laughs along the way, as well as swapping recipes.

To my friends in the Mammal Ecology lab past and present. To those out the gates first, Niamh, Peter and Conall for welcoming me back into the fold and providing endless entertainment. To the present, Emma, where to start, thank you for your advice, helping me with my GIS woes and out in the field. To Emily and Mags, thanks for your continued support. I wish you all huge success in the future. To my friends in the zoology department, Ishla, thank you for being so understanding and giving great advice all along, you deserve lots of success. To Vijay and Kelly, thank you for the laughs, Vijay, France has gained an expert cricketer! Best of luck to you all in the future.
Finally, to my non-zoological friends, Andrea and Damien, for always being at the end of a phone with words of wisdom and friendship, thanks. To Tom and Paul, for always being interested in what I was doing and offering encouragement. To the girlies, Marie, Niamh and Sharon, thanks for being great friends and always listening to zoological matters.

To all those I may have forgotten to mention by name, this has been an uphill battle at times but the support and patience of all those involved in any small way has made it easier for me to achieve, thank you.

P.S. To my proof readers and computer experts, you know who you are, thanks for the hard work and for doing a fantastic job.
### List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Order Rodentia Classification according to Carleton and Musser (2005)</td>
</tr>
<tr>
<td>1.3</td>
<td>Red squirrel <em>Sciurus vulgaris</em> world distribution (Harris &amp; Yalden 2008)</td>
</tr>
<tr>
<td>1.4</td>
<td>Spread of the grey squirrel following its original introduction in Co. Longford</td>
</tr>
<tr>
<td>1.5</td>
<td>Red squirrel and Grey squirrel distribution</td>
</tr>
<tr>
<td>2.1</td>
<td>Map of Belleek Forest Park including tree species composition</td>
</tr>
<tr>
<td>2.2</td>
<td>Locations of the enclosure and supplementary feeders at Belleek Forest Park</td>
</tr>
<tr>
<td>2.3</td>
<td>Percentage range against peeled MCP (percentage of fixes) for male 306</td>
</tr>
<tr>
<td>2.4</td>
<td>Location of live squirrel traps at Belleek Forest Park</td>
</tr>
<tr>
<td>2.5</td>
<td>Home ranges of six radio-tracked squirrels in April 2008, represented by 95% MCPs</td>
</tr>
<tr>
<td>2.6</td>
<td>Core areas of six radio-tracked squirrels in April 2008</td>
</tr>
<tr>
<td>2.7</td>
<td>Home range of six radio-tracked squirrels in September 2009</td>
</tr>
<tr>
<td>2.8</td>
<td>Core area of six radio-tracked squirrels in September 2009</td>
</tr>
<tr>
<td>3.1</td>
<td>Derryclare wood including the location of the Nature Reserve and tree species composition</td>
</tr>
<tr>
<td>3.2</td>
<td>Aerial photo of Derryclare wood divided into blocks used throughout the study</td>
</tr>
<tr>
<td>3.3b</td>
<td>New trapping grid in Derryclare incorporating areas into which red squirrels were dispersing. Trapping commenced April 2010 – March 2011</td>
</tr>
<tr>
<td>3.4</td>
<td>Population estimates at Derryclare using Minimum Number Present and Fisher-Ford estimates</td>
</tr>
<tr>
<td>3.5</td>
<td>New recruits captured each trapping month including phases one and two at Derryclare wood</td>
</tr>
<tr>
<td>3.6</td>
<td>New recruit weight (grams) at Derryclare wood</td>
</tr>
</tbody>
</table>
3.7 Linear regression of shin bone length against weight for all the squirrels at Derryclare wood 82
3.8 Linear regression of shin bone length against weight for adult male squirrels at Derryclare wood 83
3.9 Breeding status of female squirrels in each trapping session at Derryclare wood 83
3.10 Breeding status of males captured each trapping month in both phases at Derryclare wood 84
3.11 The sex ratio (proportion captured that were male) for each trapping session 85
3.12a-e The dispersal of red squirrels through Derryclare woods as seen through positive records derived from live trapping, hair tubes and feeding signs 88 - 90
3.13 The correlation between lodgepole pine cone availability and feeding activity of red squirrels at Derryclare wood 92
3.14 Population estimates at Belleek Forest Park using Minimum Number Present and Fisher-Ford estimates 96
3.15 New recruits captured and tagged each trapping session at Belleek Forest Park 98
3.16 New recruit weight (grams) at Belleek Forest Park 99
3.17 Box-plot displaying the body condition of red squirrels at both Derryclare and Belleek Forest Park 100
3.18 Linear regression of shin bone length against weight of adult squirrels at Belleek Forest Park 101
3.19 Significant linear regression of female adult squirrels body weight and shin bone length at Belleek Forest Park 102
3.20 Breeding status of female squirrels in each trapping session at Belleek Forest Park 103
3.21 Breeding status of males caught in each trapping session at Belleek Forest Park 103
3.22 The sex ratio (expressed as proportion of females in the population) caught during the study at Belleek Forest Park 104
3.23 OS discovery map of Ballina town, Co Mayo showing red sightings since the translocation of red squirrels to Belleek Forest Park 105
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1a</td>
<td>Aerial photo of Derryclare wood divided into blocks used throughout the study</td>
</tr>
<tr>
<td>4.1b</td>
<td>Map of Derryclare including areas clear-felled and corresponding years this was conducted</td>
</tr>
<tr>
<td>4.2</td>
<td>Map of Derryclare wood and the area affected by the forest fire</td>
</tr>
<tr>
<td>4.3</td>
<td>The new trapping grid used following the fire and clear-felling events</td>
</tr>
<tr>
<td>4.4</td>
<td>Density estimates based on the Minimum Number of squirrels captured</td>
</tr>
<tr>
<td>4.5</td>
<td>New recruits captured and tagged</td>
</tr>
<tr>
<td>4.6</td>
<td>Breeding status of adult female squirrels of all trapping sections at Derryclare wood</td>
</tr>
<tr>
<td>4.7</td>
<td>Breeding status of adult male squirrels of all trapping sections at Derryclare wood</td>
</tr>
<tr>
<td>4.8</td>
<td>Maps representing 2011 and 2020 had the fire not occurred</td>
</tr>
<tr>
<td>4.9</td>
<td>Maps representing 2011 and 202 had the fire been devastating</td>
</tr>
<tr>
<td>5.1</td>
<td>The composition of field boundaries by O’Sullivan and Moore (1974) adapted to illustrate the favourability of boundaries for squirrel dispersal</td>
</tr>
<tr>
<td>5.2a</td>
<td>The area targeted during the squirrel survey</td>
</tr>
<tr>
<td>5.2b</td>
<td>Counties of Ireland</td>
</tr>
<tr>
<td>5.3</td>
<td>Flow diagram of the LCP model</td>
</tr>
<tr>
<td>5.4</td>
<td>Location of all squirrel survey returns</td>
</tr>
<tr>
<td>5.5</td>
<td>Location of 10 km² with red squirrel sightings</td>
</tr>
<tr>
<td>5.6</td>
<td>Corine land-cover data categorised by grey squirrel habitat preference</td>
</tr>
<tr>
<td>5.7</td>
<td>Four Least Cost Pathways displayed on habitat preference map for grey squirrels</td>
</tr>
<tr>
<td>5.8</td>
<td>Sentry post locations</td>
</tr>
<tr>
<td>6.1</td>
<td>Follow-chart of stages of species or population post-translocation monitoring</td>
</tr>
<tr>
<td>List of Tables</td>
<td>Page</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>2.1 History of the main previous red squirrel translocations throughout Europe</td>
<td>17</td>
</tr>
<tr>
<td>2.2 Work schedule for translocation of red squirrels to Belleek Forest Park</td>
<td>32</td>
</tr>
<tr>
<td>2.3 The 15 red squirrels translocated from Lough Key Forest Park and Union wood to Belleek Forest Park and individual weight and shin bone length at time of translocation</td>
<td>33</td>
</tr>
<tr>
<td>2.4 Home range and core area size and percentage time spent utilising the core area for radio tracked squirrels in April 2008</td>
<td>34</td>
</tr>
<tr>
<td>2.5 Home range and core area size and percentage time spent utilising the core area for radio tracked squirrels in September 2009</td>
<td>35</td>
</tr>
<tr>
<td>2.6 Overlap of core areas of radio tracked squirrels in April 2008 and September 2009</td>
<td>35</td>
</tr>
<tr>
<td>2.7 Nine translocated red squirrels recaptured in the first trapping session after completion of translocation (August 2008)</td>
<td>40</td>
</tr>
<tr>
<td>2.8 Mean weight, shin bone length including 95% confidence intervals and sex ratio of recruited red squirrels captured in post-translocation monitoring trapping session (August 2008)</td>
<td>41</td>
</tr>
<tr>
<td>2.9 The 15 translocated red squirrels sorted by the date they were last captured, weight and gender</td>
<td>41</td>
</tr>
<tr>
<td>2.10 Male and female red squirrel core area size reported in various studies</td>
<td>49</td>
</tr>
<tr>
<td>3.1 Practical methods for monitoring squirrels indirectly</td>
<td>55</td>
</tr>
<tr>
<td>3.2 Summary of baseline survey including blocks surveyed</td>
<td>68</td>
</tr>
<tr>
<td>3.3 Work schedule of post-release monitoring for both sites (Derryclare wood and Belleek Forest Park) May 2008 to May 2011</td>
<td>75</td>
</tr>
<tr>
<td>3.4 Population estimates for each trapping month in phases one and two using three techniques at Derryclare wood.</td>
<td>77</td>
</tr>
<tr>
<td>3.5 Population density (squirrels per ha) for each trapping session and phase based on three population estimates at Derryclare wood</td>
<td>79</td>
</tr>
</tbody>
</table>
3.6 The potential number of squirrels (rounded to the nearest whole number) at Derryclare wood each year of the study based on the mean Minimum Density Present and the area in which red squirrels occupied.

3.7 Habitat use (%) by radio collared squirrels at Derryclare wood.

3.8 Overall mean weight (each individual counted once) for each trapping month at Derryclare wood with 95% confidence limits.

3.9 Mean shin bone length with 95% confidence intervals for squirrels at Derryclare wood.

3.10 The number of potential young born in each breeding season (based on an average of three kits per female) and the new recruits marked in both phases at Derryclare wood.

3.11 Number of cones or energy available per m² from feeding line transects along ‘frontier areas’ of Derryclare.

3.12 Available energy and consumed energy in Derryclare wood for 2008.

3.13 Observations of broadleaved seed production per m² for 2009 and 2010 at Derryclare Nature Reserve.

3.14 Available energy and consumed energy per m² for lodgepole pine and sitka spruce detected from 2008 to 2011 at Derryclare wood.

3.15 Population estimates for each trapping month using the three techniques MNP, Lincoln Index and Fisher-Ford at Belleek Forest Park.

3.16 Population density for each trapping month based on the three population estimates at Belleek Forest Park.

3.17 Overall mean weight for each trapping month at Belleek with 95% confidence intervals.

3.18 Mean shin bone length with 95% confidence intervals for all trapping sessions at Belleek Forest Park.

3.19 The number of new recruits marked compared to the potential number of young born as detected through breeding females at Belleek.

3.20 Cone densities (cones/m²) on quadrats beneath beech, Scots pine, sitka spruce and larch in 2009 and 2010 at Belleek Forest Park.
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.21</td>
<td>Seed crop available in Belleek Forest Park in 2009 and 2010, extrapolated from 33 quadrats examined during each trapping session</td>
</tr>
<tr>
<td>3.22</td>
<td>Seed producing capabilities for major tree species at Belleek Forest Park based on age</td>
</tr>
<tr>
<td>4.1</td>
<td>Work schedule for post-release monitoring including investigations into disturbance by clear-felling and forest fire</td>
</tr>
<tr>
<td>4.2</td>
<td>Population estimates of study area incorporating trapping sessions after the clear-felling and fire (December 2010 and April 2011 respectively)</td>
</tr>
<tr>
<td>4.3</td>
<td>Average weight (grams) of male and female adult squirrels in each trap month</td>
</tr>
<tr>
<td>4.4</td>
<td>The potential carrying capacity in Derryleclare wood and the Nature Reserve over four years incorporating clear-fell and forest fire incidences</td>
</tr>
<tr>
<td>4.5</td>
<td>Area occupied by squirrels from 2007 to 2011 through dispersal of individuals and the potential number of individuals within the given area based on 0.32 squirrels per hectare</td>
</tr>
<tr>
<td>4.6</td>
<td>The amount of scheduled clear-felling due to take place according to Coillte’s forest management plan for Derryleclare wood</td>
</tr>
<tr>
<td>4.7</td>
<td>The amount of suitable habitat available to the red squirrel population (without the fire but after clear-felling procedures, with the fire if the event had been destructive) by 2020</td>
</tr>
<tr>
<td>4.8</td>
<td>Cones available and energy available (kJ) for lodgepole pine and sitka spruce in burnt and unburned regions of Derryleclare wood</td>
</tr>
<tr>
<td>5.1</td>
<td>Habitat description and maximum grey squirrel densities</td>
</tr>
<tr>
<td>5.2</td>
<td>The number of responses gathered for each targeted county during survey work</td>
</tr>
<tr>
<td>5.3</td>
<td>Five categories for grey squirrel habitable preferences</td>
</tr>
<tr>
<td>5.4</td>
<td>Length of each LCP (km)</td>
</tr>
<tr>
<td>5.5</td>
<td>Average density of hedgerows in counties of Connacht and four counties of Leinster</td>
</tr>
</tbody>
</table>
### List of Plates

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Red squirrel skull</td>
<td>5</td>
</tr>
<tr>
<td>2.1</td>
<td>Soft release enclosure constructed by the BFPEC including feeding platform and nest boxes</td>
<td>24</td>
</tr>
<tr>
<td>2.2</td>
<td>Supplementary feeder secured to a tree filled with maize and peanuts</td>
<td>24</td>
</tr>
<tr>
<td>2.3</td>
<td>Live squirrel trap secured in branches of a tree</td>
<td>30</td>
</tr>
<tr>
<td>2.4</td>
<td>Red squirrel held in a handling cone</td>
<td>30</td>
</tr>
<tr>
<td>2.5</td>
<td>Red squirrel being weighed with a Pesola spring balance</td>
<td>31</td>
</tr>
<tr>
<td>2.6</td>
<td>PIT tag and measuring a squirrels shin bone length with a set of Vernier callipers</td>
<td>31</td>
</tr>
<tr>
<td>3.1</td>
<td>One of the two enclosures used during soft release procedure of red squirrels to Derryclare wood</td>
<td>60</td>
</tr>
<tr>
<td>3.2</td>
<td>Hair tube baited and attached securing to tree with twine</td>
<td>71</td>
</tr>
<tr>
<td>3.3</td>
<td>Impressions in gelatine left by red squirrel hair shield and shaft</td>
<td>71</td>
</tr>
<tr>
<td>3.4</td>
<td>A typical line transect measured by 50 m tape and a metre stick</td>
<td>72</td>
</tr>
<tr>
<td>3.5</td>
<td>Lodgepole pine cone and a sitka spruce cone</td>
<td>73</td>
</tr>
<tr>
<td>4.1</td>
<td>Example of a clear-felled area at Derryclare wood 2010</td>
<td>131</td>
</tr>
<tr>
<td>4.2</td>
<td>Example of the on-site collection of timber ready for transportation</td>
<td>131</td>
</tr>
<tr>
<td>4.3</td>
<td>An example of the scorched ground and damage to young trees</td>
<td>133</td>
</tr>
<tr>
<td>4.4</td>
<td>An example of damage done to mature trees scorched from ground to approx. one metre up the trunk</td>
<td>133</td>
</tr>
<tr>
<td>4.5</td>
<td>Squirrel trap secured in the branches of a tree within the burnt section of the trapping grid. Regeneration of grass occurred within three months of fire</td>
<td>134</td>
</tr>
</tbody>
</table>
1 General Introduction

1.1 Squirrel taxonomy

Squirrels belong to the order Rodentia, which is the most diverse order of extant mammals with over 2100 species or 41% of all mammal species (Harris & Yalden 2008). Characterised by a distinct dentition, rodents have a single pair of incisors used for gnawing that are anteriorly positioned in the upper and lower jaws, a diastema (gap between incisors and first set of molars, where the canines and anterior premolars are absent) and reduced number of 3 – 5 pairs of cheek teeth (Harris & Yalden 2008). Incisors grow throughout a rodent’s life and are usually a yellow-orange in colour due to the colour of the enamel. Jaw muscles are arranged in a complex structure in order to facilitate the differential type of dentition and feeding behaviour. Rodents feed on seeds or other fruit but some are specialist herbivores, eating leaves and stems. Some are insectivores and a few are even specialist fish feeders. European species are mainly herbivores and granivores, though most also eat some insects (Harris & Yalden 2008). This feeding behaviour can be related to the area in which the rodent is found in the world. Rodents are widely distributed throughout all habitable continents and are found in a diverse number of habitats including desert, tundra and rainforest. They include different species that can be terrestrial and aquatic as well as arboreal and fossorial.

Rodentia is one of the most controversial orders with respect to its monophyly, relationships between families and divergence dates (Huchon et al. 2002). Both morphological and molecular studies have been used to try and correct the problems in rodent phylogeny. It has been suggested that the uncertainty has been due to the rapid radiation that occurred in the Paleocene rather than the presence of conflicting phylogenetic and non-phylogenetic signals in the dataset (Blanga-Kanfi et al. 2009). Figure 1.1 displays Carleton and Musser’s (2005) depiction of the order Rodentia in which they have broken the order into five suborders. Squirrels occur in the suborder Sciurotomorpha, which contains three families; Sciuridae, Aplodontiidae and Gliridae, with 307 living species in 61 genera.

The family Sciuridae is a large family with 289 species in 51 genera (Thorington & Hoffmann 2005), a family of arboreal and gliding squirrels, terrestrial marmots, ground squirrels and intermediate chipmunks. Squirrels are geographically cosmopolitan, found in a wide variety of habitats, occurring in most land masses apart from Madagascar, Australia, New Zealand and Antarctica (Harris & Yalden 2008). Until recently, the family Sciuridae was classified into two subfamilies; the Sciurinae (tree and ground squirrels) and the Pteromyinae (the flying squirrels) (Hoffman et al. 1993, Thorington et al. 2002). After studies on cranial morphology and genetic sequencing, it was found that tree squirrels were more closely related to flying squirrels than...
ground squirrels, thus a re-organisation of the traditional classification had to be applied (Steppan & Hamm 2006). Recent findings through molecular phylogenetics mean the family Sciuridae now comprises of five subfamilies (Thorington & Hoffmann 2005). Figure 1.2 displays the classification of the family Sciuridae based on studies by Mercer and Roff (2003) and Steppan et al. (2004) which also shows the further breakdown of subfamilies into known tribes. The subfamily Sciurinae has three tribes which consist of the Sciurini (tree squirrels), Pteromyini (flying squirrels) and Tamiasciurini (chickarees) (Steppan & Hamm 2006). Tree squirrels are known for their long bushy tails, sharp claws and large ears. Flying squirrels are known for gliding between trees; this is achieved by a furred membrane (patagium) which extends from the wrist to the ankle.

**Figure 1.1:** Order Rodentia classification according to Carleton and Musser (2005). (+) – extinct, (?) – phylogenetic positioning is uncertain.
The species of squirrels inhabiting Ireland belong to the genus *Sciurus*, a group of tree-dwelling squirrels with long bushy tails. There are 28 species in this genus that most commonly occur in North and Central America, with three species in the Palaearctic. The Eurasian red squirrel (*Sciurus vulgaris* Linnaeus 1758) is one such member of this genus. Figure 1.3 shows the red squirrel’s distribution which can be found across forests from Ireland in the west to Sakalin Island off the east coast of Russia and the northern Japanese Island, Hokkaido in the east. Their southern range runs along a line including the Mediterranean, the Caucasus Mountains, the southern Ural Mountains of western Russia and the Altai mountains in central Mongolia (Gurnell 1987). There are two other species of tree squirrel that share some of the range with the red squirrel, these are the Persian squirrel (*Sciurus anomalus* Gmelin 1778) and the Japanese squirrel (*Sciurus lis* Temminck 1844).
The earliest record of *Sciurus vulgaris* from the fossil record occurs from Hőrvölgy cave in Hór valley, southern Bükk Mountains, Hungary and has been aged to the middle of the Pleistocene era (Jánossy 1986). In Britain, the earliest record of *Sciurus* occurred in the Isle of Wight and radiocarbon data has dated it to 4,480 ± 100 years ago (Preece 1986).

The red squirrel is well adapted for a life in the trees with features for climbing and leaping, as the bones are relatively light and hind limbs are disproportionately long and heavy (Shorten 1962). The feet are semi-plantigrade with long toes, apart from the thumb, which is reduced and long curved claws. The tail is well developed for balance as well as for thermoregulation and can also be used as a signalling device (Lurz, Gurnell & Magris 2005). Its skull is relatively small (Plate 1.1), smooth and rounded with a deep, broadly ovate braincase and short, narrow rostrum (Harris & Yalden 2008). The red squirrel has the dental formula: I 1/1, C 0/0, P 2/1, M 3/3 with 22 in total (Lurz, Gurnell & Magris 2005), which are well adapted for the squirrel’s specialist feeding habits.

Red squirrels show no sexual dimorphism in size (Wauters, Lurz & Gurnell 2000) or fur colour. Sex can be determined by distance between genital opening and anus. In females they are close together whereas in males they are approximately 10 mm apart. Body size can range, with total body plus head measurements of 206 – 250 mm and the length of the tail 150 – 205 mm (Lurz, Gurnell & Magris 2005). Colour can vary geographically and seasonally. In winter months red squirrels have a thick deep red-brown coat, with thick ear tufts (2.5 – 3.5 cm in length). After the spring moult (which is one of two molts per year, the other being autumnal) the body colour is a lighter red-brown. Bleaching of the tail and ear tufts to blond or white is common in Ireland (Finnegan *et al.* 2009), ear tufts are reduced or absent in the summer (Harris & Yalden 2008).
1.2 Red squirrel biology

Red squirrels inhabit both coniferous and deciduous forests but mixed habitat offers the best resources, allowing squirrels to exploit a greater variety of food sources, which is of benefit in years of poor seed crop (Lurz et al. 1995). The density of squirrels differs depending on the type of habitat in which it resides; in coniferous and deciduous forests the average density can range between 0.5 – 1.5 squirrels per hectare (Lurz, Gurnell & Magris 2005), but year to year fluctuations can occur closely related to the weather and the availability of tree seed (Wauters & Lens 1995, Andren & Lemnell 1992). Squirrel densities increase in the year following a good seed crop, mainly due to high winter survival and increased breeding success during years with a large supply of tree seed (Gurnell 1983).

The red squirrel is diurnal (i.e. mainly active during daylight hours). In the winter the squirrel has a short, uninterrupted active phase (dawn to 1pm approx.) which is an adaptation for conserving energy in cold months; in the summer it has a longer active phase (dawn to 6pm approx.) that is usually broken by a rest period (Tonkin 1983, Wauters & Dhondt 1987). Most of this active time (75 – 91%) is spent foraging in the canopy, regardless of the season (Tonkin 1983). Tree seed makes up the majority of the red squirrel’s diet including pine cones from coniferous trees and fruiting bodies such as hazelnuts from broadleaved trees. When seed is scarce, red squirrels utilise food items such as fungi, buds and shoots and even animal matter (Moller 1983, Wauters & Dhondt 1987). Many studies have shown that food availability can cause annual population fluctuations (Wauters et al. 2008, Andren & Lemnell 1992) and also affect body weight (Wauters & Dhondt 1989a) and breeding success (Wauters & Lens 1995). Scatter hoarding is used by squirrels in order to store food for months when it is scarce. Cached seed is buried mainly in the autumn, the seed is relocated through sense of smell (Rice-Oxley...
1993). Adult males weigh approximately 240 – 340 grams and females weigh 220 – 355 grams (Harris & Yalden 2008). Weight can increase by approximately 10% over the winter months (Kenward & Holm 1989).

Red squirrels live in nests called dreys, which are elliptical in shape and are usually situated close to the tree trunk. They are made from twigs and leaves and are lined with moss, leaves/needles, dry grass and bark. A squirrel can alternate between 2 – 3 dreys in one time period (Lurz, Gurnell & Magris 2005).

The breeding season can begin as early as December, when testes grow and become scrotal in adult males, and females enter heat, and continue to early October when summer litters are weaned. Depending on female fecundity, two breeding peaks can be found within a season, spring-born litters (February – April) and summer-born litters (May – August) (Wauters & Dhondt 1995, Harris & Yalden 2008). Little courtship occurs other than a mating chase. Males attracted to a female by her odour can follow her for one or more hours, with the leading male in the group (usually the heaviest and most dominant) accounting for most of the matings (Wauters & Dhondt 1990). Young are born blind, deaf and naked and are about 10 – 15 grams (Gurnell 1987). Hair covers the body at 21 days and the young are weaned at 8 – 10 weeks.

Red squirrels can live up to six years in the wild, though high levels of juvenile mortality means the average life span is much lower. Causes of death are principally predation, starvation and cold weather (Lurz, Gurnell & Magris 2005). Predation of squirrels is mainly associated with animals such as the pine marten (Martes martes), stoat (Mustela erminea), fox (Vulpes vulpes), cat (Felis catus and silvestris), some owls (Asio and Tyto spp.) and raptors such as goshawk (Accipiter gentilis). Stoats have been found to take young squirrels from their nests and cats may take squirrels when they are on the ground. Humans can also kill squirrels through road kills by cars (Shuttleworth 2001) and destruction of habitat (Koprowski et al. 2006).

Red squirrels do not defend individual territories but instead have individual home ranges controlled by a social hierarchy within the population (Wauters & Dhondt 1992). Generally, dominant females maintain nearly exclusive core areas within their home range from other females (intraxsexual territoriality) and subordinate females live in home ranges that overlap partly with those of one or more dominant females, avoiding their core areas as much as possible (Wauters & Dhondt 1992). Adult males use larger home ranges than females and their home ranges overlap strongly with those of females and with those of other males (Lurz et al. 2000).

Dispersal is usually not sex-biased and local competition determines dispersal distances (Wauters, Casale & Dhondt 1994). However, a seasonal sex-bias can occur with more males dispersing in the spring and more females dispersing in the autumn (Wauters & Dhondt 1993),
this is related to mating behaviour and foraging habits (Lurz et al. 2000) with males looking for mates and females foraging for food.

### 1.3 History of squirrels in Ireland

The red squirrel is believed to have been a member of Ireland’s fauna since prehistoric times but may have become extinct during the ice age about 10,500 years ago, becoming re-established in the postglacial period. Suitable habitats developed by about 9000 years ago (Hayden & Harrington 2000). However, Ireland was isolated from Britain by then, so it is not clear whether it colonised naturally or was re-introduced. The red squirrel features in scripts by Augustin, an Irish writer of the 17th century, through the word “sesquivolos” (Barrington 1880). The red squirrel became extremely rare in Ireland if not extinct in the late 17th and early 18th century (O’Teangana et al. 2000), due to deforestation of extensive native forests (Scharff 1922) and exploitation for skins (Fairley 1984). Barrington (1880) reported that the red squirrel was introduced to ten localities between the years 1815 and 1875 from England. Recent genetic evidence now suggests that the current Irish red squirrel population is a mix of native (lineages that survived the deforestation in some large woods that remained throughout the country (Moffat 1923, Scharff 1923)) and translocated stock and that a number of colonisation events of the island may have taken place (Finnegan, Edwards & Rochford 2008).

The second species of squirrel inhabiting Ireland, the grey squirrel (Sciurus carolinensis Gmelin 1788), was introduced more recently. Native to the broadleaf forests of the eastern United States, the grey squirrel was introduced to Castleforbes, Co Longford in 1911 from English stock (Watt 1923). Since its introduction, it has proved to be a considerable forestry pest through bark stripping damage and competing with the native red squirrel species (O’Teangana et al. 2000). The grey squirrel is the larger of the two species – adult females weigh between 480 – 720 grams and males 500 – 650 grams (Lawton 1999) – and is distinguishable from the red squirrel by its brown-grey coat, lack of ear tufts and silver tail fringe.

### 1.4 The distribution of squirrels in Ireland

The first field based survey of squirrel distribution in Ireland took place in 1968 in response to damage caused to trees by squirrels in commercial plantations (NPWS 1968). O’Teangana et al. (2000) carried out a squirrel survey from which the expansion of the grey squirrel range was determined (Figure 1.4) and it was found to have spread into 22 of the 32 counties of Ireland. Carey et al. (2007) carried out the most recent survey of squirrels in Ireland. Its findings showed that the grey squirrel’s range included 26 of the 32 counties (absent in Cork, Kerry, Clare, Galway, Mayo and Sligo (Figure 1.5)).
Figure 1.4: Spread of the grey squirrel following its original introduction in Co Longford (O’Teangana et al. 2000, Carey et al. 2007)

Figure 1.5: Red squirrel (Left) and Grey squirrel (right) distribution published by Carey et al. (2007) based on 10 km squares.
The average rate of spread from the site of release has been approximately 3 km/year. Since 1997, grey squirrels have advanced into counties Wexford and Wicklow at a rate of 50 km in ten years. They have also pushed into counties Antrim, Tipperary and east Limerick.

Red squirrels are still widespread, but scattered, and are absent from areas of the midlands where the greys have been longest established. The river Shannon has acted as a natural barrier preventing the grey squirrel advancing into the west, however, there have been reports of breaches in three locations in counties Leitrim and Roscommon in the most recent survey (Carey et al. 2007). The grey squirrel has not established itself on the western side of the Shannon indicating that it is not just the river Shannon acting as a barrier to their spread west. The lack of suitable corridors linking forested areas and the overall gap between these woods has prevented easy movement in this region. The absence of both species in the far west of the country shows that the red squirrel has also struggled to become established in this region (Poole 2007). Historically there was very little suitable squirrel habitat there, but the planting of forest in the 20th century has created areas of substantial squirrel habitat, which may remain inaccessible to the populations due to the possible lack of dispersal corridors to reach them.

1.5 Competition

The decrease in red squirrel numbers has been attributed to the introduction of the grey squirrel. Interspecific competition has been the main contributing factor in the displacement of the red squirrel in Ireland (Carey et al. 2007).

In Britain, the grey squirrel was introduced from America in the late 19th century, the situation is more advanced and the grey has replaced the red squirrel in much of the country. Small red squirrel populations persist on the Isle of Wight (Rushton et al. 1999), in Thetford Forest, East Anglia (Venning et al. 1997) and in parts of Wales (Gurnell & Pepper 1993, Cartmel 1997), northern England and Scotland (Pepper & Patterson 2001). Competition and disease (SQPV) has had a leading role in the demise of the red squirrel in Britain. Grey squirrels have also been introduced into two locations in northern Italy; Candilol and Stupinigi forests in Piedmont in 1948 and Nervi Park in Liguria in 1966 (Bertolino et al. 2006), from which they may eventually spread into the rest of Eurasia (Wauters et al. 1997).

Evidence suggests that the grey squirrel is more efficient than red squirrels at exploiting broadleaf tree seeds and that competition for resources is the most significant factor in the replacement of red by grey squirrels (Kenward & Holm 1989) with the two species showing similar dietary preferences (MacKinnon 1978). Red squirrels occur at lower densities than greys in broadleaved woodland (Gurnell 1987). In Britain, this has been explained by the inability of red squirrels to predate upon acorns in the same way grey squirrels can, as oak (Quercus robur) are most abundant in British deciduous woods (Kenward et al. 1998).
Although red squirrel density and breeding are enhanced by the presence of hazel-nuts, modelling suggests reds will be replaced by greys when more than 14% of the tree canopy is made of oak (Kenward & Holm 1993). During winter months greys have been known to pilfer red squirrel food caches causing the reds to have a reduced energy intake and reduced reproductive output the following spring (Wauters et al. 2002). In broadleaved woodland, grey squirrels have been found to increase their body mass by 23% over winter, compared with only 12% for red squirrels (Kenward & Holm 1989). However, Lurz & Lloyd (2000) reported that neither species increased their weight in autumn or winter in conifer woodland. Therefore, increase in body weight, which can affect fitness, fecundity and juvenile recruitment, is subject to habitat type.

In general, the larger body mass of grey squirrels means they have larger fat reserves to exploit in poorer food conditions. The grey squirrel also has a more varied diet than the red which is a specialist feeder (Harris & Yalden 2008).

Wauters, Lurz & Gurnell 2000 reported that grey squirrels occurred at higher densities at red-grey sites and tended to have higher breeding rates. In the presence of greys there was little recruitment of sub-adults to red squirrel populations. Red squirrels are also known to undergo population fluctuations (Andren & Lemnell 1992) related to seed supplies, winter temperature (Wauters & Dhondt 1990) and predation. Grey squirrels may take advantage of times of low red squirrel population density by occupying richer food patches in the habitat (Wauters, Lurz & Gurnell 2000).

Another threat to red squirrel populations is the squirrel poxvirus (SQPV) which has further contributed to the decline of red squirrels and their replacement by the grey squirrel in Britain (Tompkins et al. 2003). The grey squirrel acts as a reservoir host to the pathogen (Bruemmer et al. 2010), which can cause death in red squirrels within two weeks of infection, while the grey squirrel only displays an antibody response. The introduction of the disease to red squirrels was attributed to the introduction of the grey squirrel (Sainsbury & Gurnell 1995). SQPV has been reported as another form of interspecific competition and has influenced the decline of the red squirrel in England and Wales (Rushton et al. 1999, Gurnell et al. 2006). Until recently no infected squirrels had been found in Scotland but reports now suggest that the virus has appeared in south Scotland (McInnes et al. 2009). Within the last year, communications have reported the first confirmed outbreak of SQPV in Ireland with four definite incidences and one suspected case. These outbreaks were discovered first in counties Down and Antrim (Dr Declan Looney, Northern Ireland Environmental Agency) Northern Ireland. This was then followed by a suspect outbreak in Co Wicklow (Dr Ferdia Marnell pers. comm), which has now been confirmed by pathology report (Sean Callanan, UCD) as squirrel pox. Another case has now also been confirmed in Co Wicklow and a new suspected case has been found in South Dublin.
Ferdia Marnell *pers. comm.*. Tompkins *et al.* (2003) showed that the virus has played a crucial role in the decline of reds in the UK and that the monitoring of this disease will play a vital role in the conservation of the species.

1.6 Legislation and conservation

The red squirrel is protected under the Irish Wildlife Act 1976 and the Irish Wildlife Amendment Act 2000, meaning it is illegal to intentionally injure, hunt or kill the animal. It is also listed under Annex III of the Bern Convention for Conservation of European Wildlife and Natural Habitats. Although considered to be of “Least Concern” at an international level ([www.iucn.org](http://www.iucn.org)), *Sciurus vulgaris* is listed as “Near Threatened” in Ireland’s most recent Mammal Red List (Marnell *et al.* 2009) alongside the otter (*Lutra lutra*) and Leisler’s bat (*Nyctalus leisleri*). The red squirrel has reached this status due to the 20% decline in range since 1911. It is not however listed in the Habitats Directive, which means it is not seen as a priority species for conservation at a European level.

Eradication of the grey squirrel from Ireland is not an option as their distribution is too widespread to make it feasible, but targeted grey squirrel control can be used as a means of conserving red squirrels (Lawton 2005). In order to conserve the red squirrel while accepting the presence of the grey, the two species must be separated either by habitat or geographically. By habitat means creating conifer-only forests in which studies have shown that red squirrels do well but grey squirrels may struggle (Smith & Gurnell 1997). Although both squirrel species show no particular advantage in productivity in a coniferous environment (Kenward *et al.* 1998), red squirrels display the ability to reach pine and spruce cones on fine branches that the heavier grey squirrel cannot. It has also been suggested that large areas of seed producing broadleaved trees would be required to enable the initial invasion of greys into a conifer habitat (Gurnell & Pepper 1996). However, once they have established grey squirrel breeding and density can be correlated to the abundance of pine cones (Kenward *et al.* 1998). Studies have shown that red squirrels will inhabit spruce areas readily at red-grey sites avoiding competition with the grey in pine areas (Wauters, Lurz & Gurnell 2000). Separating the species geographically means using natural barriers of unfriendly squirrel habitat. Such barriers include natural landscape such as lakes, rivers, mountains and peat-land, which do not facilitate squirrel dispersal, helping prevent grey squirrels from colonising beyond the barrier.

Other than the threat from grey squirrel competition, red squirrel populations in Ireland and the UK can also be threatened by habitat fragmentation and disease. A Species Action Plan for the red squirrel was published by the UK Government as part of the UK Biodiversity Action Plan (UK BAP 1994) outlining conservation tactics to protect populations that were under threat. Its main aims were to maintain populations of red squirrels where greys were absent or rare, where possible to expand red populations that were isolated or too small or in close proximity to grey
populations and to reintroduce red squirrels to their former range where the ecosystem is managed to support a viable population. These aims were to be based on conservation management principles such as maintaining or improving habitat to sustain red populations and minimising competition by greys (Pepper & Patterson 2001). In Northern England, these aims were to be put into practice through the establishment of buffer zones approximately 5 km wide, ringing an area in which red squirrel populations can be protected by deterring grey squirrel establishment and the threat to the reserve (EWGS 2005). Strategies for protecting the red squirrel were also applied in Scotland (Scottish strategy for red squirrel conservation 2004) with the aims to maintain the current range of reds, to monitor changes, prioritise woods where conservation work can be focused and to improve woodlands for red squirrels as well as reducing the threat from greys. These programmes also help raise awareness amongst the public as well as adding to red squirrel conservation research.

In 2008, the National Parks and Wildlife Service in the Republic of Ireland and the Environment and Heritage Service Northern Ireland published an All Ireland Species Action Plan for the conservation of the red squirrel in Ireland (NPWS & EHS 2008). The aims of the Action Plan include restricting the contraction in range of the red squirrel to a minimum, extending its range to new areas of favourable habitat and ensuring the needs of the red squirrel are met by planning authorities, nature conservation strategies and forest strategies. The Action Plan further proposes to reach agreement on cross-border strategies for red squirrel conservation and the use of grey squirrel control methods, to evaluate red squirrel translocation research and formulate policy with regard to future translocations.

The Mammal Ecology Group at the National University of Ireland, Galway has been conducting research on translocation as a conservation tool for red squirrels since 2005 (Poole & Lawton 2009).

1.7 Translocation

The intentional release of animals to the wild in an attempt to establish a viable free ranging population is known as translocation (Griffith et al. 1989). Other various terminology has also been used to describe this movement such as relocation, re-introduction, re-stocking or repatriation (Dodd & Seigel 1991, Wolf et al. 1996). Given the high level of species extinction rates, translocation has become an important tool in nature conservation (Nolet et al. 1997).

Translocation is used as a tool for the management of the natural and man-made environment to bring about benefits to natural biological systems and man (IUCN 1987). However, if misused translocation can have the potential to cause enormous damage (Hodder & Bullock 1997) for example adverse effects on species and the habitat at release sites (Cunningham 1996), genetic out-breeding and hybridisation (Rhymer & Simberloff 1996), impact on donor sites, unwanted
competition and/or out-break of disease and predation (Hodder & Bullock 1997). Therefore the International Union for Conservation in Nature (IUCN) have published stringent guidelines to follow when undertaking translocation (IUCN 1987, 1998).

Translocation has been used as a means to re-introduce an extinct species, to re-establish a threatened species or to aid in the dispersal of a species to its former range. Other uses of translocation include the bolstering of genetic heterogeneity of small populations, establishing satellite populations to reduce the risk of species loss due to catastrophes and speeding recovery of species after their habitat has been restored or recovered (Griffith et al. 1989). The movement of individuals into a new area in order to restock the resident population has also been used for hunting purposes (Kleiman 1989) and to provide prey species for threatened predators, such as restocking of wild rabbits (*Oryctolagus cuniculus*) in Spain as a prey species for the Iberian Lynx (*Lynx pardinus*) and the Imperial and Bonelli eagles (*Aquila adalberti* and *Hieraaetus fasciatus*) (Letty et al. 2002).

### 1.8 Post-release monitoring

Post-release monitoring is an essential aspect of a translocation programme and is integral in identifying the success or failure of a project. The IUCN (1987, 1998) direct that where possible long-term research to determine the changing status of a new population should be conducted, identification of the need of further releases carried out and the reasons behind the success or failure should be established.

Extensive monitoring of translocated populations has been the subject of many studies (Bright & Morris 1994, Goosens et al. 2005), however, this is not always the case and monitoring can be neglected (White et al. 2003, Hodder & Bullock 1997). When defining a translocation as a success or failure, by certain criteria, the overall outcome of success can be limited by the time in which monitoring is carried out (Seddon 1999). If the aim is to establish a self-sustaining population, then the given project can say it has achieved its aim only at the time of which the assessment has been made. The aim to determine success or failure of a translocated population may be examined through short-term monitoring procedures.

In a review of the changing status of reintroduction projects (Wolf et al. 1996), 5% of projects were found to have a declining population 6 years on. Therefore, reports of “successful” translocations imply an endpoint which may deem further releases or monitoring unnecessary (Seddon 1999). There is a general consensus that translocation programmes need to spend more time on long-term monitoring, at specified time intervals (Fisher & Lindenmayer 2000, Dodd & Seigel 1991). This however may add a further expense to the project.
During the medium-term, post-release monitoring can not only be used as a method to assess the current status of translocated populations, which may include survival of the released generation, breeding of the released generation and their offspring, and the persistence of the re-established population, but also to regularly assess the degree of intervention necessary (Seddon 1999). Such intervention may include further releases, veterinary care, predator control, supplementary feeding or habitat management where applicable. This ensures that problems are identified at an early stage as well as facilitating decisions about the future of the project (Carter et al. 1999) including long-term monitoring.

### 1.9 Project Aims

The main aim of this project was to investigate red squirrel populations following translocation to previously uninhabited woodlands. The first aim of the study was to complete a red squirrel translocation in the west of Ireland. Following the release of red squirrels short-term success of the translocation was examined. This assessment aimed to investigate the survival of squirrels immediately after translocation, to examine settlement and spread of the new population and to monitor the breeding condition of squirrels and recruitment of new progeny.

The second aim of the project was to investigate establishment of two red squirrel populations after translocation in the medium-term, and their subsequent spread throughout available habitat. The overall fitness of the populations was determined using breeding condition, recruitment, population density and individual health. Suitability of each habitat was investigated by the availability of resources such as cone crop.

The third and final aim of the project was to examine the long-term prospects of both populations. This was achieved by considering the threats to the populations through habitat loss and the potential invasion of the grey squirrel into the region.
2 Translocation and early post-release settlement of a red squirrel population in the west of Ireland

2.1 Introduction

2.1.1 Considerations for translocation

When conducting a translocation many factors have to be considered; the suitability of the target habitat that the animals are being released into to support the long-term survival of a species, the use of wild stock or captive stock for translocation and whether the source population can survive the removal of individuals. Source populations should be closely related genetically to native stock as those that originate from different environments risk being poorly adapted to the new area (IUCN 1998). The findings of Wolf et al. (1996) indicate that releases into the centre of a species’ historical range are more likely to succeed than those released on the outside or the periphery of its range.

There are two main types of techniques that can be used during a translocation study; soft release (using an enclosure to acclimatise animals in the new area) or hard release (immediate release of animals in the new area). Studies using soft release have shown that animals have a tendency to remain within the vicinity of the enclosure and have a high level of site fidelity (Poole & Lawton 2009, Eastridge & Clark 2001), which can prevent greater dispersal and increased mortality. In studies using a hard release programme, mammals have shown a high tendency to navigate back to the site of removal depending on the distance they are moved. Ground squirrels (*Spermophilus beecheyi*) in California had to be moved at least 1500 metres in order to prevent homing back to the removal site (Van Vuren et al. 1997) and the most commonly translocated ursid, the black bear (*Ursus americanus*), has been known to navigate a distance of 229 km back to its native site (Rogers 1984). During the translocation of gopher tortoises (*Gopherus polyphemus*) in south Carolina in the USA, penning was used as a method to test for site fidelity and it was found the longer the tortoises spent within the pen the shorter distance they dispersed upon release, showing a significantly higher site fidelity (Tuberville et al. 2005). In general, it seems that juveniles move more after their release than adults; this is related to poorer site fidelity associated with young animals (Linnell et al. 1997). However, young individuals are prone to high mortality whereas adults experience a higher survival during reintroductions in natural populations (Sarrazin & Legendre 2000).

The welfare of the animals to be released is also of high priority and any means to reduce stress while transporting animals to the target site is fundamental to the overall success of a project.
For example, during the re-introduction of the Eurasian otter (*Lutra lutra*) to North-eastern Spain, individuals were assessed and transported once they had been chemically immobilised (Fernández-Morán *et al.* 2002) in order to reduce stress during transportation as well as for the ease of handling individuals. Tranquilisers were also used to reduce the stress in a translocation of European rabbits, however it was found that their use did not increase survival and in fact environmental stress seemed to override handling stress in the study (Letty *et al.* 2000). The use of such techniques would be important in translocation of large mammals such as certain carnivores and ungulates.

### 2.1.2 History of red squirrel translocation in Europe

There have been nine main translocation studies of red squirrels in the last 25 years in Ireland, Britain and the rest of Europe in which success and failure were reported. Of the nine studies three failed to establish red squirrel populations (Bertram & Moultu 1986, Jackson *et al.* 1998, Kenward & Hodder 1998) due to either the presence of the grey squirrel and/or squirrel pox virus. Five were successful (Fornasari *et al.* 1997, Wauters *et al.* 1997, Shuttleworth *et al.* 2008, Poole & Lawton 2009, Dennis *et al.* 2011) in establishing a red squirrel population. The ninth study (Venning *et al.* 1997) comprised of four release studies in which overall success was achieved due to the establishment of red squirrels into the population. However, the outbreak of disease and presence of the grey squirrel caused failure in two of the four studies. Each translocation advanced the methodology, with recommendations being taken on board in subsequent translocations.

Six of the projects used a soft release programme and two used a hard release, one used both soft and hard release techniques. Each of the soft release methods used a different sized enclosure and the time that the squirrels spent within the pen varied. In theory, using a soft release ensures the translocated animal’s original site fidelity is lost meaning they are less likely to flee the area upon release. It also allows the animals to become accustomed to feeding stations, thus when released, recognise supplementary feeding platforms. However, soft release may cause problems when animals become reluctant to leave the enclosure (Venning *et al.* 1997) or if disease is an issue (Jackson *et al.* 1998). In situations where the public is privy to the project, soft release can help impress the importance (through due care and diligence) and scope of the project. Soft release can also increase the survival prospects of individual squirrels, if not the whole population.

Supplementary food was used during all the soft release programmes and one hard release (Fornasari *et al.* 1997) which provided the red squirrels with excess food in enclosures and in areas of the woodland surrounding the release site. In the study of Bertram and Moultu (1986) where grey squirrels were present, selective feeding hoppers were designed to allow red-only
access. Supplementary food however is not a substitute for natural food sources and the availability of seed crop in woods remains an important supply of nutrition for red squirrels (Shuttleworth 1997a). In general, supplementary feeding allows a strong increase in recruitment (Klenner & Krebs 1991) and can also be used as a possible incentive to prevent excursions away from the release site (Poole & Lawton 2009).

Shuttleworth et al. (2008) and Venning et al. (1997) included important information on the selection of donor and release sites, logistics on transportation, releasing and monitoring squirrels. Venning et al. (1997) also set targets to measure initial success based on survival, with an initial target of >75% survival from the enclosures and a further survival of 50% through to the following year’s breeding season.

Table 2.1 displays the eight previous red squirrel translocations described and incorporates the current study. This provides a clear breakdown of success or failure of each translocation and the differences in each set up.

<table>
<thead>
<tr>
<th>Location</th>
<th>Type of translocation</th>
<th>Habitat type</th>
<th>Success Yes/No</th>
<th>Reason for failure</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parco Groane, northern Italy</td>
<td>Hard release</td>
<td>Mixed</td>
<td>Yes</td>
<td>N/A</td>
<td>Fornasari et al. 1997</td>
</tr>
<tr>
<td>Antwerp, Belgium</td>
<td>Hard release</td>
<td>Mixed</td>
<td>Yes</td>
<td>N/A</td>
<td>Wauters, Somers &amp; Dhondt 1997</td>
</tr>
<tr>
<td>Thetford Forest, East Anglia, UK</td>
<td>Soft release</td>
<td>Conifer</td>
<td>Yes</td>
<td>N/A</td>
<td>Venning et al. 1997</td>
</tr>
<tr>
<td>Poole Harbour, Dorset, UK</td>
<td>Soft release</td>
<td>Conifer</td>
<td>No</td>
<td>Presence of grey squirrel</td>
<td>Kenward &amp; Hodder 1998</td>
</tr>
<tr>
<td>Colwyn Bay, Wales</td>
<td>Soft release</td>
<td>Mixed</td>
<td>No</td>
<td>SQPV</td>
<td>Jackson et al. 1998</td>
</tr>
<tr>
<td>Anglesey Island, Wales</td>
<td>Soft release</td>
<td>Conifer</td>
<td>Yes</td>
<td>N/A</td>
<td>Shuttleworth et al. 2008</td>
</tr>
<tr>
<td>Derrycclare wood, Ireland</td>
<td>Soft release</td>
<td>Mixed</td>
<td>Yes</td>
<td>N/A</td>
<td>Poole &amp; Lawton 2009</td>
</tr>
<tr>
<td>Dundonnell Estate, Scotland</td>
<td>Soft and Hard release</td>
<td>Mixed</td>
<td>Yes</td>
<td>N/A</td>
<td>Dennis et al. 2011</td>
</tr>
</tbody>
</table>

Table 2.1: History of the main previous red squirrel translocations throughout Europe.
2.1.3 Background to Belleek Forest Park translocation

After the success of the translocation of red squirrels to Derryclare wood, Co Galway in 2005 by Dr Alan Poole (Poole 2007) as part of his PhD with the Mammal Ecology Group at NUI Galway, a second translocation was initiated in 2006.

An assessment of Belleek Forest Park, Ballina, Co Mayo for the suitability for a red squirrel translocation was carried out (Lawton 2006) as commissioned by the National Parks and Wildlife Service (NPWS) in response to an application by the Belleek Forest Enhancement Committee to introduce red squirrels to the wood. The 2006 report fulfilled part of the conditions set down under the IUCN guidelines (1998) in which it is recommended that a feasibility study and background research is carried out. The report found that Belleek Forest Park was an isolated woodland with the nearest substantial blocks of woodland 13 km south, 15 km west and 16 km east. Lawton (2006) also pointed out that the K for Belleek was low (65 squirrels), however given the suitability of the habitat, the chances of survival could be strong. The Minimum Viable Population (MVP) of red squirrels has been suggested to consist of 200 individuals (Gurnell 1996 as cited by Shuttleworth & Gurnell 2001). However, there are a number of habitats around Ireland that have less than a MVP of 200 (e.g. in Portumna Forest Park, Galway, Lough Key Forest Park, Roscommon, Charleville, Offaly). This suggests that perhaps 200 is a large minimum number.

The next step was to find an appropriate source population. This is an important element of the translocation process as any removal of animals from a donor site must have no impact on the source population (Lawton 2006, IUCN 1998). IUCN guidelines (1998) suggest that the source population should ideally be closely related genetically to the original native stock and show similar ecological characteristics. Tests of genetic relationships between populations throughout Ireland show a genetic and morphological divergence between regions (Finnegan et al. 2008). As such, potential donor sites were chosen from the northwest region of Ireland and were within a distance of 50 km and a travel time of one hour. Transportation distance and time from target site were kept to a minimum to ensure as little stress as possible to animals (Poole 2007). Squirrels sourced from the west of Ireland, which is free of grey squirrels, also have not been exposed to the SQPV, a major determining factor in the success or failure of red squirrel translocation. Suitability of the donor woodland was assessed and the source population was investigated prior to translocation to ensure individuals were fit and healthy.

It was recommended that a soft release system be used, meaning red squirrels would be introduced to the woodland via an enclosure, with the animals retained in the enclosure for 4 – 6
weeks before release. The number of animals chosen for release has an important effect on whether the translocation will be successful or not (Griffith et al. 1989, Wood et al. 2007).

Poole’s (2007) population model based on red squirrel translocation data, recommended that a minimum initial breeding population of 13 individuals (with at least 7 females) be introduced. Poole (2007) stated, as the population may be over-wintering before they reach their first active breeding season, a minimum number of 19 to 20 individuals should be translocated, allowing a survival rate of 67% through the winter. A target of 15 – 20 individuals was therefore chosen to allow for some mortality before breeding (Finnegan 2007).

The timing of the translocation was another key factor that was considered, the squirrels needed to be released from the enclosure prior to winter months, to enable them to begin to forage and cache foods and construct dreys while there were enough natural resources in the woodland (Poole & Lawton 2009). Translocating them in early spring may mean that that year’s breeding season is lost, and mortality high before the next breeding season. During autumn months, squirrels are notoriously difficult to catch when natural food levels are high (Gurnell & Pepper 1993).

The translocation began in March 2007 by Dr Laura Finnegan (2007) under NPWS contract and licence; this was to become phase one of a three phase translocation. Each phase included the removal of individuals from the donor site until their release from the enclosure at the target site. Finnegan chose two potential donor sites based on their size (a larger source site is less likely to be impacted by the translocation) and distance (within 50 km) from Belleek Forest Park. The first woodland chosen was Lough Key Forest Park (G825 075), just outside Boyle, Co Roscommon. It is approximately 200 ha of mixed wood, managed as an amenity forest. The second woodland chosen was Union wood, Ballysadere, Co Sligo (G685 285). It is approximately 300 ha of mainly sitka spruce and is managed for commercial purposes. The work was carried out with the permission and cooperation of the woodland owners Coillte Teoranta.

Donor sites were assessed to ensure that the source population was healthy and capable of surviving after individuals had been removed from the habitat. Assessments were made using live trapping; results estimated a density of 0.22 squirrels/ha for Lough Key Forest Park and 0.16 squirrels/ha for Union wood. Trapping success was quite low during this assessment and hence the estimations were believed to be very conservative. It also had an influence on the number translocated which in phase one was only five individuals. A further nine red squirrels were removed from Lough Key Forest Park in subsequent phases. Following the removal of red squirrels from donor sites the potential impact was monitored. Hair tube surveys were carried out to assess the post-translocation status of the donor site (Goldstein 2009). The results
indicated a density of 0.319 squirrels/ha for the complete sampling area. Compared to the pre-translocation density of 0.22 squirrels/ha this suggests that the population at Lough Key had not been impacted by the removal of individuals. Although hair tube analysis may not be as accurate as live trapping data, it does suggest a lot of squirrels were active in Lough Key after translocation had taken place.

In total only one squirrel was removed from Union wood, this was due to a poor capture rate and lower density of squirrels at the site. As such investigations into this site to evaluate density were deemed unnecessary. However, the local Forest Manager (Coillte) was contacted to confirm that red squirrels were still a common sight at the woodland.

2.1.4 Aims and Objectives

Still very little is known about the practical problems connected with re-introducing red squirrels and data on squirrel behaviour, adaptation and survival after release are limited (Wauters et al. 1997). Following the successful translocation of red squirrels to Derryclare wood, this study aims to further enhance the information gathered by Poole & Lawton (2009) by investigating translocated squirrels in differing habitats.

The main aim was to complete the translocation of red squirrels to Belleek Forest Park. The same criteria for initial success was adapted for the Belleek translocation as outlined by Venning et al. (1997) and used by Poole (2007). These were as follows:

1. A percentage of at least 75% of red squirrels must successfully be released from the enclosure.
2. At least 50% of red squirrels released must survive to the following year’s breeding season.
3. The subsequent population must begin to breed successfully.

Once the first task had been achieved and the red squirrels were translocated, objectives were set out to investigate the settlement of the population. These were:

- To determine settlement pattern as displayed by home range and core area usage.

- To relate settlement pattern to availability of resources such as supplementary food and natural habitat.
2.2 Materials and Methods

2.2.1 Target site

Belleek Forest Park (Figure 2.1, G25 21) is situated alongside the river Moy, approximately one mile from Ballina town, Co Mayo. Since 1950, the majority of the woodland has been managed by the Irish State and is now owned by Coillte Teoranta. The wood was originally managed for timber production, however, in more recent years Belleek wood has been used for recreation by the adjoining town of Ballina and the wider community. Over the last thirteen years (1999 – 2012) Belleek Forest Park has been managed by the Belleek Forest Park Enhancement Committee (BFPEC) in order to create an amenity woodland. Coillte in conjunction with the BFPEC have detailed a management scheme for Belleek woodland until 2030 (Tiernan et al. 2009).

The main block of Belleek Forest Park is approximately 61.5 ha of mature woodland with 18.1 ha of adjacent blocks, giving a total available woodland habitat of 79.6 ha. The woodland is predominately coniferous trees (61%), with 30% broadleaf and 9% open space. Norway spruce *Picea abies* is the most dominant species occurring in 25.9 ha of woodland. Other coniferous species include Scots pine *Pinus sylvestris*, sitka spruce *Picea sitchensis*, larch *Larix kaempferi* and Monterey pine *Pinus radiata*. The next largest group is beech *Fagus sylvatica* which accounts for 7.6 ha. Other broadleaf species include oak *Quercus* sp., ash *Fraxinus excelsior*, sycamore *Acer pseudoplatanus*, birch *Betula pendula* and elm *Ulmus* sp. The understorey is mainly comprised of brambles *Rubus fruticosus*, holly *Ilex aquifolium* and ferns. Invasive species such as laurel *Prunus laurocerasus* is found within the woodland but rhododendron *Rhododendron ponticum* has been almost completely removed.

Coillte has derived a management plan to thin certain areas of woodland to promote the growth of the remaining trees and allow the undergrowth to develop. Saplings will also be planted with “squirrel friendly” species such as Scots pine and hazel *Corylus avellana*. This will allow the woodland to become a much more sustainable habitat with a staggered age structure. This will be of benefit to the squirrels as seed crop will be available in the future and ensure continuous canopy cover will be available into the future, which will allow the squirrels to navigate between patches of woodland with ease.
Figure 2.1: Map of Belleek Forest Park including tree species composition (adapted from Tiernan et al. 2009).
2.2.2 Translocation procedure

The translocation of red squirrels to Belleek Forest Park was conducted in three phases, phase one was conducted by Dr Laura Finnegan (Finnegan 2007) under contract from the NPWS. Phases two and three and the initial radio telemetry and live trapping were conducted by Nicola Condell of the Mammal Ecology Group, NUI Galway. All other work (after August 2008) was conducted by the author and all data collected was analysed by the author.

The translocation procedure began with the live trapping of individuals from source populations. Traps were set at first light and were left for at least three hours before they were re-checked. Red squirrels were chosen for translocation based on the condition of the individual which considered weight, breeding condition, shin bone length and health assessment. Only squirrels with a weight of 210 g or greater were translocated (Poole & Lawton 2009), making sure juveniles and potentially unhealthy individuals were not moved; pregnant or lactating females were also not considered. All squirrels that were chosen to be translocated were marked with a Trovan Passive Integrated Transponder ID-100 PIT tag.

A soft release programme as described by Poole & Lawton (2009) and Venning et al. (1997) was used. Squirrels were transported from the donor site to the release site in re-enforced pet carriers. Once the release site was reached squirrels were released into a holding enclosure built by the BFPEC. The enclosure was made from slanted timber poles around a Monterey pine tree surrounded by wire mesh, standing approx 10 m in height (Plate 2.1). The wire mesh was buried 30 cm under the ground; six nest boxes and a feeding platform were placed inside.

A mixture of peanuts, maize, sunflower seeds, walnuts, hazelnuts and pine cones were provided at all times. Sliced apple and water were also available and replenished every two days. Individuals were to be kept in the enclosure for four weeks with no more than six squirrels in the enclosure at any one time. A total of 15 red squirrels were translocated to Belleek Forest Park, five were released during phase one, four during phase two and six individuals during phase three; male to female ratio was 1:2. Eight supplementary feeders were positioned throughout the woodland and were filled with a mix of peanuts, maize and hazelnuts and replenished twice a week (Figure 2.2 and Plate 2.2).
Plate 2.1: Soft release enclosure constructed by the BFPEC including feeding platform and nest boxes.

Plate 2.2: Supplementary feeder secured to a tree, filled with maize and peanuts.
**Figure 2.2:** Locations of the enclosure (x) and supplementary feeders (•) at Belleek Forest Park (OSI 2005).
2.2.3 Radio telemetry

In April 2008 after the second phase of translocation of the red squirrels was complete, the initial settlement patterns of six individuals were monitored by radio telemetry. Three females and three males were chosen at random and each was fitted with a radio collar (SOM-2190, Wildlife Materials International, Illinois, USA). Fixes were recorded, with a gap of at least three hours between to avoid auto-correlation, until 30 fixes in total were gathered for each individual. In total fixes were gathered between three to four weeks. Signals were picked up with a TRX-1000s receiver and Yagi antenna. Each squirrel’s position was recorded using a Garmin Extrex Venture GPS. Individual home ranges and core areas were analysed using Arcview GIS 9.3 and are presented using peeled minimum convex polygons (MCP) (Bath et al. 2006). Home range size was based on 95% MCPs, those squirrels with ranges expanding out into areas in which squirrels would not be found such as the river Moy were adjusted and calculations did not include these areas. Core areas were determined by plotting the percentage home range against the percentage of fixes (peeled MCPs). The inflection point in this graph indicates that a significant increase in the home range has resulted from an increase in the number of fixes; the percentage of fixes where this inflection occurs is taken as the core area (Reilly 1997) as shown in Figure 2.3. Core areas were then expressed as a percentage of home range which was converted to a ‘core usage factor’ by comparing this figure with the core area usage for each individual.

![Graph](image)

**Figure 2.3:** Percentage range against peeled MCP (percentage of fixes) for male 306. The inflection point indicates the percentage fixes corresponding to core area (85%).
Eighteen months after the initial radio-tracking was undertaken, another session was conducted in September 2009. Eight individuals were fitted with collars, four female and four male. Individuals were collared randomly from those captured during live-trapping sessions.

### 2.2.4 Live trapping

Live trapping was conducted between August 2008 and May 2011, 35 traps were placed at a density of one per hectare in sections of Belleek Forest Park and their location marked on a Garmin Extrex GPS (Figure 2.4a). In February 2010, the trapping grid was adjusted, with a redistribution of the traps, to incorporate areas of the woodland that were previously untrapped (Figure 2.4b). In order to potentially capture individuals previously uncaught and enhance population estimates.

Traps were based on the design of a converted mink trap with a nest box attached, each trap worked off a treadle system in which the door snapped shut once the occupant had entered the trap (Plate 2.3). Traps were placed at a height of approximately 1.5 to 2 m in a tree and secured between branches or with rope where necessary. Each trap was baited with a mix of whole maize, peanuts and hazelnuts. Hazelnuts were only placed behind the treadle at the end of the trap to attract individuals onto the treadle.

Before each trapping session, each trap was pre-baited three times within a weekly period; trapping mechanisms were disarmed during this time. Three or four trapping days were undertaken following the last day of pre-baiting depending on the season and the daylight hours available. Four trap days were conducted in the autumn/winter period (September to February), when day-length was shortest. Each trap was set just after dawn and left for at least four hours before being checked. Four days of trapping was conducted, with the exception that if on the third day of trapping all squirrels caught were recaptures, then only three days were conducted (Reilly 1997). During the spring/summer period (March to August) three days trapping followed pre-baiting, during this period traps were left for longer after being set (at least six hours).

Once a squirrel had been caught in the trap, it was then transferred into a handling cone (Plate 2.4) from which its sex, weight (to the nearest five grams) using a Pesola precision spring balance (Plate 2.5) and shin bone length were measured (to the nearest 0.1mm) using Vernier callipers (Plate 2.6). Each squirrel was marked using a passive integrated transponder (PIT tag, Plate 7) which was injected into the scruff of the neck. On re-capture squirrels could then be scanned with a Trovan PIT tag reader, which displays an individual code.

The breeding status for each squirrel was also considered. In males, the size and location of the testes were ascertained. Juvenile and sub-adult males have abdominal testes with no scrotal sac.
Adult males have a scrotal testes and were judged to be in reproductive condition according to the presence of yellow/brown stain around the scrotal region attributed to scent marking (Gurnell 1987). Females were determined as being non-reproductive (nipples invisible, vulva not swollen) or positively reproductive (i.e. in oestrus (vulva swollen and pink, perforated), actively lactating (nipples large with surrounding hair loss indicating suckling young), or pre/post lactation (prominent nipples, no signs of hair loss)).

In order to further assess fitness an index of body condition of each translocated squirrel was calculated. Body condition was calculated by dividing body weight by shin bone length (Wirsing et al. 2002).

The age class of newly recruited squirrels was based on the fact that there was no immigration and that all new progeny were from resident squirrels. Therefore, new recruits joining the population were juvenile, sub-adult or were detected as adults. Determination of which age class an individual belonged to was based on weight, time of year of first capture and breeding status.
Figure 2.4: Location of live squirrel traps at Belleek Forest Park; 
A – August 2008 to November 2009 and 
B – February 2010 to May 2011
Plate 2.3: Live squirrel trap secured in branches of a tree.

Plate 2.4: Red squirrel held in a handling cone.
Plate 2.5: Red squirrel being weighed with a Pesola spring balance.

Plate 2.6: PIT tag (left) and measuring a squirrel’s shin bone length (right) with a set of Vernier callipers.
### 2.2.5 Work Schedule

Table 2.2 displays a month by month schedule for the process of translocating red squirrels to Belleek Forest Park. It includes the initial donor site monitoring schedule which consisted of live trapping, and the months in which squirrels were transported to and released in phases one to three of translocation. Initial monitoring used in the assessment of the translocation continues in Chapter 3 of this project with post-release monitoring.

<table>
<thead>
<tr>
<th>Years</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Donor site monitoring</td>
<td>Lough Key Forest Park</td>
<td>Union Wood</td>
</tr>
<tr>
<td>Translocation</td>
<td>Phase one</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phase two</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phase three</td>
<td></td>
</tr>
<tr>
<td>Post-translocation monitoring</td>
<td>Live-trapping</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radio tracking</td>
<td></td>
</tr>
<tr>
<td>Supplementary feeding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* First radio tracking session April 2008, the second is not situated in this table as it was conducted in September 2009 – 18 months later. Supplementary feeding was available to the squirrels officially until June 2010.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.2: Work schedule for translocation of red squirrels to Belleek Forest Park.
2.3 Results

2.3.1 Translocation

In total 15 red squirrels were translocated to Belleek Forest Park at a ratio of male to female 1:2. Table 2.3 displays the 15 squirrels including their weight and shin bone length at the time of translocation. Of the 15 squirrels translocated, 14 were taken from Lough Key Forest Park and one from Union wood, Co Sligo.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Sex</th>
<th>Weight (g)</th>
<th>Shin bone length (mm)</th>
<th>Body Condition Index</th>
<th>Donor site</th>
<th>Freq ID:</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Male</td>
<td>315</td>
<td>64.1</td>
<td>4.91</td>
<td>Lough Key</td>
<td>165</td>
</tr>
<tr>
<td>One</td>
<td>Female</td>
<td>260</td>
<td>62.8</td>
<td>4.14</td>
<td>Lough Key</td>
<td>339</td>
</tr>
<tr>
<td>One</td>
<td>Female</td>
<td>320</td>
<td>63.7</td>
<td>5.02</td>
<td>Lough Key</td>
<td>265</td>
</tr>
<tr>
<td>One</td>
<td>Male</td>
<td>295</td>
<td>68.0</td>
<td>4.33</td>
<td>Union wood</td>
<td>306</td>
</tr>
<tr>
<td>One</td>
<td>Female</td>
<td>280</td>
<td>64.0</td>
<td>4.38</td>
<td>Lough Key</td>
<td></td>
</tr>
<tr>
<td>Two</td>
<td>Female</td>
<td>315</td>
<td>69.6</td>
<td>4.52</td>
<td>Lough Key</td>
<td>256</td>
</tr>
<tr>
<td>Two</td>
<td>Male</td>
<td>230</td>
<td>67.5</td>
<td>3.41</td>
<td>Lough Key</td>
<td>216</td>
</tr>
<tr>
<td>Two</td>
<td>Male</td>
<td>230</td>
<td>66.6</td>
<td>3.45</td>
<td>Lough Key</td>
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<tr>
<td>Two</td>
<td>Female</td>
<td>260</td>
<td>64.3</td>
<td>4.04</td>
<td>Lough Key</td>
<td></td>
</tr>
<tr>
<td>Three</td>
<td>Female</td>
<td>265</td>
<td>67.2</td>
<td>3.94</td>
<td>Lough Key</td>
<td></td>
</tr>
<tr>
<td>Three</td>
<td>Female</td>
<td>270</td>
<td>67.8</td>
<td>3.98</td>
<td>Lough Key</td>
<td></td>
</tr>
<tr>
<td>Three</td>
<td>Female</td>
<td>275</td>
<td>62.0</td>
<td>4.44</td>
<td>Lough Key</td>
<td></td>
</tr>
<tr>
<td>Three</td>
<td>Female</td>
<td>275</td>
<td>66.4</td>
<td>4.14</td>
<td>Lough Key</td>
<td></td>
</tr>
<tr>
<td>Three</td>
<td>Male</td>
<td>295</td>
<td>66.1</td>
<td>4.46</td>
<td>Lough Key</td>
<td></td>
</tr>
<tr>
<td>Three</td>
<td>Female</td>
<td>315</td>
<td>69.9</td>
<td>4.51</td>
<td>Lough Key</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.3: The 15 red squirrels translocated from Lough Key Forest Park and Union wood to Belleek Forest Park and individual weight and shin bone length at time of translocation. Radio-collared individuals are noted by the frequency ID of their radio collar.

During phase two of the translocation it became apparent that the soft release technique did not succeed as squirrels were able to escape the enclosure through the roof, due to a malfunction with the wire netting. Attempts to fix the enclosure did not rectify the problem. Due to the failure of the enclosure it was not possible to estimate an initial survival rate, however, 67% of red squirrels translocated were captured in subsequent live trapping sessions. Despite the squirrels escaping the enclosure it was found that they re-entered it on a regular basis to access food in feeding hoppers therein. This was confirmed with squirrels live trapped inside the
enclosure on various occasions. All squirrels released in phase one of the translocation were subsequently recaptured in following trapping sessions, whereas only 50% of squirrels released in both Phases two and three were recaptured again. Females were recaptured more frequently than males with 70% of the translocated female squirrels being re-caught compared to 60% of the translocated males.

2.3.2 Radio telemetry

In April 2008, three females and three males were tracked to investigate settlement of squirrels; Figures 2.5 and 2.6 display the home range and core areas analysed. Four of the six squirrels established their home range to include the release enclosure, which was being provided with food at this time. This caused an overlap in male-male, female-female and female-male core areas. Two squirrels (216 and 339) established initial home ranges away from the enclosure. However, these areas did include a supplementary feeder. As well as including the enclosure in their home range, male squirrels 165 and 306 also included a supplementary feeder in their home ranges. Table 2.4 shows the size of each home range and core area, together with the time spent utilising the core area.

<table>
<thead>
<tr>
<th>Freq ID</th>
<th>Sex</th>
<th>95% Home range size (ha)</th>
<th>Core area usage (%)</th>
<th>Core area size (ha)</th>
<th>Core usage factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>165</td>
<td>Male</td>
<td>15.18</td>
<td>65</td>
<td>3.14</td>
<td>3.14</td>
</tr>
<tr>
<td>216</td>
<td>Male</td>
<td>0.8</td>
<td>90</td>
<td>0.49</td>
<td>1.46</td>
</tr>
<tr>
<td>306</td>
<td>Male</td>
<td>12.85</td>
<td>85</td>
<td>11.05</td>
<td>0.99</td>
</tr>
<tr>
<td>256</td>
<td>Female</td>
<td>6.67</td>
<td>60</td>
<td>0.96</td>
<td>4.16</td>
</tr>
<tr>
<td>265</td>
<td>Female</td>
<td>4.22</td>
<td>80</td>
<td>0.97</td>
<td>3.48</td>
</tr>
<tr>
<td>339</td>
<td>Female</td>
<td>7.39</td>
<td>85</td>
<td>4.9</td>
<td>1.29</td>
</tr>
</tbody>
</table>

Table 2.4: Home range and core area size and percentage time spent utilising the core area for radio tracked squirrels in April 2008.

It was found that three of the individuals tracked (165, 256 and 265) had settled in the woodland with established core areas. However, three individuals (306, 216 and 339) although establishing home ranges could not be determined as having core areas due to the large size of estimated core area relative to home range size in each case. This suggests that these individuals had not determined their core area and had not yet settled fully into the woodland.

In September 2009, two of the eight radio collars fitted on red squirrels failed shortly after tracking began, despite being tested before being fitted. Therefore, six squirrels four female and two male were tracked. Table 2.5 shows the size of each home range and core area, together with time spent utilising the core area. There were no significant differences found in home
range size or core area size between sessions or between genders. Figure 2.7 and 2.8 displays the home ranges and core areas of the squirrels.

<table>
<thead>
<tr>
<th>Freq ID</th>
<th>Sex</th>
<th>95% Home range size (ha)</th>
<th>Core area usage (%)</th>
<th>Core area size (ha)</th>
<th>Core area usage factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>235</td>
<td>Female</td>
<td>2.72</td>
<td>80</td>
<td>1.33</td>
<td>1.64</td>
</tr>
<tr>
<td>183</td>
<td>Female</td>
<td>2.78</td>
<td>55</td>
<td>0.85</td>
<td>1.79</td>
</tr>
<tr>
<td>429</td>
<td>Female</td>
<td>3.00</td>
<td>60</td>
<td>0.85</td>
<td>2.12</td>
</tr>
<tr>
<td>197</td>
<td>Female</td>
<td>2.86</td>
<td>50</td>
<td>0.61</td>
<td>2.35</td>
</tr>
<tr>
<td>329</td>
<td>Male</td>
<td>2.76</td>
<td>70</td>
<td>0.77</td>
<td>2.51</td>
</tr>
<tr>
<td>475</td>
<td>Male</td>
<td>5.10</td>
<td>60</td>
<td>1.87</td>
<td>1.60</td>
</tr>
</tbody>
</table>

Table 2.5: Home range and core area size and percentage time spent utilising the core areas for radio tracked squirrels in September 2009.

Overlap of core areas is minimal in September 2009 and female core areas were maintained as exclusive from other females. The only overlap observed was between a male and female (475 and 197). Of the six squirrels tracked in September 2009, one individual was also tracked in April 2008 (339/429). Analyses of home range showed that this individual maintained its range in the same general location from session to session. The only change being a slight contraction in the size of its area as a core area was established. Supplementary feeders were not utilised by all squirrels tracked and only two individual home ranges included a feeder.

Table 2.6 shows the amount of overlap that occurred in the initial tracking session in April 2008 and 18 months later in September 2009. Of the six red squirrels radio tracked in April 2008, four show overlap in their core areas. These include male-male, female-female and male-female pairings. There is more male-female overlap of core areas with all four squirrels showing some degree of overlap around the area of the enclosure. Of the six squirrels tracked in September 2009, only two show any degree of overlap male 475’s core area overlaps 100% of female 197’s core area.

<table>
<thead>
<tr>
<th>Squirrel 1</th>
<th>Squirrel 2</th>
<th>Sex</th>
<th>Area of overlap (ha)</th>
<th>% overlap for squirrel 1</th>
<th>% overlap for squirrel 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>165</td>
<td>306</td>
<td>Male/Male</td>
<td>3.14</td>
<td>100</td>
<td>28.4</td>
</tr>
<tr>
<td>256</td>
<td>265</td>
<td>Female/Female</td>
<td>0.10</td>
<td>10.4</td>
<td>10.3</td>
</tr>
<tr>
<td>165</td>
<td>265</td>
<td>Male/Female</td>
<td>0.47</td>
<td>14.9</td>
<td>100</td>
</tr>
<tr>
<td>165</td>
<td>256</td>
<td>Male/Female</td>
<td>0.92</td>
<td>29.3</td>
<td>25.4</td>
</tr>
<tr>
<td>306</td>
<td>256</td>
<td>Male/Female</td>
<td>0.98</td>
<td>100</td>
<td>25.7</td>
</tr>
<tr>
<td>475</td>
<td>197</td>
<td>Male/Female</td>
<td>1.01</td>
<td>37.8</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 2.6: Overlap of core areas of radio tracked squirrels in April 2008 and September 2009 (pair 475 and 197).
Figure 2.5: Home ranges of six radio-tracked squirrels (A – three male and B – three female) in April 2008, represented by 95% MCPs. The enclosure is marked X, supplementary feeders marked •.
Figure 2.6: Core areas of six radio-tracked squirrels (A – three male and B – three female) in April 2008. The enclosure is marked X.
Figure 2.7: Home range of six radio-tracked squirrels (A – two male and B – four female) in September 2009.
Figure 2.8: Core area of six radio-tracked squirrels (A – two male and B – four female) in September 2009.
2.3.3 Initial live trapping sessions

After the second phase of translocation, red squirrels were trapped (March 2008) in order to fit them with radio collars; during this trapping period two new offspring were captured. These juveniles were the progeny of the nine individuals translocated from phases one and the first of the new recruits to be caught. After the third and final phase of translocation was completed, the first session of post-translocation monitoring began with live trapping (August 2008). Of the 15 squirrels translocated nine were recaptured; the weights of these nine were compared with their original weight at translocation and were found to have significantly increased (paired t test, \( t = 2.816, df = 8, P = 0.011 \)). Of the nine translocated individuals being captured, five of these were found to be in a breeding condition. One other translocated individual was captured in a later month. Table 2.7 displays the nine individuals captured in August 2008 and their respective weight and breeding conditions at the time.

<table>
<thead>
<tr>
<th>Phase translocated</th>
<th>Sex</th>
<th>Breeding status</th>
<th>Weight (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Male</td>
<td>Actively reproductive</td>
<td>325</td>
</tr>
<tr>
<td>One</td>
<td>Male</td>
<td>Actively reproductive</td>
<td>330</td>
</tr>
<tr>
<td>One</td>
<td>Female</td>
<td>In oestrus</td>
<td>340</td>
</tr>
<tr>
<td>One</td>
<td>Female</td>
<td>Negative</td>
<td>310</td>
</tr>
<tr>
<td>Two</td>
<td>Male</td>
<td>Actively reproductive</td>
<td>355</td>
</tr>
<tr>
<td>Two</td>
<td>Female</td>
<td>Lactating</td>
<td>345</td>
</tr>
<tr>
<td>Three</td>
<td>Female</td>
<td>Negative</td>
<td>295</td>
</tr>
<tr>
<td>Three</td>
<td>Female</td>
<td>Negative</td>
<td>295</td>
</tr>
<tr>
<td>Three</td>
<td>Female</td>
<td>Negative</td>
<td>295</td>
</tr>
</tbody>
</table>

Table 2.7: Nine translocated red squirrels recaptured in the first trapping session after completion of translocation (August 2008).

During the same trapping session 10 new recruits were tagged as offspring of the translocated stock. Table 2.8 displays the mean weight, shin bone length and sex ratio of newly recruited squirrels from the trapping session in August 2008. Weight of new recruits and translocated squirrels captured in August 2008 were compared using a Mann-Whitney U test and it was found that there was a significant difference (\( U = 16.50, P = 0.009 \)) with new recruits being lighter. However, there was no significance found when comparing the shin bone length of the same individuals.
Overall mean weight (grams) | Overall mean shin bone length (mm) | Sex ratio (male:female)
---|---|---
282.5 ± 10.96 | 67.02 ± 2.21 | 1:1.5

**Table 2.8:** Mean weight, shin bone length including 95% confidence intervals and sex ratio of recruited red squirrels captured in post-translocation monitoring trapping session n = 10 (August 2008).

Only 67% of squirrels translocated were ever re-captured. No carcasses were recovered thus assumptions as to the cause of their disappearance cannot be made. However, soon after translocation was complete local residents of property surrounding Belleek Forest Park reported sightings of red squirrels visiting bird feeders in resident’s gardens and small wooded plots surrounding Ballina town. It indicates that some translocated individuals did not stay within the vicinity of the wood.

<table>
<thead>
<tr>
<th>Phase of translocation</th>
<th>Last captured</th>
<th>Weight at last capture</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>N/A</td>
<td>N/A</td>
<td>Male</td>
</tr>
<tr>
<td>2</td>
<td>N/A</td>
<td>N/A</td>
<td>Female</td>
</tr>
<tr>
<td>3</td>
<td>N/A</td>
<td>N/A</td>
<td>Female</td>
</tr>
<tr>
<td>3</td>
<td>N/A</td>
<td>N/A</td>
<td>Male</td>
</tr>
<tr>
<td>3</td>
<td>N/A</td>
<td>N/A</td>
<td>Female</td>
</tr>
<tr>
<td>2</td>
<td>August 2008</td>
<td>345</td>
<td>Female</td>
</tr>
<tr>
<td>2</td>
<td>August 2008</td>
<td>355</td>
<td>Male</td>
</tr>
<tr>
<td>3</td>
<td>August 2008</td>
<td>295</td>
<td>Female</td>
</tr>
<tr>
<td>1</td>
<td>November 2008</td>
<td>330</td>
<td>Male</td>
</tr>
<tr>
<td>3</td>
<td>November 2008</td>
<td>290</td>
<td>Female</td>
</tr>
<tr>
<td>1</td>
<td>September 2009</td>
<td>310</td>
<td>Male</td>
</tr>
<tr>
<td>1</td>
<td>September 2009</td>
<td>255</td>
<td>Female</td>
</tr>
<tr>
<td>1</td>
<td>February 2010</td>
<td>275</td>
<td>Female</td>
</tr>
<tr>
<td>1</td>
<td>February 2011</td>
<td>350</td>
<td>Female</td>
</tr>
<tr>
<td>3</td>
<td>May 2011</td>
<td>355</td>
<td>Female</td>
</tr>
</tbody>
</table>

**Table 2.9:** The 15 translocated red squirrels sorted by the date they were last captured, weight and gender.

Table 2.9 displays all 15 individuals translocated and the last date of capture which may give some representation of survival. Five squirrels were caught regularly and for a long-term period; four of these individuals were translocated in phase one, and one from phase three.
Supplementary feeding was carried out with the assistance of the Belleek Forest Park Enhancement Committee and continued until June 2010 when it ended. During the translocation of red squirrels to Belleek the general public became very interested in the work being carried out and comments on squirrel sightings became an on-going occurrence whilst carrying out trapping and monitoring procedures. As the population became more established and began to increase in size the sighting of squirrels was regular.
2.4 Discussion

2.4.1 Translocation of red squirrel to Belleek Forest Park

The translocation of red squirrels to Belleek Forest Park was carried out in compliance with the International Union of Conservation in Nature (IUCN) guidelines (1998). The knowledge gained through other translocations was paramount to its success and hence recommendations from other studies were considered (e.g. Poole 2007, Hodder & Bullock 1997, Venning et al. 1997).

At approximately 79.6 ha, Belleek Forest Park was calculated as being potentially capable of carrying 65 squirrels (Lawton 2006). Reynolds and Bentley (2001) assessed forests in Britain; in order to select potential reserves for red squirrels, the relative size of the woodland was considered. Only woodlands greater than 200 ha were categorised as good for squirrel populations, anything smaller was deemed poor. Although in theory a woodland > 200 ha has potential to be a highly resourceful habitat for squirrels, it is not always feasible to find woodlands of such size that configure to the necessary requirements for translocation such as a healthy habitat composition and tree age structure with acceptable forest management plans, reduced competition and low predation pressure. Wauters, Somers and Dhondt (1997), during translocation of red squirrels to a wood in Antwerp, Belgium, advised against attempting reintroductions in small woodlands (< 50 ha), as animals may be more inclined to leave the release site altogether. Although Belleek Forest Park was considered to be a small woodland in relation to Reynolds and Bentley’s (2001) criteria, it is maintained as an amenity forest by Coillte Teoranta; the silviculture of the woodland is monitored and managed. A healthy seed crop is vital to a healthy population of red squirrels and can affect the density, fecundity and recruitment of a population (Wauters & Lens 1995, Lurz et al. 1995).

In Britain studies have suggested that red squirrels may be better suited to living in conifer forests and grey squirrels to broadleaved or mixed forests, due to the native distribution of the two squirrel species (Kenward & Tonkin 1986). In mixed habitat grey squirrels have a competitive edge over reds, however in the absence of the grey and away from the threat of incursion, mixed forests provide red squirrels with optimal habitat. Ideally a forest containing 80% lodgepole pine and Norway spruce is regarded as optimal habitat for red squirrels (Lurz et al. 1995). Wauters et al. (2008) suggest that red squirrels occur at higher densities in Scots pine forest which are characterised by a more stable seed-crop compared to Norway spruce which can provide abundant seed but at a more variable rate. Taking this into consideration Belleek Forest Park provides an optimal habitat for red squirrels providing them with a large amount of
Norway spruce and Scots pine which is accompanied by beech and other suitable squirrel-friendly species. Hence the translocation of red squirrels to Belleek was considered beneficial due to the ability of the woodland to sustain a healthy population.

The isolation of Belleek Forest Park from other woodlands or other red squirrel populations can prevent red squirrels from naturally dispersing to other woodlands and hence decreases gene flow, local density and genetic diversity in local red squirrels (Wauters 1997). The loss of genetic variation in small isolated populations reduces their chance of survival (Wauters et al. 1994). However, it is this isolation that prevents grey squirrels from accessing the area. During Poole’s (2007) study at Derryclare wood, the influence of inbreeding on the population was modelled. It was found that the mean probability of extinction in 10 years is less than 0.05 for translocated populations, whether inbreeding occurs or not. The threat of extinction at Derryclare was low for the first 10 years suggesting that a sufficient number of individuals had been translocated. The probability of extinction is low in the first few years as it is assumed that even if the population fails to breed some individuals will survive for several years. It is only after four years that inbreeding starts to increase the threat of extinction in the population.

Overall Poole found that to maintain a 0.1 level of risk of extinction over 50 years, an initial founder population of 13 squirrels required an addition of a further four pairs of squirrels. It was recommended that after the initial translocation, intervention is required once every eight years on four occasions to translocate one pair of squirrels per occasion. These small additions to the gene pool are sufficient to reduce the extinction risk in theory, but there is no guarantee in reality that both these squirrels would survive and establish themselves within the population. It does, however, emphasise the need for long term management and commitment to translocation projects. Ogden et al. (2005) also highlight the importance of considering genetic management in reintroduction programmes and recommend it occurs at an early stage. They found that supplementation of the population can be positively linked to population survival.

Over the course of the three phases of translocation no mortalities or injuries were sustained between capture and release into the enclosure, showing that the transportation and handling techniques were effective. A further advantage of the donor site was that its location ensured these animals were not from areas where grey squirrels had invaded, meaning they had not been exposed to the SQPV. Red squirrels were chosen for translocation based on criteria used by Poole (2007), one of these criterion was that individuals should not weigh less than 210 grams, it is the recommendation of this study that for future translocations a skeletal reference should be included.

The release of squirrels at Belleek Forest Park was to be conducted as a soft release translocation (meaning individuals were kept within an enclosure in order to acclimatise them to
the area). However, the enclosure design proved to be unsuitable as squirrels in phases two and three managed to push between the wire mesh of the enclosure and the central tree around which it was built. Attempts to rectify the problem by the Belleek Forest Park Enhancement Committee between phases were unsuccessful. This effectively led to the Belleek translocation becoming a hard release, albeit with supplementary feeders and nest boxes provided. This meant that the first criteria for success of the translocation of >75% of squirrels surviving release from the enclosure did not apply here.

As post-translocation monitoring commenced through live trapping in August 2008, 67% of red squirrels captured were translocated individuals. This fulfilled the second criteria for the success of the translocation, which stated that at least 50% of red squirrels released must survive to the following year’s breeding season. As August was within the year’s breeding season of squirrels translocated in phases one and two, the result was a positive one. The recruitment of young animals can be attributed to the availability of space in the wood unoccupied by adult squirrels and the availability of food. The juvenile recruitment of both sexes into the population (and immigrants where applicable) depends on body weight and on the degree of intrasexual competition for space (Wauters & Dhondt 1993, Wauters, Bijnens & Dhondt 1993). As the population was well below carrying capacity, competition for space was minimal, with available access to underutilised, high-quality food patches.

The final criterion to be fulfilled was the successful breeding of the population. In March 2008, during a short period of trapping for fitting of radio collars, two juveniles were captured. These were the first offspring of the individuals that had already been translocated. In the subsequent trapping session of August 2008, ten new recruits were captured and tagged. These individuals provided further evidence that the population had indeed begun to breed successfully. Further evidence of breeding were the signs of breeding status displayed by captured individuals, with females displaying signs of lactation and males in an actively reproductive state. Hence, the criteria set for a successful breeding population was accomplished. Therefore a fourth phase of translocation was deemed unnecessary.

Fundamentally, the translocation of red squirrels to Belleek Forest Park was a success with the two of the two (one not applicable) criteria being achieved. However, there were other signs to show that the population had begun to establish itself in the woodland. During post-translocation monitoring, body weight was examined to assess the impact of translocation on squirrels to Belleek Forest Park. During the first full trapping session (August 2008) it was found that the original squirrels recaptured had significantly increased their body weight and new recruits also displayed a healthy weight. Survival of red squirrels has been positively
correlated to body weight and in coniferous woodlands both body weight and longevity have been significantly linked to reproductive success in females (Wauters & Dhondt 1989a).

Although the Belleek Forest Park translocation was a success despite the fault with the enclosure, a strong case for the use of soft release in future translocations was shown. The percentage of squirrels being recaptured between phase one and phase two to three show that soft release may influence survival and site fidelity of squirrels. In Bradley et al.’s (2005) evaluation of wolf (Canis lupus) translocation in the USA, the use of soft release technique was highly recommended, as it discouraged the homing behaviour of these carnivores travelling distances of 74 – 316 km back to capture sites. Homing behaviour is a common occurrence in carnivore translocation (Rodgers 1988). Small mammals have also been reported to make further excursions away from release sites following hard release techniques (Van Vuren 1997). However, it has been suggested that small mammals vary excursory distances depending on their home range size (Bovet 1978 & 1984, Bowman et al. 2002). Over the course of the three year study at Belleek Forest Park, members of the public reported sightings of red squirrels in areas surrounding Ballina town (refer to section 3.3.10). Residents adjacent to the woodland found that the squirrels became frequent visitors to bird feeders on their property. It also became apparent that squirrels were crossing the river Moy to patches of wooded areas on the other side of the river. The furthest distance in which red squirrels were reported was 6 km south of Belleek on a hotel’s grounds which consist of 40.47 ha of mixed habitat. Studies on Italian red squirrels have shown that exploring behaviour had caused squirrels to make excursions more than one kilometre in distance (Wauters, Casale & Foranasari 1997). Although dispersing squirrels had found suitable habitat in each case reported, invariably it was only a small size and therefore would not support more than a minor number of individuals. It is possible that the hard style release may have had an influence on individuals leaving the wood.

Site fidelity is an important concept when encouraging a translocated population to establish itself and can be attributed to the release technique used as well as the quality of the target habitat. Larkin et al. (2004) investigated the importance of habitat type on site fidelity in translocated “elk” (Cervus elaphus) finding that the quality of habitat and the presence of human disturbance had an effect on the success of the translocation. Studies of mountain hares (Lepus timidus) in northern Sweden have found that dispersal of juveniles or adults occurred at a low rate in boreal forest during prevailing conditions, which produced limited natal dispersal and a high degree of adult site fidelity (Dahl & Willebrand 2005). Spencer, Cameron and Swihart (1990) studied the cotton rat (Sigmodon hispidus) and found that site fidelity was intrinsically linked to whether an animal had a home range or not, otherwise it was just random movement by individuals. In tree squirrels, territorial behaviour is expected if the benefits of holding a territory prevail over the costs of defending it (Gurnell 1987).
territorial pine squirrel (*Tamiasciurus hudsonicus*) and Douglas squirrel (*T. douglasii*) of America, which defend large hoards of pine and spruce cones in coniferous woodlands (Gurnell 1987, Smith 1981). In contrast, European red squirrels (*Sciurus vulgaris*) which inhabit similar habitats scatterhoard tree seed (Wauters & Dhondt 1987) and do not defend individual exclusive territories (Wauters & Dhondt 1992) but live in home ranges. Therefore, site fidelity in red squirrel populations is associated with the availability of resources and the creation of home ranges rather than territories. This emphasises the need to ensure that the selected habitat for translocation is the most favourable (Moorhouse, Gelling & Macdonald 2009).

Another aspect that may affect survival and/or the retention of individuals released into woodland, is the time of year in which the translocation takes place. Results show that more individuals were recaptured from phase one of the translocation and that individuals in phases two and three were less readily recaptured. This may be as a result of either fatalities suffered or dispersal from the forest. Individuals from phase one were also found to have bred relatively soon after release as juveniles were captured in March 2008. However, with the recruitment of ten more individuals in August 2008, squirrels from phase two also bred in the breeding season of 2008. Poole (2007) recommended that red squirrels be translocated from the start of July, as appropriate individuals for translocation will be found at donor sites and it ensures that squirrels can settle into their new environment before the on-set of winter months. The increased survival and retention of individuals from phase one may be related to the availability of natural resources in the woodland shortly after release. The on-set of autumnal months created a habitat plentiful in food (Wauters, Swinnen & Dhondt 1992) and although supplementary food was also available, the availability of natural resources would have maintained a healthy cohort of squirrels. Individuals from phase two were found to be in a breeding condition during trapping months in 2008 but unlike phase one not all squirrels were recaptured. Phase three displayed the poorest recapture rates and/or retention of those red squirrels translocated. However, those individuals that remained bred in the following year’s breeding season (2009). The longevity of translocated squirrels was also best displayed by those individuals translocated in phase one, therefore time of year and/or the nature of release (soft verses hard release) had an effect on the success of translocated stock.

### 2.4.2 Settlement behaviour and home ranges.

Settlement behaviour in April 2008 showed that four of the six squirrels set up home ranges around the release enclosure (being provided with food at the time) and two males incorporated a supplementary feeder in their home range. This provides evidence that as well as being important as an additional food source, the feeders provide an incentive for squirrels to remain within the vicinity. Despite the escape from the enclosure, the squirrels still returned on a
regular basis unlike previous studies in which squirrels from a soft-release utilised the surrounding feeders and were never found to re-enter the enclosure (Poole & Lawton 2009, Jackson 1998). The other two of the six red squirrels established their home ranges away from the enclosure, however, in both cases their range included a feeder. Results also indicate that three squirrels (two male and one female) had not established true core areas during this time and were still exploring the area. This supports the findings of Wauters, Casale and Fornasari (1997) in which some individuals move immediately away from the release site and settle away from the area, while others gradually explore the area around the release site and settle nearby. Translocation of fox squirrels (Sciurus niger cinereus) in the USA has shown that individuals can make long-distance exploratory movements away from the release site but return to the release vicinity, indicating that these movements are not an attempt to wander or leave the area (Bendel & Therres 1994). Kenward and Hodder (1998) found that the movement of squirrels was related to the tree species of the donor site. In this study the main donor site had similar tree species present to those found in Belleek Forest Park (Scots pine, sitka spruce, beech, oak and horse chestnut Aesculus hippocastanum). Therefore red squirrels were familiar with the tree seed crop present at Belleek.

In general, dominant red squirrel females maintain nearly exclusive core areas that are defended against other females (intrasexual territoriality) and subordinate females live in ranges that overlap partly with those of one or more dominant females, avoiding their core areas as much as possible (Wauters & Dhondt 1992). Adult males use larger home ranges than females and their ranges overlap strongly with those of females and with those of other males (Lurz et al. 2000). The settlement pattern of the radio tracked squirrels at Belleek Forest Park (April 2008) displayed a high percentage of overlap, with four of the six (two female and two male) overlapping core areas in the vicinity of the release enclosure. The majority of the overlap was between male and female squirrels. Wauters et al. (2005) reported that red squirrels respond to food shortage by dispersing to areas with other food resources and abandon the spacing patterns of reduced core area overlap among males and nearly exclusive core areas among females. Although at Belleek Forest Park there was not a food shortage, typical dispersion of a population within a woodland was affected by supplementary feeders and/or the low population density in relation to natural food resources available.

In September 2009, radio tracking was conducted for a second time, the pattern of core areas of red squirrels during this time was more typical of the spacing behaviour and territoriality of established populations, with clear intrasexual territoriality between female core areas (Wauters & Dhondt 1992) and males showing a stronger overlap of home ranges with both males and females (Wauters & Dhondt 1990). Although supplementary feeders were still being supplied with food at the time, not all squirrels tracked had a feeder within their home range and
individuals were shown to be utilising areas of woodland that were not near feeder locations. Therefore during this session there seemed to be less emphasis on finding feeders and more on finding natural resources.

Only one squirrel was radio-tracked in both telemetry sessions, this female was found to be in a similar location in both sessions. Wauters et al. (1995) found, of 44 females in a coniferous forest in Belgium, only seven moved from home ranges on which they first settled to adjacent, vacant areas and that territory shifts were adaptive, occurring as a response to poor breeding conditions. Core area shift have been noted as occurring in grey squirrel populations following control programmes, with the overall home range remaining the same (Lawton & Rochford 2007). This indicates a shift in home range use, rather than a shift in the position of the home range.

Although results gathered through radio telemetry at Belleek Forest Park are quite qualitative in nature due to the number of individuals tracked, core area sizes detected within the study are similar to those found in similar habitats elsewhere in the red squirrel’s range (Table 2.10).

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Country</th>
<th>Core area (ha)</th>
<th>n</th>
<th>Method</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed</td>
<td>Belgium</td>
<td>M: 1.01 – 1.12 F: 0.8 – 1.24</td>
<td>35</td>
<td>MCP and cluster analysis</td>
<td>Wauters et al. 1994</td>
</tr>
<tr>
<td>Broadleaved</td>
<td>Belgium</td>
<td>M: 2.68 F: 1.94</td>
<td>94</td>
<td>MCP</td>
<td>Wauters &amp; Dhondt 1992</td>
</tr>
<tr>
<td>Coniferous</td>
<td>Ireland</td>
<td>M: 1.02 F: 1.5</td>
<td>5</td>
<td>MCP</td>
<td>Reilly 1997</td>
</tr>
<tr>
<td>Mixed</td>
<td>Italy</td>
<td>M: 2.3 F: 1.1</td>
<td>8</td>
<td>MCP and cluster analysis</td>
<td>Wauters et al. 1997</td>
</tr>
<tr>
<td>Mixed</td>
<td>Ireland</td>
<td>M: 0.77 – 3.14 F: 0.61 – 1.33</td>
<td>12</td>
<td>MCP</td>
<td>Current study, 2012</td>
</tr>
</tbody>
</table>

Table 2.10: Male (M) and female (F) red squirrel core area size reported in various studies, top four from established populations, last three from monitoring of translocated populations.

Of the studies displayed in Table 2.10 the last three were taken from data collected from translocated red squirrel populations. Core area sizes were also similar to those reported from other studies.
2.4.3 Public involvement and the use of supplementary feeding

Another factor affecting the decision to translocate red squirrels to Belleek Forest Park was the presence and involvement of the general public. The education benefits of introducing red squirrels to the area were seen as highly favourable, demonstrating the impact that an introduced species can have on a native species and the implications in preserving that species. As well as enhancing the local biodiversity and creating the potential for eco-tourism in the area.

Belleek Forest Park is run as an amenity woodland and is regularly used by the local community and visitors from the wider district. People use the forest walks on a daily basis in order to walk dogs, go for jogs and generally enjoy the natural space. The Belleek Forest Park Enhancement Committee has improved the woodland for visitors to incorporate paths and walkways through the majority of the woodland. Red squirrels translocated to Belleek therefore have to become accustomed to the presence of people and the potential disturbance that this brings. Wauters, Somers and Dhondt (1997) reported that squirrels removed from a donor site that were used to living in close proximity to humans had an increased probability of surviving and breeding than those squirrels removed from more natural forests. It may be important during an attempt to reintroduce populations in disturbed areas to use squirrels already adapted to such habitats. The majority of squirrels translocated to Belleek Forest Park were removed from another amenity woodland (Lough Key Forest Park). Red squirrels in Lough Key contend with the presence of cars as well as the other aspects of human presence. It is feasible to say that those 14 squirrels moved from Lough Key were already adapted to the presence of people.

Supplementary feeding of animals can be used to maintain high densities of game species, improve body weight and condition, enhance reproduction and fertility, increase over-winter survival and potentially reduce levels of damage caused to forestry and agriculture (Putman & Staines 2004). In translocated populations, supplementary feeding can support the establishment of animals into an area (Poole 2007). Red squirrels at Belleek Forest Park were a common sight at feeders and local people regularly witnessed squirrels in these areas. Shuttleworth’s (2000) investigation into the foraging behaviour of supplementary fed red squirrels suggests that a higher percentage (47 and 50%) of foraging activity occurs on the ground than in relation to non-supplementary fed populations. This may explain the chance of passers-by sighting squirrels. However, the importance of the availability of pine cones and other natural food sources accounts for the majority of material consumed by squirrels (Shuttleworth 2000). Supplementary food at Belleek Forest Park mainly consisted of peanuts, hazelnuts, walnuts and some maize. Feeding boxes were not exclusively designed for squirrels and could provide the chance for other opportunistic animals (such as, stoats, pine marten and
rats) to raid boxes. In the long term this may deplete the actual amount of food available to the squirrels.

**2.5 Summary and Conclusion**

The translocation of red squirrels to Belleek Forest Park was deemed successful as a free ranging breeding red squirrel population was established. Translocation techniques honed by Poole & Lawton (2009) and the influence of previous studies provided useful information on the practicalities of the introduction. Two of the three short term criteria were fulfilled, however, the third became null and void, which meant that two of two criteria were achieved. It is the case that the most important target is that the population begins to breed and recruit individuals successfully.

During the fitting of radio collars in March 2008, two juveniles were caught. During the first live trapping session in August 2008, ten new recruits were tagged as offspring of the translocated squirrels. This showed that the red squirrels population had begun to successfully breed. These findings agree that red squirrels can increase their numbers quickly in newly colonised habitat, when initial adult densities are low, by producing a large number of offspring that can successfully settle within the forest (Wauters, Somers & Dhondt 1997).

Settlement patterns showed the immediate importance of food availability and supplementary food played an important role in the initial spacing behaviour of individuals, with all squirrels tracked locating their home ranges in the vicinity of a feeder. After initial settlement, red squirrels began to show more typical spacing patterns and were less reliant upon feeders, utilising areas of woodland outside the locality of feeding hoppers, thus, becoming more dependent on natural resources.

Although part of the translocation became a hard release, this did not affect the overall success of the translocation. Squirrels did re-enter the release enclosure to access food provided and the utilisation of supplementary food was important in the initial spacing patterns of the translocated stock. Therefore, there is a case for the preferred use of a hard release procedure, albeit with nest boxes and supplementary feeders. A hard release is not ideal in areas that contain grey squirrels either at the target site or donor site, as soft release technique allows for a closer, contained monitoring of translocated stock which may be affected by disease such as SQPV. However, squirrels should be kept in enclosures to contain losses caused by disease. Soft release may also enable the individual’s original site fidelity to be cancelled as it becomes accustomed to the new environment. A case by case assessment of the best technique to use in a translocation may be more appropriate when planning the procedure.
Squirrels were reported to have been sighted outside the forest, either within local residents’ gardens or small woodlots surrounding the local town (approximately one mile from Belleek Forest Park). There are a number of reasons why this may have occurred; simply that this could be the exploratory behaviour of newly introduced individuals, the small size of the woodland influencing individuals to investigate new areas or the type of release of translocation. This scenario emphasises the importance of choosing an appropriate release site for red squirrels. However, the dispersal of individuals away from the forest did not affect the translocation’s overall success.

The release of red squirrels received a high amount of publicity nationally and within the local community. This emphasises the benefit of translocating squirrels for educational purposes. Local involvement through the Enhancement Committee and local volunteers has facilitated the continued support for the project as well as helping construct the enclosure and providing supplementary food on a practical level. However, this can relinquish some control from project managers and the timing and quantities of supplementary food provided were not always possible to monitor, which created a prolonged period of feeding compared to other studies (e.g. Poole 2007). The use of voluntary groups is to be encouraged in conservation work however training is an important element of their input. It also means that in the long term overall costs can be kept to a minimum.
3. **Medium-term post-release monitoring of a population of red squirrels.**

3.1 **Introduction**

3.1.1 **Techniques for monitoring wildlife**

The reasons behind monitoring wildlife are diverse, for example a population may be valued as game that is being sustained for a potential yield; an endangered species may need to be assessed and a recovery programme implemented; a species may be considered a pest causing harm to agricultural outputs or the biological diversity of an area may be in question (Witmer 2005). Whatever the purpose for monitoring, a clear objective must be determined in order to use the correct technique.

Direct or indirect field techniques can be used to monitor wildlife populations for demographics affected by population density, dispersal and individual fitness (Gurnell, Lurz & Pepper 2001). Direct field methods can include mark-recapture studies via live trapping and radio telemetry. In general mark-recapture methods are used to investigate population size and individual health and radio telemetry is used to determine retention and home range, describe movement and estimate survival (Powell *et al.* 2000). Many studies have used such techniques to investigate wild populations; in Croatia a radio tracking study was undertaken on the protected wolf species (*Canis lupus*) in an area in which 97% of predation by wolves was on livestock and illegal hunting of wolves was known to occur (Kusak *et al.* 2005). This study provided information on home range size, movements and daily activity of wolves, which was important in investigating the behaviour and conservation of the species in this region. Another example of the use of radio tracking is a study on the lesser horseshoe bat (*Rhinolophus hipposideros*) in the UK (Bontadina *et al.* 2002). This species is one of the most endangered European bat species and gathering reliable information has been difficult due to the relative size of the bat (4 – 8 g) and difficulty in detecting its echolocation calls. Development of light weight radio transmitters for this study allowed recommendations for the species’ conservation to be made.

Direct field methods such as trapping or radio-tracking are not always feasible or suitable to a study; this can be related to the size of the area under investigation, licensing requirements for capture and handling and/or the overall cost. In this instance indirect techniques are more amenable; these can include transects, hair tube surveys and visual sightings. For example faecal transects can be used to investigate carnivore density (Webbon, Baker & Harris 2004), hair tubes can be used to look for the presence of animals (Mills *et al.* 2002) and visual surveys can be used to investigate species presence and abundance (Williams *et al.* 2006).
Some studies have made comparisons between techniques to analyse which are the most reliable. In north-western Spain, the Iberian wolf (*Canis lupus signatus*) is researched using simulated howling to determine pack numbers in the area. This technique was compared with wolf scat and scratch mark transects and it was found that such field techniques provided reliable results (Llaneza *et al.* 2005). The tiger (*Panthera tigris*) is an endangered felid and techniques for estimating abundance have been unreliable, however, in India a photographic capture recapture study was used to compare prey density influences on number of tigers in an area. This comparison proved positive, giving potential to the use of photographic method as a non-invasive technique (Karanth & Nichols 1998). A study assessing goshawk (*Accipiter gentilis*) diet in Southeast Alaska compared three methods: video recording of prey deliveries, prey remains and pellet dissection. Of all the methods, the video recording was the most successful and detected the most prey categories (Lewis, Fuller & Titus 2004). Genetic monitoring has now developed as a non-invasive technique to investigate wild populations. Such procedures use molecular tags to identify individuals and can be used in measuring the abundance of animal populations. It can also be used to identify species or other groups, as well as insights into demographic and evolutionary processes in natural and captive populations (Schwartz, Luikart & Waples 2006). A study in north-east Scotland has used genetic monitoring to investigate how closely related bottlenose dolphins (*Tursiops truncatus*) are to other populations in the UK and Ireland (Parsons *et al.* 2002). The collection of hair, scat, feather or other materials can be used as a genetic sample, which can be gathered through indirect field methods. Indirect field methods as well as more direct methods can gather important credible information on wildlife, however it is essential to use the most reliable method and in some incidences this may include a combination of direct and indirect techniques (Schauster *et al.* 2002).

### 3.1.2 Techniques for monitoring squirrel populations

Monitoring techniques are vital for the study and/or management of squirrel populations in forests and woodlands. Techniques can be used to survey a given area and establish the presence of squirrels. If used at regular intervals techniques can also be used to detect squirrel abundance or density and changes to this over time, to compare populations in different areas, to check the efficacy of grey squirrel controls and to assess changes to woodland or management plans (Gurnell *et al.* 2009). In regions where squirrel species are threatened, such as the red squirrel, data gathered through monitoring can determine how a population of red squirrel responds to conservation management or environmental change (Gurnell & Lurz 1997).

Monitoring squirrels can be conducted via direct field techniques, which can include the trapping and handling of squirrels requiring certain skills. This must be undertaken with a
licence from the relevant governing body (e.g. NPWS in Ireland), as the red squirrel is a protected species in Ireland and Britain and any interference with the animal or its nest is illegal.

Indirect field techniques can also be used to investigate the signs and sightings of squirrels. These methods are not as accurate for assessing abundance as the direct ones but can be used as a practical monitoring approach (Gurnell et al. 2009). In either case it is essential to have a well planned out surveying method, information on the type of habitat and its age and composition can dictate what methods may be best suited to a monitoring programme.

There are five main techniques used to monitor squirrels indirectly (Gurnell et al. 2001, 2009), these include; visual surveys, drey counts, hair tube surveys, feeding sign surveys and whole maize bait (Table 3.1).

<table>
<thead>
<tr>
<th>Method</th>
<th>Can it distinguish between red and grey squirrels?</th>
<th>Can density be estimated effectively?</th>
<th>Woodland type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual survey</td>
<td>Yes</td>
<td>Moderate</td>
<td>All</td>
<td>Poor in dense conifer forests</td>
</tr>
<tr>
<td>Drey counts</td>
<td>No</td>
<td>Poor – moderate</td>
<td>All</td>
<td>Not reliable. Poor in dense conifer forests</td>
</tr>
<tr>
<td>Hair tube survey</td>
<td>Yes</td>
<td>Poor – moderate</td>
<td>All</td>
<td>Labour and equipment expensive</td>
</tr>
<tr>
<td>Feeding sign survey</td>
<td>No</td>
<td>Moderate</td>
<td>Conifer</td>
<td>Best carried out in conifer forests</td>
</tr>
<tr>
<td>Whole maize bait</td>
<td>No</td>
<td>No</td>
<td>All</td>
<td>Quick method to investigate presence of squirrels</td>
</tr>
</tbody>
</table>

Table 3.1: Practical methods for monitoring squirrels indirectly, adapted from Gurnell et al. 2009.

Visual surveys use direct sightings of squirrels within a woodland; therefore it is important to be able to identify the difference between species. Visual surveys can investigate squirrel density and total number of squirrels per hectare. This method is carried out by predetermining survey lines of 500 and 1000 metres in length between trees every 10 – 20 hectares. Lines are walked at first light when squirrels are most active (Tonkin 1983) and all squirrel sightings are recorded. It is recommended that such surveys should not be carried out in bad weather as squirrels are unlikely to be sighted (Gurnell et al. 2009, Gurnell et al. 2004).

Drey counts are mainly used as an indication of squirrel presence but cannot distinguish between species of squirrel. Dreys are semi-permanent structures that are usually built close to the trunk of a tree, they are spherical in shape and can be 50 cm in diameter and more than 30 cm deep. It can be easier to see such structures in broadleaved woodlands during winter.
months. The number of dreyys tends to reflect the number of squirrels present over a season or a year (Wauters & Dhondt 1988). Counts of dreyys can be done by one or more people, walking in a line 20–25 m apart through the forest and recording intact and active dreyys. However, it is not always possible to see dreyys in dense woodland or heavy ivy and squirrels are also known to use holes in trees as shelter (Gurnell 1987) making this method unreliable for estimating density.

Hair tube surveys can establish whether different species of squirrel are present (Finnegan et al. 2007). Essentially this method uses a length of drainpipe which is baited to attract squirrels and fitted with patches of adhesive tape which collect squirrel hairs. Collected hairs are removed from tubes in predetermined time intervals and identified in the laboratory. If this method is used systematically it can determine population trends and density (Garson & Lurz 1998).

Feeding sign surveys cannot be used to distinguish between squirrel species but can provide information on squirrel numbers, habitat use and the availability of tree seed per year (Lurz, Shirley & Geddes 2008). This method involves an estimation of the number of cones eaten and uneaten by squirrels in conifer forests. Squirrel density can be calculated by converting the amount of conifer seeds eaten into the number of squirrels per unit area, based on dietary requirements.

Whole maize bait can determine the presence of squirrels from the remains of whole maize left behind when it is put out as food or bait. Red and grey squirrels remove the germ from the maize grain and discard the rest, creating a clear sign that it was eaten by squirrels. This can also be done using whole hazelnuts which can be identified as eaten by squirrels due to the manner in which they were cracked open. This method can only be used as an indication of presence.

The monitoring methods described are non-invasive means of surveying squirrel populations, however, they are not ideal for assessing population trends in habitats that contain low densities of squirrels. Squirrel populations can be low in conifer habitats (typically less than one squirrel per hectare) (Gurnell et al. 2009). This is especially true of sitka spruce woodlands/patches, as it has been found that squirrels avoid predating upon sitka spruce when other tree species are available (Lurz, Garson & Wauters 2000). However, when these methods are used correctly they can build an important data set for squirrel conservation and management.

3.1.3 Post-release monitoring techniques of translocated squirrel populations

Post-release monitoring of translocated animals is essential in determining whether the study was a success or failure initially. However, the continued assessment of success is also important to monitor, monitoring has been adopted by the red squirrel translocation projects
undertaken in Europe in recent times. Some of the successful studies discussed in Chapter 2 are reviewed here to assess how the continued success of translocation was determined.

All studies reviewed used the direct field technique of radio telemetry within their investigations to analyse squirrel behaviour and settlement after release. Other methods used were live trapping and the indirect field methods, drey counts and feeding signs.

During the successful red squirrel translocations post release monitoring was conducted for differing lengths of time. In every translocation monitoring was conducted for at least a year after release. In the Italian red squirrel translocation to Parco Groane (between December 1986 and August 1987, Fornasari et al. 1997) radio tracking was conducted for two months after red squirrels had been released (Wauters et al. 1997a). This was then followed by drey counts which were repeated three and six years after the initial release of squirrels, feeding sign surveys were also used within Parco Groane and neighbouring woodland to monitor further spread of squirrels. A report from the province of Milan (Relazione tecnica di gestione 2004) confirmed the red squirrels as an important population within Parco Groane in 2004.

In the release of red squirrels to Antwerp, Belgium (Wauters et al. 1997b) both live trapping and radio tracking were used. Release of squirrels occurred in 1987 and 1988, after which trapping was conducted on a bi-monthly period between March 1987 to October 1989, October 1990 to May 1991 and March 1992 to May 1993. From this study the ecology of red squirrels was investigated through live trapping (Wauters & Lens 1995). No other records of red squirrels were published for the specific forest in which translocation occurred in Antwerp, but further studies of red squirrels from donor sites continued (Wauters & Casale 1996, Wauters, Lens & Dhondt 1995, Wauters & Dhondt 1993).

The release of red squirrels to Thetford Forest, East Anglia, England (Venning et al. 1997), a 1700 ha red squirrel reserve. Four experiments were undertaken between 1993 and 1996 to reinforce the small resident red squirrel population and to investigate translocation as a conservation tactic. Squirrels were monitored using both live trapping and radio tracking. However, tracking was hampered due to failure of radio collars and the presence of the SQPV caused a number of fatalities. Studies of the fate of reds were intended to be on-going and in 1999 a captive breeding and release programme commenced (Carroll et al. 2009). However, the SQPV once again caused problems and deaths ensued; this prompted investigation into the disease (Carroll et al. 2009 and Brummer et al. 2010) as it places the conservation of red squirrels in jeopardy. Red squirrels at Thetford were also reported to be effected by another fatal virus known as adenovirus (Sainsbury et al. 2001), which can cause death in both species of squirrel. It was suggested that the reintroduction of red squirrels to Thetford was a sufficient stressor to have precipitated disease, however, inbreeding and loss of genetic diversity was also
linked to its outbreak (Martinez-Jimenez et al. 2011). Another tactic used in the conservation of red squirrels at Thetford was grey squirrel control methods (Gurnell & Steele 2002) and forecasting habitat suitability using a geographic information system (GIS) approach (Gurnell et al. 2002). However, it was found that it was not practical to remove all grey squirrels from the study area. Therefore, it was decided that release of red squirrels would not continue until a vaccine for SQPV could be found. To date, Thetford has been maintained as suitable for red squirrels by planting a larger amount of Scots pine and keeping broadleaves to a minimum.

The translocation of red squirrels to Anglesey in Wales (Shuttleworth et al. 2008) was the second attempt to bolster the red squirrel population of Wales, after failure at Colwyn Bay (Jackson et al. 1998). Anglesey is an island of 720 km$^2$ and the encroachment of grey squirrels into Wales put remaining red squirrels within the region under threat. Therefore before any more introductions of red squirrels were undertaken, a grey squirrel eradication programme was implemented (Shuttleworth et al. 2008). This was to become a 13 year trapping campaign to remove grey squirrels (Schuchert et al. 2012). Once grey squirrel control was underway and a decline in numbers was achieved, a re-introduction programme to Newborough Forest (770 ha) on Anglesey was undertaken. Post-release monitoring of the population was designed as a three year study and the primary technique used was radio tracking. The population was found to have expanded and settled into the area. However, like Thetford Forest in England, Anglesey has had problems with the occurrence of adenovirus (Everest et al. 2012), this virus was identified in October 2007 during reintroduction of red squirrels to the area. Although the reintroduction of red squirrels was successful the presence of adenovirus caused a significant negative impact on captive husbandry (Everest et al. 2012). Recommendation for future blood screening to ensure the virus is not moved between collections has been made (Everest et al. 2012). Another form of post-release monitoring at Anglesey has occurred through DNA analysis in order to evaluate levels of diversity across the island (Ogden & McEwing 2011). Post-release monitoring at Anglesey has yielded a large amount of important information for future release projects and recommendations have been made from this experience (Shuttleworth et al. 2008).

The need for post-release monitoring is emphasised, this is evident in areas such as Thetford and Anglesey where the grey squirrel and disease are major threats to the newly established red squirrel populations. Post-release monitoring studies have also enhanced our knowledge of red squirrel ecology including population trends and what improves their survival in such habitats.
3.1.4 Background to two post-release monitoring studies in Ireland

During the years 2003 to 2007 a red squirrel translocation was undertaken by Dr Alan Poole as part of his PhD project (Poole 2007, Poole & Lawton 2009) with the Mammal Ecology Group, NUI Galway. The study’s primary aim was to investigate the feasibility of translocation as a tool to conserve the red squirrel in Ireland. Initially a distribution survey was carried out that confirmed that both species of squirrel were absent from large areas of coniferous woodland in counties Mayo and Galway due to the lack of suitable habitat and suitable terrain for dispersal (Carey et al. 2007). This was considered to be a prime region for red squirrel translocation, due to the distance from the current grey squirrel range and inaccessibility of the region for grey squirrels, due to natural barriers such as the river Shannon and unfavourable habitat for dispersal.

In keeping with the IUCN guidelines for re-introductions (1998) the donor site was investigated in order to make sure that the removal of animals would not endanger the population. The donor site chosen was Portumna Forest Park, Co Galway, a mixed wood dominated by Scots pine *Pinus sylvestris* and Norway spruce *Picea abies*. Through direct and indirect field techniques it was found that the woodland contained a population with a density of 0.93 squirrels per hectare with no sign of disease. Monitoring of the source population continued post-removal and it was found to recover quickly from the removal of relatively few (19) squirrels.

The target woodland was sourced from a shortlist of five potential woodlands in the Connemara area of county Galway. Of those five, Derryclare wood was chosen following the criteria for selecting red squirrel reserves developed in Britain (Reynolds & Bentley 2001). These criteria included the recommended minimum size of 200 hectares, with trees of mixed age structure and threat from the grey squirrel presence being very low.

A soft release technique was adopted for the translocation of red squirrels as recommended by Venning *et al.* (1997). The enclosure design was based on the Anglesey re-introduction project in Wales (Jackson *et al.* 2002). Two enclosures were constructed in the deciduous area of Derryclare wood; they were positioned one kilometre apart from each other to minimise the risk of disease spreading between the two. Enclosures were made from a steel scaffold frame 3.6 m x 3.6 m x 3.9 m high and enclosed with a 25 mm x 25 mm, 1.6 mm gauge galvanised welded mesh walls and roofs (Plate 3.1). Each enclosure was equipped with branches, platforms containing food and water, four nest boxes and supplementary feeders.
Plate 3.1: One of the two enclosures used during soft release procedure of red squirrels to Derrynlare wood (Photo: Dr Alan Poole).

In total 19 red squirrels were translocated from Portumna Forest Park, nine females and ten males, between July and October 2005. The red squirrels were moved in three phases with no more than five squirrels in an enclosure at any one time. They were held for three to ten weeks before being released, depending on the trappability of individuals at the donor site.

Six supplementary feeders were distributed in areas surrounding the release sites and maintained with a 50:50 peanut/maize mix. Twenty nest boxes were also provided throughout the surrounding wood. Supplementary feeding was carried out until July 2006.

The released squirrels were monitored through a combination of live-trapping and radio telemetry to assess settlement patterns and monitor health and breeding status of individuals. The translocation was deemed successful with 94.7% of squirrels successfully surviving release from the enclosure (against a target of 75%) and 68.4% (13 of 19 squirrels) surviving to the following breeding season (against a target of 50%). By May 2006, 11 of 13 surviving squirrels were reproductively active and at least 9 new young were present. Eleven of the 13 squirrels that were radio tracked were found to include the woodland immediately surrounding the enclosures in their home range as this area contained supplementary feeders. Only two squirrels established initial home ranges away from the release area.
3.1.5 Aims and Objectives

The main aim was to investigate the ecology of two red squirrel populations after translocation through medium-term post-release monitoring techniques. The first examination was of a translocated population released in 2005 at Derrycclare wood and last examined before the current study in 2007. The second examined a translocated population introduced to Belleek Forest Park in 2007 and 2008. The objectives were as follows:

- To monitor population growth and development through juvenile recruitment and breeding condition.

- To monitor population trends in abundance and density.

- To examine squirrel dispersal and spread through each woodland from year to year.

- To monitor individual fitness through body condition and hence overall population health.

- To investigate habitat use and squirrel feeding and to examine the seed crop being harvested by the population.

Comparisons were made between data gathered at the two different study sites and possible differences discussed.
3.2 Materials and Methods

3.2.1 Study site

Site one, Derryclare wood (OS: L 83 50), is situated in Connemara, west Co Galway. The woodland resides alongside Lough Inagh and Lough Derryclare at the foot of Mount Derryclare (Dhoire chlíár) one of the twelve bens (Benna Beola) also referred to as the twelve pins. Derryclare consists of 789 ha of Coillte-owned commercial conifer forest (planted in the 1960s) and a 19 ha Nature Reserve owned by the National Parks and Wildlife Service of which 8 ha is a natural broadleaved wood.

The conifer forest is mainly dominated by Lodgepole pine *Pinus contorta* (63%) and sitka spruce *Picea sitchensis* (30%) (Figure 3.1). The 789 ha forest has a 570 ha area contained in one large block which adjoins the Nature Reserve. Of the 570 ha, approximately 393 ha are forested; the remainder is either felled or bare. The commercial forest has a well managed felling plan with a variable age structure.

The Nature Reserve consists of 8 ha of wooded area and 4 ha of pond, wet moorland and lake-shore habitat. It was designated as a Nature Reserve in 1980 (Statutory Instrument 177/1980) and is characterised as a WN1 site (Fossitt 2000), mainly consisting of oak *Quercus petraea* and *robur*, Ash *Fraxinus excelsior*, birch *Betula* sp. and hazel *Corylus avellana*. The Nature Reserve is approximately 200 years of age and is protected under Article 2, Section 15 of the Wildlife Act 1976. Ferguson & Westhoff (1987) examined the Nature Reserve and they compiled a comprehensive report of plant species and environmental factors on the mature woodland. They also classify the woodland as one of the few remaining examples of an Atlantic wood.

Site two has been described in Section 2.2.1 in the translocation of red squirrels to Belleek Forest Park.
Figure 3.1: Derryclare wood including the location of the Nature Reserve and tree species composition (Coillte 2004).
3.2.2 Direct field techniques

A) Live trapping

Derryclare wood: In May 2008, a feeding signs survey of Derryclare woodland was conducted to examine changes to the squirrel population since the end of Poole’s study in 2007. The main wood of was divided into different sections, 18 blocks in total (Figure 3.2 and Table 3.2). Each block was examined and searched for the presence of red squirrels, using feeding signs or sightings. The Nature Reserve was included as this was the site of release during the 2005 translocation.

A trapping grid of 40 traps was set out incorporating those areas identified as positive for squirrel presence (Figure 3.3a). Traps were placed at one per hectare and the grid incorporated the Nature Reserve and the immediate surrounding coniferous areas. The number of traps used was later reduced to 33, mainly due to time constraints due to day-length during winter months. The trapping procedure was carried out as described in section 2.2.4. Trapping occurred from June 2008 to March 2011 at Derryclare.

In March 2010, the trapping grid was adjusted to incorporate other areas of the woodland that the squirrels were dispersing into, see Figure 3.3b. Twenty traps were kept in place on the original trapping grid and twenty were placed in new areas of woodland. Fourteen of the twenty traps relocated were situated in an area known not to contain squirrels; it was deemed that this area was the next locality that the population may disperse into, and offered the opportunity to study these animals at the face of spread.

In December 2010, 20 ha of woodland was clear-felled (see Chapter 4) from an established area of woodland, which contained three traps. Therefore density calculations considered this change in area containing squirrels for estimates January 2011 and March 2011.

Belleek Forest Park: Trapping was conducted as described in section 2.2.4 and was carried out from August 2008 to May 2011. The trapping session March 2008 was not incorporated in these results as it was not conducted using the full trapping grid. Due to the fact that Belleek is an amenity for public use, traps were hidden from view as much as possible. However, in the course of the three year study, ten traps went missing, vandalism and tampering also occurred. Signs were affixed to each trap clearly stating their purpose but this did not prevent damage occurring. Due to this situation when calculating density results were adjusted accordingly.
B) Population estimates via mark-recapture data

Population estimates were made using three different techniques based on the mark-recapture data collected. When using these techniques there were a number of assumptions that were made: all marks were permanent; being captured, handled and marked had no effect on an individual’s choice of being recaptured, dying or emigrating; all individuals had an equal chance of being caught and that sampling periods were short in relation to total time (Begon 1979).

The first estimate used the Minimum Number Present (MNP). This calculates the animal known to be present in the wood at any one time, and is based on the individuals captured in each trapping session, plus those that were not captured, but were marked previously and caught in subsequent samples. These animals were assumed to have been present on the trapping grid but just not detected in that session.

The second estimate used the Petersen/Lincoln Index (often shortened to Lincoln Index). The index assumes that there are no births, deaths, immigration or emigration during the period under investigation. Estimates are derived from the proportion of individuals marked in a first sample which are present as recaptures in a second sample (Fowler, Cohen & Jarvis 1998). Individuals were marked with a PIT tag (see section 2.2.4 and plate 2.6), which remains as a permanent mark throughout the individuals life.

\[ N = \frac{rn}{m} \]

As each trapping period in this study lasted for three to four days, the final day trapping was taken as the second sample (n) and the individuals captured in the earlier days giving the first sample (r) with recaptures (those already PIT tagged) counted on the final day (m). This means that a separate estimate was derived for each trapping month and the estimation was based on a relatively short time span, reducing the likelihood of gains or losses occurring in the population. The Lincoln Index is known to be affected by chance fluctuations, especially when working with small numbers, which is usually the case in squirrel studies.

The third estimate used was the Fisher-Ford method. This method relies on several marking occasions and several recaptures. It works on a similar principle to the Lincoln Index but incorporates a measure of survival of animals (and their marks) from one session to the next. For studies with relatively small amounts of data, the estimate derives a constant survival rate by grouping data and as such samples are combined, reducing sampling error (Begon 1979).

These population estimates were converted to a population density based on the area covered by the trapping grid, including an outer boundary strip to allow for the edge effect. Boundary strip was calculated as the radius of the squirrel’s home range and added to the parameter of the
trapping grid. At Belleek Forest Park the boundary strip was calculated as 100.93 m and at Derrycclare wood it was 146.7 m, both were estimated from radio tracking data. Any change in trapping grid was incorporated into calculations and boundary strip did not extend into unfavourable squirrel habitat.

The body condition of individual red squirrels was calculated to assess fitness at both sites, it was calculated by dividing body weight by shin bone length (as mentioned in section 2.2.4). In order to compare the two sites the mean body condition was calculated for each individual squirrel, this allowed for overall effect of habitat to factor in on an individual’s development but also removed seasonal factors.
Figure 3.2: Aerial photo (OSI 2005) of Derryclare wood divided into blocks used throughout the study.
### Table 3.2: Summary of baseline survey including blocks surveyed, approximate area (ha) and habitat available.

<table>
<thead>
<tr>
<th>Section</th>
<th>Approximate forested area (ha)</th>
<th>Tree species</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>Lodgepole pine</td>
</tr>
<tr>
<td>2</td>
<td>29</td>
<td>Sitka Spruce</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>Mainly Lodgepole pine with some sitka spruce</td>
</tr>
<tr>
<td>4</td>
<td>42</td>
<td>Lodgepole pine</td>
</tr>
<tr>
<td>5</td>
<td>23</td>
<td>Mainly lodgepole pine with some sitka spruce</td>
</tr>
<tr>
<td>6</td>
<td>42</td>
<td>Mainly lodgepole pine with some sitka spruce</td>
</tr>
<tr>
<td>7</td>
<td>15</td>
<td>Immature Lodgepole pine</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>Lodgepole pine</td>
</tr>
<tr>
<td>9</td>
<td>16</td>
<td>Mainly bare with some sitka spruce</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>Sitka spruce and lodgepole pine</td>
</tr>
<tr>
<td>11</td>
<td>32</td>
<td>Immature sitka spruce and bare</td>
</tr>
<tr>
<td>12</td>
<td>17</td>
<td>Lodgepole pine</td>
</tr>
<tr>
<td>13</td>
<td>16</td>
<td>Lodgepole pine and sitka spruce</td>
</tr>
<tr>
<td>14</td>
<td>17</td>
<td>Lodgepole pine and bare</td>
</tr>
<tr>
<td>15</td>
<td>35</td>
<td>Mainly lodgepole pine with some sitka spruce</td>
</tr>
<tr>
<td>16</td>
<td>8</td>
<td>Lodgepole pine and open bog</td>
</tr>
<tr>
<td>17</td>
<td>20</td>
<td>Mainly sitka spruce with some lodgepole pine</td>
</tr>
<tr>
<td>18</td>
<td>8</td>
<td>Broadleaf Nature Reserve</td>
</tr>
</tbody>
</table>

**Total approximate area**: 393

Table 3.2 gives a summary of the map used for the baseline survey; the approximate area of each block was calculated using ArcGIS 9.3.
Figure 3.3a: Derryclare trapping grid incorporating the Nature Reserve and surrounding coniferous woodland. Trapping commenced June 2008 to March 2010.

Figure 3.3b: New trapping grid in Derryclare incorporating areas into which red squirrels were dispersing. Trapping commenced April 2010 to March 2011.
C) Radio telemetry

**Derryclare wood:** Radio tracking was undertaken in March, April and May 2009 to investigate squirrel home range. Methods were carried out as described in section 2.2.3 for Belleek Forest Park. Seven red squirrels were fitted with radio collars. However, it became apparent that due to the topography of the land and difficulty in its traverse that gathering the fixes needed to examine home range would not be possible in a reasonable amount of time (within three months). The radio tracking was also subject to a lot of reflection and refraction due to the mountainous landscape. The results obtained here were used to indicate habitat preference rather than individual home range.

### 3.2.3 Indirect field techniques

A) Hair tube surveys

**Derryclare wood:** Hair tube surveys were conducted in two areas adjacent to the trapping grid. Tubes were made from 300 mm lengths of 65 x 65 mm square ended PVC piping (modified from Garson & Lurz 1998). The tubes were inserted with two wooden blocks at either end; each block was covered in three 1cm² patches of glue. Tubes were secured to the trees at head height at the trunk of the tree with coloured twine (Plate 3.2).

Each tube was baited with a mix of maize and peanuts. Bait was placed on top of the tube to attract the squirrel down from the tree and four hazelnuts were placed inside to entice the squirrel in. Hair tubes were re-baited after one week and collected two weeks after being deployed. Blocks were covered in grease proof paper, to protect the glue and hair and placed in clearly labelled polythene bags.

The first survey was conducted in February 2009 in block 12 (Figure 3.2). Twenty-four tubes were placed at intersections of a grid at 100 m apart. A second survey took place in July 2009 in block 8. In this instance hair tubes were placed out at a density of two per hectare.

Hairs were removed from the glue squares by soaking them in vegetable oil, to remove the hairs from glue without damaging them. Hairs were cleaned using distilled water. In order to remove any further grease from the hair, they were treated with histo-clear and soaked again with distilled water.
Plate 3.2: Hair tube baited and attached securely to tree with twine.

A 10-20% stock of gelatine solution was made with warm distilled water and thymol salts (Teerink 1991). A thin layer of the solution was then poured over a glass slide; any waste gelatine was allowed to run off onto filter paper. Hairs were placed onto the gelatine covered slide. Slides were left overnight until gelatine hardened. The hairs were then removed using a fine forceps to avoid damage to the distal end of the hair. The impression left was observed under high magnification (x400) for identification of cuticular scales (Teerink 1991) (Plate 3.3).

Plate 3.3: Impressions in gelatine left by red squirrel hair shield (A) and shaft (B) (as viewed under x400 magnification) (Emily Goldstein 2009).
B) Feeding line transects

**Derryclare wood:** To further assess dispersal of red squirrels feeding line transects were used in mature stands of trees.

A transect of 50 m² was walked, one for every four hectares (Gurnell, Lurz & Pepper 2001). The length of each transect was measured using 50 m tape and the width with a metre stick (Plate 3.4). Along each transect, all lodgepole pine and sitka spruce cones were identified and counted. Cones eaten by squirrels were taken as a sign for squirrel presence in that area (Plate 3.5). Transects were conducted in blocks 1, 2, 3, 4 and 6 (Figure 3.2), and were continued into neighbouring sections depending on the evidence of squirrels found in the area at that time.

![Plate 3.4: A typical line transect measured by 50 m tape and a metre stick.](image)

Lodgepole pine cones are known to remain closed for several years on the trees (Lurz *et al.* 2000). This is a natural adaptation to their native habitat (NW America). These cones are described as serotinous (seed release occurs in response to an environmental trigger rather than seed maturation); as this is an adaptation of the trees living in a very dry environment where seed shedding occurs after forest fires (Gurnell 1987). Quantifying available seed using line transects on the forest floor cannot give an exact measure of annual seed crop due to the retention of cones after maturation, therefore the estimation of available lodgepole pine cones is likely to be conservative. However, these counts can give an indication of food availability and habitat quality from year to year and accurate measurements of cone predation by squirrels can be made as cone cores fall to the forest floor. Cones consumed by squirrels were counted and
information on energy value per unit area was estimated, this was then converted into squirrel density. Potential and estimated squirrel density was calculated from energy available and energy consumed.

Line transects were also used to assess food availability and energy consumption in the coniferous areas of Derrycclare wood in 2008, 2009 and 2010.

Plate 3.5: Lodgepole pine cone (A), whole (top) and eaten by squirrel (bottom) and a sitka spruce cone (B), whole (top) and eaten by a squirrel (bottom).

In 2008, this was undertaken by an undergraduate in their degree year (Emma Sheehy B.Sc.). Thirty-one transects were examined along 50 m x 1 m plots. These transects followed the same methodology as described above. Twenty-three of the transects were carried out in the immediate vicinity of squirrel traps, such that the transect either began at, or passed directly by an individual trap. No trapping took place during the period that line transects were carried out. The remaining eight transects were carried out in random parts of the forest where traps were not in place and at least 100 m distance from other transect locations. Information on food availability and consumption along transects (1550 m$^2$) was then extrapolated to the entire survey area (670,000 m$^2$). The energy content of a lodgepole pine cone and sitka spruce seed was obtained from Smith 1968, 1981 and Gurnell et al. 2001. The amount of seeds available in an average lodgepole pine cone is 20 to 40 seeds (Gurnell 1987); during calculations of energy content the median value of 30 seeds was used. A value of 0.098 KJ was used as the energy content per lodgepole pine cone, which gave an average value of 2.94 KJ per cone (Gurnell et al. 2001). A sitka spruce cone contains approximately 215 seeds per cone (Smith 1968) and has an energy value of 5.3 KJ per cone (Gurnell et al. 2009). The potential energy consumed on a daily basis by adult squirrels ranged from 400 to 700 kJ (Gurnell et al. 2001)
In 2009, 2010 and 2011 the study was repeated. On these occasions, ten transects were conducted, one every four hectares (Gurnell, Lurz & Pepper 2001), covering approximately the trapping area. These transects covered an area of 500 m$^2$ (0.05 ha) and were not conducted in areas that did not contain squirrels.

C) Feeding quadrats

**Belleek Forest Park:** In 2009 and 2010, the amount of natural resources available to the red squirrels was assessed at Belleek Forest Park. This was studied using eleven line transects placed randomly in areas of different tree composition throughout the Forest Park. Each transect consisted of three 1 m$^2$ quadrats placed on a randomly chosen line about 20 metres apart (Wauters & Dhondt 1988). Quadrats were marked using wooden stakes painted white in order to locate them easily each session. The quadrats were also marked using a Garmin GPS in case stakes were lost. Each trapping month, fallen seeds were identified and counted on each quadrat after which debris was removed. Tree seeds such as beech mast and pine cones (Scots pine, Norway spruce, sitka spruce and larch) were counted; cones eaten by squirrels were also recorded. These values were extrapolated to give the overall seed crop, feeding signs in beech mast were not distinguished as the beech nuts are removed not only by squirrels but also by birds (e.g. chaffinch *Fringilla coelebs*). As such the amount of food eaten by squirrels in the wood could not be fully quantified. However, the seasonality of tree seed was assessed and the amount available in the woodland was recorded.

**Derrycclare Nature Reserve:** In 2009 and 2010, the same method as described above was used to monitor the availability of seed crop in Derrycclare Nature Reserve. Four line transects were placed at random in areas of different tree composition.

### 3.2.3 Work Schedule

Table 3.3 displays the work schedule for post-release monitoring experiments carried out both at Derrycclare wood and Belleek Forest Park, running from May 2008 to May 2011.

Post-release monitoring at Derrycclare began in May 2008 with a feeding signs survey which was carried out by Nicola Condell of the Mammal Ecology Group, NUI Galway. Live trapping sessions June and August 2008 were also carried out by Nicola Condell, however all other work was conducted by the author.

The schedule shown for Belleek Forest Park continues from the schedule in Chapter 2 (section 2.2.5) until May 2011. Live trapping at both sites was initially intended to be carried out on a bi-monthly basis; however, the investigation into other areas of the study required time spent on other experiments which meant that some trapping months were omitted.
Table 3.3: Work schedule of post-release monitoring for both study sites (Derrycclare wood and Belleek Forest Park), May 2008 to May 2011

* Re-organising squirrel traps for new trapping grid.
** Second radio tracking session covered in Chapter 2.
3.3 Results

**Derryclare wood**

3.3.1 Population estimation

Of the 18 blocks of woodland investigated using feeding signs and sightings May 2008, only four areas were found to be positive for the presence of squirrels through feeding signs; blocks 13, 16, 17 and the Nature Reserve (18, Figure 3.2). All other areas examined were found to be negative for the signs of squirrels.

During the initial live trapping (June 2008) it was found that six of the original 19 red squirrels translocated in 2005 were still occupying the woodland. Three of these animals survived until 2011. Assuming they were a minimum of one year of age when translocated, they were at least seven years old in 2011. Eleven other squirrels were also captured in this first session (Table 3.4).

Population estimates based on mark-recapture data for each trapping session were made and are displayed for each phase in Table 3.4. Estimates were calculated using one of three methods; Minimum Number Present, Lincoln Index and Fisher-Ford model. The Minimum Number Present (MNP) estimates show a baseline of squirrels present in the trapping area, Figure 3.4 displays the trend of this estimate against that of the Fisher-Ford estimate, both show that the population increased from year to year.

The Lincoln Index follows a similar trend to the MNP in the first five trapping sessions, however, the estimates drop below that of the MNP in a number of months.

The Fisher-Ford estimate gives the highest figure in the first month of the study and lowest in the second month. As the trapping months continue this estimate continues to increase to the highest estimate in March 2011 of 51.43 squirrels (Figure 3.4). The Fisher-Ford model produces a single-survival rate from trapping session to trapping session; this rate (Ø) was 0.97. From this an annual rate of 0.850 can be extrapolated.
Table 3.4: Population estimates for each trapping month in phases one and two using three techniques at Derrycclare wood.

<table>
<thead>
<tr>
<th>Trapping months</th>
<th>MNP</th>
<th>Lincoln Index</th>
<th>Fisher-Ford</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 2008</td>
<td>17</td>
<td>17 (±N/A)</td>
<td>27.44</td>
</tr>
<tr>
<td>August 2008</td>
<td>12</td>
<td>11.2 ± 2.29</td>
<td>10.35</td>
</tr>
<tr>
<td>October 2008</td>
<td>10</td>
<td>10 (±N/A)</td>
<td>12.1</td>
</tr>
<tr>
<td>December 2008</td>
<td>10</td>
<td>10 (±N/A)</td>
<td>10.67</td>
</tr>
<tr>
<td>February 2009</td>
<td>14</td>
<td>15.16 ± 1.86</td>
<td>19.4</td>
</tr>
<tr>
<td>June 2009</td>
<td>11</td>
<td>8 (±N/A)</td>
<td>16.6</td>
</tr>
<tr>
<td>August 2009</td>
<td>11</td>
<td>8 (±N/A)</td>
<td>11.72</td>
</tr>
<tr>
<td>October 2009</td>
<td>13</td>
<td>17.5 ± 12.12</td>
<td>19.36</td>
</tr>
<tr>
<td>December 2009</td>
<td>12</td>
<td>10 (±N/A)</td>
<td>17.96</td>
</tr>
<tr>
<td>April 2010</td>
<td>13</td>
<td>7 (±N/A)</td>
<td>16.81</td>
</tr>
<tr>
<td>June 2010</td>
<td>18</td>
<td>17.5 ± 2.3</td>
<td>29.29</td>
</tr>
<tr>
<td>August 2010</td>
<td>15</td>
<td>13 ± 2.42</td>
<td>37.96</td>
</tr>
<tr>
<td>January 2011</td>
<td>16</td>
<td>14 ± 3.2</td>
<td>34.55</td>
</tr>
<tr>
<td>March 2011</td>
<td>22</td>
<td>25.7 ± 3.73</td>
<td>51.43</td>
</tr>
</tbody>
</table>

When calculating density using the area for the second trapping grid, 12 hectares (block 10) were not considered as no squirrel feeding signs were found in the area. In June 2010, one adult male (255 g) was captured on this area (10) of the grid. However, since that capture no other squirrels were ever caught or recaptured in this section.

Across the trapping period 21 total captures were made in traps situated within the Nature Reserve, with an average of 3.8 squirrels caught per trapping session. Five of these individuals were tagged for the first time in the broadleaved area. The six originally translocated squirrels still found in Derrycclare were captured in the Nature Reserve over the course of the study, three of which were still present in March 2011.

Overall trapping success was calculated and broken into trapping success on the original trapping grid and again when the trapping grid was changed. Based on the original grid, the lowest trapping success was found in October 2009 (14.4%), the highest was found in June 2008 (34.6%), with an average trapping success for the phase as 21.96%. Based on the new trapping grid, the lowest trapping success was found in April 2010 (10%) when adjustments had been made to the trapping grid, the highest trapping success was found in March 2011 (27.4%), giving an average trapping success for phase two as 20.4%.
Figure 3.4: Population estimates at Derryclare, using Minimum Number Present and Fisher-Ford estimates.
Table 3.5: Population density (squirrels per ha) for each trapping session and phase based on three population estimates at Derryclare wood.

<table>
<thead>
<tr>
<th>Trapping months</th>
<th>MDP</th>
<th>Lincoln Index</th>
<th>Fisher-Ford</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 2008</td>
<td>0.29</td>
<td>0.29 (±N/A)</td>
<td>0.47</td>
</tr>
<tr>
<td>August 2008</td>
<td>0.21</td>
<td>0.19 ± 0.03</td>
<td>0.18</td>
</tr>
<tr>
<td>October 2008</td>
<td>0.17</td>
<td>0.17 (±N/A)</td>
<td>0.21</td>
</tr>
<tr>
<td>December 2008</td>
<td>0.17</td>
<td>0.17 (±N/A)</td>
<td>0.18</td>
</tr>
<tr>
<td>February 2009</td>
<td>0.24</td>
<td>0.26 ± 0.03</td>
<td>0.33</td>
</tr>
<tr>
<td>June 2009</td>
<td>0.19</td>
<td>0.14 (±N/A)</td>
<td>0.29</td>
</tr>
<tr>
<td>August 2009</td>
<td>0.19</td>
<td>0.14 (±N/A)</td>
<td>0.2</td>
</tr>
<tr>
<td>October 2009</td>
<td>0.21</td>
<td>0.3 ± 0.21</td>
<td>0.33</td>
</tr>
<tr>
<td>December 2009</td>
<td>0.21</td>
<td>0.17 (±N/A)</td>
<td>0.31</td>
</tr>
<tr>
<td>April 2010</td>
<td>0.22</td>
<td>0.12 (±N/A)</td>
<td>0.28</td>
</tr>
<tr>
<td>June 2010</td>
<td>0.28</td>
<td>0.29 ± 0.04</td>
<td>0.49</td>
</tr>
<tr>
<td>August 2010</td>
<td>0.25</td>
<td>0.22 ± 0.04</td>
<td>0.63</td>
</tr>
<tr>
<td>January 2011</td>
<td>0.29</td>
<td>0.25 ± 0.06</td>
<td>0.62</td>
</tr>
<tr>
<td>March 2011</td>
<td>0.39</td>
<td>0.46 ± 0.07</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Table 3.6: The potential number of squirrels (rounded to nearest whole number) at Derryclare wood each year of the study, based on the mean Minimum Density Present and the area in which red squirrels occupied.

<table>
<thead>
<tr>
<th>Year</th>
<th>Area occupied by red squirrels (ha)</th>
<th>Minimum mean density from live trapping</th>
<th>Total minimum number of squirrels</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>104</td>
<td>0.21</td>
<td>22</td>
</tr>
<tr>
<td>2009</td>
<td>120</td>
<td>0.21</td>
<td>25</td>
</tr>
<tr>
<td>2010</td>
<td>140</td>
<td>0.25</td>
<td>35</td>
</tr>
<tr>
<td>2011</td>
<td>181</td>
<td>0.34</td>
<td>62</td>
</tr>
</tbody>
</table>

3.3.2 Recruitment

Of the 17 squirrels captured in June 2008, six were from the originally translocated stock and 11 were new progeny.
As the red squirrel population at Derryclare is isolated from other red squirrel populations, all newly tagged animals were considered offspring of the translocated stock. Figure 3.5 shows the new recruits caught each trapping month on both trapping grids.

![New recruits captured each trapping month including phases one and two at Derryclare wood.](image)

**Figure 3.5:** New recruits captured each trapping month including phases one and two at Derryclare wood.

### 3.3.3 Habitat use by radio collared squirrels

Four of the five individuals investigated incorporated the Nature Reserve within their home range, four utilised lodgepole pine regions and only one used sitka spruce (Table 3.7). It was also found that within the amount of fixes gathered some overlap between male and female home range occurred; female 236 overlapped with male 175 and female 197 overlapped with 276. Core areas could not be calculated due to the small number of fixes gathered.

<table>
<thead>
<tr>
<th>Freq ID</th>
<th>Sex</th>
<th>Fixes gained</th>
<th>Nature Reserve (%)</th>
<th>Lodgepole pine (%)</th>
<th>Sitka Spruce (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>328</td>
<td>Female</td>
<td>25</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>236</td>
<td>Female</td>
<td>14</td>
<td>71.4</td>
<td>28.6</td>
<td>0</td>
</tr>
<tr>
<td>197</td>
<td>Female</td>
<td>7</td>
<td>28.6</td>
<td>71.4</td>
<td>0</td>
</tr>
<tr>
<td>276</td>
<td>Male</td>
<td>18</td>
<td>5.6</td>
<td>55.5</td>
<td>38.9</td>
</tr>
<tr>
<td>175</td>
<td>Male</td>
<td>3</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>317</td>
<td>Male</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>285</td>
<td>Male</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>67</strong></td>
<td><strong>23.9</strong></td>
<td><strong>65.6</strong></td>
<td><strong>10.5</strong></td>
</tr>
</tbody>
</table>

**Table 3.7:** Habitat use (%) by radio collared squirrels at Derryclare wood.
3.3.4 Individual fitness and breeding status

Overall mean weight for each trap month is displayed in Table 3.8. There was no significant difference detected between sessions or between years for overall mean weight.

<table>
<thead>
<tr>
<th>Trap month</th>
<th>Overall mean weight each trapping month</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 2008</td>
<td>260.59 ± 23.26, n = 17</td>
</tr>
<tr>
<td>August 2008</td>
<td>296 ± 27.85, n = 10</td>
</tr>
<tr>
<td>October 2008</td>
<td>274.5 ± 19.04, n = 10</td>
</tr>
<tr>
<td>December 2008</td>
<td>278 ± 17.7, n = 10</td>
</tr>
<tr>
<td>February 2009</td>
<td>280 ± 12.6, n = 14</td>
</tr>
<tr>
<td>June 2009</td>
<td>265.63 ± 29.68, n = 8</td>
</tr>
<tr>
<td>August 2009</td>
<td>272.5 ± 19.98, n = 8</td>
</tr>
<tr>
<td>October 2009</td>
<td>272 ± 12.97, n = 10</td>
</tr>
<tr>
<td>December 2009</td>
<td>271 ± 12.93, n = 10</td>
</tr>
<tr>
<td>April 2010</td>
<td>277.86 ± 22.47, n = 7</td>
</tr>
<tr>
<td>June 2010</td>
<td>283.26 ± 14.17, n = 17</td>
</tr>
<tr>
<td>August 2010</td>
<td>251.92 ± 29.46, n = 13</td>
</tr>
<tr>
<td>January 2011</td>
<td>275.83 ± 13.96, n = 12</td>
</tr>
<tr>
<td>March 2011</td>
<td>267.5 ± 11.36, n = 22</td>
</tr>
</tbody>
</table>

Table 3.8: Overall mean weight (each individual counted once) for each trapping month at Derryclare wood with 95% confidence limits, new trap grid is highlighted with black outline.

Figure 3.6: New recruit weight (grams) at Derryclare wood. Values on the x-axis show the mid-points of the range for each class.
Chapter 3

Results

The frequency distribution of weight (Figure 3.6) measured from new recruits was examined to study the weight of these individuals at tagging. It was found that most new recruits weighed over 230 grams at first capture.

Body condition was also investigated at Derryclare, a one way Anova showed that body condition changed between trapping months as a significant difference was found ($F = 1.905, df = 13, P = 0.033$).

Body size was investigated, as indicated by mean shin bone length (Table 3.9). There was no significant difference found between the sexes.

<table>
<thead>
<tr>
<th>Mean shin length (mm)</th>
<th>Mean male shin length (mm)</th>
<th>Mean female shin length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>66.1 ± 2.07</td>
<td>65.78 ± 2.32</td>
<td>67.19 ± 1.16</td>
</tr>
<tr>
<td>n = 47</td>
<td>n = 32</td>
<td>n = 15</td>
</tr>
</tbody>
</table>

**Table 3.9:** Mean shin bone length with 95% confidence intervals for squirrels at Derryclare wood.

The linear regression of shin bone length on body weight is presented for all squirrels in Figure 3.7. Regression analysis showed that there was a highly significant relationship between shin bone length and body weight for all squirrels ($P < 0.0001$).

**Figure 3.7:** Linear regression of shin bone length against weight for all squirrels at Derryclare wood.

Regression analysis was also conducted for adult male and female squirrels; males (Figure 3.8) showed a highly significant relationship between shin bone length and weight ($P < 0.0001$) whereas, females were found not to be significant ($P = 0.24$).
Figure 3.8: Linear regression of shin bone length against weight for adult male squirrels at Derryclare wood.

The breeding condition of female and male squirrels was calculated each trapping month in both phases of the study (Figures 3.9 and 3.10). In June 2008 the female captured in a non-breeding condition was a juvenile.

Figure 3.9: Breeding status of female squirrels in each trapping session at Derryclare wood.
The weight of breeding females compared to non-breeding females was examined. A two-way ANOVA was conducted that examined the effect of breeding status and season on the weight of females. Season was defined as winter months (December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November). There was a significant interaction between breeding status and season ($F = 7.689$, $df = 2$, $P = 0.001$). A significant difference was found between seasons ($F = 4.150$, $df = 3$, $P = 0.011$). A significant difference was also found between breeding and non-breeding female weights ($F = 15.005$, $df = 1$, $P < 0.0005$).

Figure 3.10: Breeding status of males captured each trapping month in both phases at Derryclare wood.

Male squirrels were found to be actively breeding in every trapping month except October 2008 (Figure 3.10).

The number of breeding females caught in each breeding season was used to calculate the potential number of young born each year, assuming an average of three kits per litter (Table 3.10). This can be compared to the number of new recruits tagged during each trapping session. New recruits that were tagged at the beginning of a breeding season and were clearly not juveniles but offspring missed from last season’s progeny, were counted in the previous season’s recruitment.
Table 3.10: The number of potential young born in each breeding season (based on an average of three kits per female) and the new recruits marked in both phases at Derryclare wood.

In the breeding season of 2011, the highest number of potential young over the course of four breeding seasons was calculated. The number of actual recruits marked could be an underestimate due to the cessation of trapping.

The sex ratio was calculated for each trapping session (Figure 3.11). It was found that males were more common than females in all but one trapping month (August 2008) during which the ratio was 1:1. Overall the proportion of animals caught that were male caught in the entire trapping series was 0.68.
3.3.5: Red squirrel dispersal through the woodland

The dispersal of squirrels through the woodland is shown through annual distribution maps as detected by live trapping, radio tracking, hair tube surveys and feeding line transects (Figures 3.12a to 3.12e). Figure 3.12a displays the red squirrel distribution at the end of Poole’s study.

In February and July 2009, hair tubes were used to assess further dispersal of squirrels into surrounding woodland. Of the twenty-four hair tubes put out in block 12 (Figure 3.2) 37.5% of them were found to contain hairs. Of the hair tubes found to contain hairs all were positive for red squirrel hair, which were identified using cuticular analysis. Another set of hair tubes were deployed in July 2009 in the next nearest area of mature trees (block 8, Figure 3.2). Of the twenty-four hair tubes put out in block 8, 83.3% of them contained red squirrel hair. Hair tubes were placed at two per hectare in this section. Whilst hair tubes were being deployed on both occasions, feeding signs were being examined on the ground. No more hair tubes were deployed after the second session, due to the absence of these signs. It was determined that the “frontier” of red squirrel dispersal had been reached for that year.

In 2010 and 2011, feeding line transects were used in order to further examine the dispersal of red squirrels. In 2010, nine transects were conducted (three in block 1, three in block 4 and three on the border between blocks 1 and 2). Details of the cones counted are given in Table 3.12 and helped form the distribution shown in map D (Figure 3.12d). No more feeding transects were conducted in 2010 as feeding signs diminished in surrounding areas.

In 2011, blocks 3, 5 and 6 were investigated for any further dispersal of squirrels as these areas were found to be devoid of squirrels in previous years. Line transects were used and a total of seven were conducted (three in block 3, three in block 5 and one in block 6), no more were considered necessary as squirrel feeding signs were not found any further than the area in which these transects covered. Both lodgepole pine and sitka spruce cones were found to have been fed upon and as such the energy consumed by squirrels for both tree species was used to calculate estimated density. Block 17 was no longer inhabited by squirrels due to the area being clear-felled (see chapter 4) displayed in map E.

Density estimations (Table 3.11) display the calculated potential and estimated density in each block investigated by feeding transects. Not all areas have an estimated density as none or few feeding signs were found. Blocks 1, 3 and 5 do display an estimated density, however it indicates a very low number of squirrels are occupying the area, even though there is potential for this area to maintain more squirrels.
<table>
<thead>
<tr>
<th>Year</th>
<th>Block</th>
<th>Cones available</th>
<th>Energy available (kJ)</th>
<th>Cones consumed</th>
<th>Energy consumed (kJ)</th>
<th>Potential squirrel density</th>
<th>Estimated squirrel density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LP   SS</td>
<td>LP   SS</td>
<td>LP   SS</td>
<td>LP   SS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>1</td>
<td>6.14 0.08</td>
<td>18.05 0.42</td>
<td>0.05 0</td>
<td>0.15 0</td>
<td>0.72 – 1.27</td>
<td>0.006 – 0.01</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.86 1.85</td>
<td>2.53 9.81</td>
<td>0 0</td>
<td>0 0</td>
<td>0.48 – 0.87</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3.35 0.06</td>
<td>9.85 0.32</td>
<td>0.06 0</td>
<td>0.18 0</td>
<td>0.41 – 0.71</td>
<td>-</td>
</tr>
<tr>
<td>2011</td>
<td>3</td>
<td>1.41 0.08</td>
<td>4.15 0.42</td>
<td>0.1 0</td>
<td>0.29 0</td>
<td>0.18 – 0.31</td>
<td>0.01 – 0.02</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.58 0.39</td>
<td>4.65 2.07</td>
<td>0.63 0.11</td>
<td>1.85 0.58</td>
<td>0.26 – 0.46</td>
<td>0.11 – 0.18</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.68 2.36</td>
<td>2.11 12.51</td>
<td>0.06 0</td>
<td>0.18 0</td>
<td>0.57 – 1.00</td>
<td>-</td>
</tr>
</tbody>
</table>

**Table 3.11:** Number of cones or energy available per m² from feeding line transects along ‘frontier areas’ of Derryclare, used to determine squirrel presence and density in each block (12 ha) investigated in 2010 and 2011.
Figure 3.12a,b: The dispersal of red squirrels through Derryclare woods, as seen through positive records derived from live trapping, hair tubes and feeding signs (A – 2007 (status as of Poole (2007)), B – 2008).
Figure 3.12c,d: The dispersal of red squirrels through Derryclare woods, as seen through positive records derived from live trapping, hair tubes and feeding signs (C – 2009, D – 2010)
Figure 3.12e:
The dispersal of red squirrels through Derryclare woods, as seen through positive records derived from live trapping, hair tubes and feeding signs (E – 2011).
### 3.3.6 Seed crop analysis

Data was collected in the autumn of 2008, 2009, 2010 and 2011 on the amount of seed crop available to red squirrels in the coniferous regions of the woodland.

In 2008, a line transect survey was undertaken by an undergraduate (Emma Sheehy) as her final year thesis project. Data was collected along 31 transects, there were no eaten sitka spruce cones recorded on any transects. The area covered was 1550 m\(^2\) (0.155 ha), which can be extrapolated to represent the available lodgepole pine in Derrycclare (276 ha). This gives a total amount of energy available from lodgepole pine cones for 2008 in Derrycclare of 30,023,280 kJ (Table 3.12).

<table>
<thead>
<tr>
<th>Line transects (1550 m(^2))</th>
<th>Cones available</th>
<th>Energy available</th>
<th>Cones consumed</th>
<th>Energy consumed kJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>5681</td>
<td>16702.14</td>
<td>828</td>
<td>2434.32</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total lodgepole pine (276 ha)</th>
<th>Cones available</th>
<th>Energy available</th>
<th>Cones consumed</th>
<th>Energy consumed kJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,212,000</td>
<td>30,023,280</td>
<td>1,462,800</td>
<td>4,333,200 (potential)</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.12:** Available energy and consumed energy in Derrycclare wood for 2008 (taken from line transects and extrapolated to the survey area and larger woodland area).

Potential squirrel density was calculated using the amount of energy consumed by an adult red squirrel per day which ranges from 400 to 700 kJ. Therefore it was calculated that in the larger area covered by Lodgepole pine (276 ha), the potential number of red squirrels that could have been supported in 2008 was estimated at between 117 and 205 individuals.

The number of eaten cones along each transect was measured against the number of available cones per transect. Feeding activity was highest in those areas where there was greater amounts of lodgepole pine cones available.

A positive correlation was found to exist between the amount of lodgepole pine cones available per transect and the amount of pine cones eaten \((r = 0.872, P < 0.01^{**}, n = 31)\) (Figure 3.13).
In 2009, another survey was conducted, this time based on the coniferous areas of the trapping grid. A total of 9,301,200 lodgepole pine cones were estimated to be available in Derryclare. Using the same method as in 2008, it was found that the total energy available from lodgepole pine cones for the year was 27,345,528 kJ. Sitka spruce cones from the area were counted and were incorporated in calculations for potential squirrel density.

The study area (40 ha) was capable of providing enough energy through lodgepole pine seeds over the year for a maximum of 15.5 to 27.1 red squirrels. This equates to a potential squirrel density of 0.4 to 0.7 squirrels per ha. From the number of eaten cones detected (355), extrapolated across the 40 ha study area, an estimated squirrel density of 0.1 to 0.14 per ha was calculated. Once again, feeding activity was highest in the most productive areas.

In 2010, a third survey was undertaken corresponding to the 2009 survey to compare seed crop for that year against previous years.

Line transects conducted in 2010 included a larger proportion of sitka spruce and for the first time in three years sitka spruce cones were found to have been consumed by squirrels in large quantities.

Using the same methods as 2008 and 2009, it was found that the total energy available for lodgepole pine was 11,522,448 kJ and 11,236,000 kJ for sitka spruce on the 40 ha study area.

**Figure 3.13:** The correlation between lodgepole pine cone availability and feeding activity of red squirrels at Derryclare wood (Sheehy 2009).
Given that the study area (40 ha) was capable of providing enough energy through both lodgepole pine and sitka spruce seeds for the red squirrels actual squirrel density was calculated by adding the amount consumed for pine and spruce (2.17 kJ), extrapolated across the 40 ha study area, the estimated density was calculated as 0.09 to 0.15 per ha.

In 2011, a final survey was undertaken in order to compare seed crop with previous years. Areas surveyed corresponded with previous years. Feeding transects conducted in 2011 showed a large number of sitka spruce cones available and for a second year in a row a large quantity had been consumed by squirrels.

Although more sitka spruce was available to the squirrels in 2011, more lodgepole pine was consumed per m$^2$ than sitka spruce. The total energy available for lodgepole pine was 10,954,440 kJ and 4,496,000 kJ for sitka spruce. Actual squirrel density was calculated in the same manner as the previous year by adding the amount consumed for pine and spruce (1.27 kJ), extrapolated across a 40 ha study area, the actual density was calculated as 0.05 – 0.09 squirrels per ha.

The Nature Reserve was also examined for the presence of food for the red squirrel population. In 2009, quadrats were placed within the Nature Reserve in order to make a count of seed crop from tree species targeted by squirrels, such as, oak, hazel and beech (Table 3.13).

<table>
<thead>
<tr>
<th>Tree species</th>
<th>Hazel</th>
<th>Oak</th>
<th>Beech</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uneaten</td>
<td>Eaten</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>11.5</td>
<td>6.5</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>7.75</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3.13: Observations of broadleaved seed production per m$^2$ for 2009 and 2010 at Derryclare Nature Reserve.

Results from quadrats showed that in the years investigated oak and beech were not recorded as producing seed crop. An amount of hazel was produced and in both years a conservative estimate was calculated. However, it was found that the methodology applied did not suit the conditions found within the Nature Reserve and were therefore discontinued at the end of 2010 (see discussion).
<table>
<thead>
<tr>
<th>Year</th>
<th>Lodgepole pine</th>
<th>Sitka spruce</th>
<th>Lodgepole pine</th>
<th>Sitka spruce</th>
<th>Squirrel density</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>3.7</td>
<td>10.88</td>
<td>0.48</td>
<td>2.54</td>
<td>0.53</td>
</tr>
<tr>
<td>2009</td>
<td>3.37</td>
<td>9.9</td>
<td>0.02</td>
<td>0.11</td>
<td>0.71</td>
</tr>
<tr>
<td>2010</td>
<td>1.42</td>
<td>4.19</td>
<td>5.3</td>
<td>28.09</td>
<td>0.2</td>
</tr>
<tr>
<td>2011</td>
<td>1.35</td>
<td>3.97</td>
<td>2.12</td>
<td>11.24</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Table 3.14: Available energy and consumed energy per m² for lodgepole pine and sitka spruce detected from 2008 to 2011 at Derryclare wood. Potential and estimated squirrel densities extrapolated into the 40 ha study area from energy available and consumed.
Belleek Forest Park

3.3.7 Population estimates and density

After translocation the first trapping session took place in August 2008, one of thirteen sessions in total. Table 3.15 shows the population estimates calculated for each trapping month. Minimum Number Present (MNP) remains constant over the trapping period reflecting animals known to be alive in each session. In general, the population trend shows a growing population which comes to a point and plateaus off (Figure 3.14).

<table>
<thead>
<tr>
<th>Trapping months</th>
<th>MNP</th>
<th>Lincoln Index</th>
<th>Fisher-Ford</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 2008</td>
<td>21</td>
<td>24 ± 6.64</td>
<td>21.84</td>
</tr>
<tr>
<td>November 2008</td>
<td>14</td>
<td>13.2 ± 3.59</td>
<td>11.94</td>
</tr>
<tr>
<td>January 2009</td>
<td>13</td>
<td>12.5 ± 1.65</td>
<td>13.55</td>
</tr>
<tr>
<td>May 2009</td>
<td>15</td>
<td>36 ± 19.7</td>
<td>22.76</td>
</tr>
<tr>
<td>September 2009</td>
<td>19</td>
<td>26.67 ± 12.15</td>
<td>34.60</td>
</tr>
<tr>
<td>November 2009</td>
<td>16</td>
<td>10 (± N/A)</td>
<td>30.53</td>
</tr>
<tr>
<td>February 2010</td>
<td>24</td>
<td>18.6 ± 4.8</td>
<td>53.39</td>
</tr>
<tr>
<td>April 2010</td>
<td>23</td>
<td>37.3 ± 20.58</td>
<td>40.95</td>
</tr>
<tr>
<td>July 2010</td>
<td>23</td>
<td>40 ± 22.05</td>
<td>43.06</td>
</tr>
<tr>
<td>November 2010</td>
<td>26</td>
<td>90 ± 25.61</td>
<td>77.20</td>
</tr>
<tr>
<td>February 2011</td>
<td>27</td>
<td>45 ± 11.55</td>
<td>56.00</td>
</tr>
<tr>
<td>May 2011</td>
<td>21</td>
<td>31.67 ± 7.36</td>
<td>53.61</td>
</tr>
</tbody>
</table>

Table 3.15: Population estimates for each trapping month using the three techniques MNP, Lincoln Index and Fisher-Ford at Belleek Forest Park.

The Lincoln Index is presented together with 95% confidence intervals. Of the three techniques used it seems to be the most erratic dropping below the MNP in four months.

The Fisher-Ford estimate gives a comparative figure to the MNP in the first month (August 2008), however it falls below the MNP in the second month (Nov 2008) of study, which is the lowest estimate of the entire investigation. As trapping months progress the Fisher-Ford estimate increases to the highest point in November 2010, when the density of squirrels is calculated as more than one per ha (Table 3.16). The estimated number of squirrels remains high there-after (Figure 3.14). The survival rate calculated from session to session at Belleek Forest Park was 0.96; from this an annual rate of 0.849 was calculated as the survival of squirrels in 2009 and 2010.
Figure 3.14: Population estimates at Belleek Forest Park, using Minimum Number Present and Fisher-Ford estimates
<table>
<thead>
<tr>
<th>Trapping months</th>
<th>MNP</th>
<th>Lincoln Index</th>
<th>Fisher-Ford</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 2008</td>
<td>0.39</td>
<td>0.44 ± 0.12</td>
<td>0.40</td>
</tr>
<tr>
<td>November 2008</td>
<td>0.26</td>
<td>0.24 ± 0.07</td>
<td>0.22</td>
</tr>
<tr>
<td>January 2009</td>
<td>0.24</td>
<td>0.23 ± 0.03</td>
<td>0.25</td>
</tr>
<tr>
<td>May 2009</td>
<td>0.28</td>
<td>0.67 ± 0.36</td>
<td>0.42</td>
</tr>
<tr>
<td>September 2009</td>
<td>0.35</td>
<td>0.49 ± 0.22</td>
<td>0.64</td>
</tr>
<tr>
<td>November 2009</td>
<td>0.3</td>
<td>0.18 (± N/A)</td>
<td>0.57</td>
</tr>
<tr>
<td>February 2010</td>
<td>0.37</td>
<td>0.3 ± 0.78</td>
<td>0.86</td>
</tr>
<tr>
<td>April 2010</td>
<td>0.34</td>
<td>0.61 ± 0.33</td>
<td>0.66</td>
</tr>
<tr>
<td>July 2010</td>
<td>0.33</td>
<td>0.65 ± 0.37</td>
<td>0.69</td>
</tr>
<tr>
<td>November 2010</td>
<td>0.42</td>
<td>1.43 ± 0.41</td>
<td>1.25</td>
</tr>
<tr>
<td>February 2011</td>
<td>0.44</td>
<td>0.73 ± 0.19</td>
<td>0.90</td>
</tr>
<tr>
<td>May 2011</td>
<td>0.34</td>
<td>0.51 ± 0.12</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Table 3.16: Population density (squirrels per ha) for each trapping month based on the three population estimates at Belleek Forest Park.

Using Minimum Number Present as the baseline for density, density of squirrels per hectare varied from 0.24 to 0.44 and the average density was found to be 0.31. Given that the total available habitat for red squirrels at Belleek Forest Park is 79.6 ha, the density provided by the MNP can be extrapolated giving an estimated minimum amount of squirrels to be 19 to 35 squirrels. Compared to the density estimated by Fisher-Ford, which gives a range of 18 to 100 squirrels.

Trapping success was calculated for each trapping month during the study and it was found that the average trap success was 22.96%, with the most successful month being February 2011 (43.6%) and the least successful month November 2009 (7.29%).

3.3.8 Recruitment

As Belleek Forest Park is isolated from other woodlands, new recruits tagged in trapping sessions were offspring born to the new population, rather than immigrants. The maximum number of new recruits caught was recorded in the trapping month of August 2008. In this trapping session, 50% of all squirrels caught were new individuals. A total of 60 new squirrels were recorded at Belleek Forest Park since translocation (Figure 3.15).
Figure 3.15: New recruits captured and tagged each trapping session at Belleek Forest Park.

Unlike Derryclare, Belleek Forest Park recruits were tagged in every trapping month.

3.3.9 Individual fitness and breeding status

Individual fitness was examined by assessing the weight of individual squirrels during live trapping sessions at Belleek Forest Park. Mean weight was calculated for all squirrels in each trapping month (Table 3.17). There was no significant difference detected between sessions or years. Mean weight for males and females was also calculated and no significant difference was found.
Table 3.17: Overall mean weight for each trapping month at Belleek, with 95% confidence intervals. Each individual is only counted once per trapping month.

<table>
<thead>
<tr>
<th>Trap month</th>
<th>Overall mean weight each trapping month</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 2008</td>
<td>298.5 ± 13.37, n = 20</td>
</tr>
<tr>
<td>November 2008</td>
<td>302.9 ± 12.15, n = 12</td>
</tr>
<tr>
<td>January 2009</td>
<td>302.27 ± 13.72, n = 11</td>
</tr>
<tr>
<td>May 2009</td>
<td>300.42 ± 33.3, n = 12</td>
</tr>
<tr>
<td>September 2009</td>
<td>287.22 ± 12.63, n = 18</td>
</tr>
<tr>
<td>November 2009</td>
<td>284.28 ± 17.8, n = 7</td>
</tr>
<tr>
<td>February 2010</td>
<td>294.06 ± 11.4, n = 16</td>
</tr>
<tr>
<td>April 2010</td>
<td>301.32 ± 19.07, n = 19</td>
</tr>
<tr>
<td>July 2010</td>
<td>291.75 ± 23.26, n = 19</td>
</tr>
<tr>
<td>November 2010</td>
<td>284.75 ± 10.4, n = 20</td>
</tr>
<tr>
<td>February 2011</td>
<td>291.2 ± 11.45, n = 25</td>
</tr>
<tr>
<td>May 2011</td>
<td>285.71 ± 14.58, n = 21</td>
</tr>
</tbody>
</table>

Figure 3.16: New recruit weight (grams) at Belleek Forest Park. Values on the x-axis show the mid-points of the range for each class.

Figure 3.16 displays the frequency distribution of weights from new recruits tagged in trapping sessions. The majority of individuals tagged for the first time exceeded 230 grams in weight. Only four individuals tagged were less than 230 grams in weight.
The weights of squirrels at Derryclare were compared to squirrel weights at Belleek Forest Park. Comparison was made using a two-way Anova which compared the weights of all squirrels against sex and site, no significant difference was found.

The body condition of red squirrels at Belleek Forest Park was tested to examine any difference between trapping months, a one-way Anova found no significant difference ($F = 1.227$, $df = 11$, $P = 0.272$).

Figure 3.17 displays the body condition of red squirrels at both sites, a t-test found that there was a significant difference between sites ($t = 2.390$, $df = 120$, $P = 0.018$). Red squirrels at Belleek were found to be in a fitter condition than those at Derryclare.

![Figure 3.17: Box-plot displaying the body condition of red squirrels at both Derryclare wood and Belleek Forest Park](image-url)
Body condition was examined through body weight and shin bone length of each individual captured. Table 3.18 displays the overall mean shin bone length of all squirrels captured as well as that for female and males.

<table>
<thead>
<tr>
<th>Overall mean shin bone length (mm)</th>
<th>Mean shin bone length for females (mm)</th>
<th>Mean shin bone length for males (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65.49 ± 0.78 n = 75</td>
<td>65.33 ± 1.09 n = 41</td>
<td>65.68 ± 1.18 n = 34</td>
</tr>
</tbody>
</table>

**Table 3.18:** Mean shin bone length with 95% confidence intervals for all trapping sessions at Belleek Forest Park.

The regression of adult squirrels caught during the study was calculated and was found to be highly significant \(P < 0.0001\). This corresponds with results found for the population in Derryleare wood.

![Linear regression of shin bone length against weight of adult squirrels at Belleek Forest Park.](attachment:image.png)

**Figure 3.18:** Linear regression of shin bone length against weight of adult squirrels at Belleek Forest Park.
Figure 3.19: Significant linear regression of female adult squirrels body weight and shin bone length at Belleek Forest Park.

The regression of male and female adult squirrels was also investigated, female squirrels showed a significant regression ($P = 0.0005$). Males however did not show a significant regression ($P = 0.12$).

Female breeding status in each trapping month is displayed in Figure 3.20. A Mann-Whitney U test was used to investigate female breeding status against weight. It was found that females in a breeding condition were significantly heavier than those that were not in a breeding condition ($U = 614.5, P < 0.0001$).

Male breeding status in each trapping month is displayed in Figure 3.21.
Figure 3.20: Breeding status of female squirrels in each trapping session at Belleek Forest Park.

Figure 3.21: Breeding status of males caught in each trapping session at Belleek Forest Park.

Table 3.19 displays the number of breeding females counted in each breeding season, the potential number of young born was calculated using an average of three kits per litter. This
was then compared with the number of new recruits marked during the trapping sessions. New recruits found in February 2010 and 2011 were included with 2009 and 2010 cohort respectively, given their weight and the fact that breeding had not yet begun in the woods at the time.

<table>
<thead>
<tr>
<th>Breeding season</th>
<th>Number of breeding females</th>
<th>Potential young</th>
<th>New recruits counted</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>2</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>2009</td>
<td>7</td>
<td>21</td>
<td>23</td>
</tr>
<tr>
<td>2010</td>
<td>9</td>
<td>27</td>
<td>22</td>
</tr>
<tr>
<td>2011</td>
<td>14</td>
<td>42</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 3.19:** The number of new recruits marked compared to the potential number of young born as detected through breeding females at Belleek.

As only one trapping session took place within the breeding season for females in 2008 (August 2008) the number of breeding females does not truly correspond with new recruits tagged. The number of new recruits counted in 2011 was also an underestimation due to the number of trapping sessions within this period.

Of the 15 red squirrels translocated the male to female ratio was 1:2. The ratio between the sexes was calculated for each trapping month; it was found that the sex ratio remained in favour of females until February 2010, when a 1:1 ratio emerged in the population.

**Figure 3.22:** The sex ratio (expressed as proportion of females in the population) caught during the study at Belleek Forest Park.
3.3.10 Dispersal of red squirrels from Belleek Forest Park

In 2008, members of the public reported sightings of the red squirrel in areas surrounding Ballina town. New reports were made each year and were plotted onto a map of the area surrounding Belleek Forest Park (Figure 3.23).

Figure 3.23: OS Discovery map of Ballina town, Co Mayo showing red sightings since the translocation of red squirrels to Belleek Forest Park (2008 reports in red, 2009 reports in black, 2010 reports in purple).
3.3.11 Habitat quality and seed crop

The main tree species for squirrel consumption were; Norway spruce, Scots pine, sitka spruce, larch, beech and oak. Table 3.20 displays the density of available seed crop in m² during 2009 and 2010. It shows that during the two year study beech was abundant, Scots pine was being consumed by the squirrels and sitka spruce was also being fed on in a smaller quantity. It was also found that during this period Norway spruce was not producing any cones.

<table>
<thead>
<tr>
<th>Year</th>
<th>Count (Per m²)</th>
<th>Beech</th>
<th>Scots pine</th>
<th>Sitka spruce</th>
<th>Larch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cones/casts available</td>
<td>94</td>
<td>26.6</td>
<td>10</td>
<td>24.4</td>
</tr>
<tr>
<td></td>
<td>Cones/casts eaten</td>
<td>-</td>
<td>21.4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2009</td>
<td>Cones/casts available</td>
<td>132</td>
<td>21.4</td>
<td>30.1</td>
<td>21.3</td>
</tr>
<tr>
<td></td>
<td>Cones/casts eaten</td>
<td>-</td>
<td>18.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(-) unable to detect whether eaten by squirrels.

Table 3.20: Cone densities (cones/m²) on quadrats beneath beech, Scots pine, sitka spruce and larch in 2009 and 2010 at Belleek Forest Park.

Table 3.21 display how many cones or beech casts were available in 2009 and 2010 in Belleek. These figures were calculated by extrapolating the amount of seed count into the known area that the tree species occupies. Potential squirrel density was then calculated from the amount of seed estimated to be available. During surveys on seed crop, other tree species were also counted that are unlikely to be predated upon by the red squirrel, such as, Monterey pine, ash and sycamore.
### Results

<table>
<thead>
<tr>
<th>Year</th>
<th>Tree species</th>
<th>Cones/casts available in woodland</th>
<th>Seeds available</th>
<th>Energy (kJ)</th>
<th>Potential squirrel density</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Beech</td>
<td>714,400</td>
<td>1,428,800</td>
<td>4,000,640</td>
<td>0.57 - 1</td>
</tr>
<tr>
<td></td>
<td>Scots pine</td>
<td>133,000</td>
<td>2,660,000</td>
<td>478,800</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sitka spruce</td>
<td>30,000</td>
<td>6,450,000</td>
<td>258,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Larch - Japanese</td>
<td>97,600</td>
<td>1,366,400*</td>
<td>122,976</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Beech</td>
<td>1,003,200</td>
<td>2,006,400</td>
<td>5,617,920</td>
<td>0.81 – 1.41</td>
</tr>
<tr>
<td></td>
<td>Scots pine</td>
<td>85,000</td>
<td>1,700,000</td>
<td>306,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sitka Spruce</td>
<td>90,300</td>
<td>19,414,500</td>
<td>776,580</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Larch - Japanese</td>
<td>85,200</td>
<td>1,192,800*</td>
<td>107,352</td>
<td></td>
</tr>
</tbody>
</table>

*Estimated from counting the average number of scales on a larch cone and comparing to those calculated for a lodgepole pine cone

**Table 3.21:** Seed crop available in Belleek Forest Park in 2009 and 2010, extrapolated from 33 quadrats examined during each trapping session.
3.4 Discussion

3.4.1 Red squirrel population abundance

Three methods were used together to investigate trends in population size and density. Over the course of the two studies, each population showed an increase in abundance, which displayed the continued success of both translocations. The establishment of red squirrels at each site differed as the habitat and woodland size were different. At Derryclare the red squirrel population began as a clumped population remaining close to the site of release. As the area became saturated with individuals, animals spread to new areas. This produced a population that maintained a constant density and expanding range, as opposed to a constant range and expanding density at Belleek Forest Park. The larger (approx. 393 ha) but poorer habitat at Derryclare promotes clumping of the population, rather than a uniform dispersion as seen in the mixed habitat at Belleek (approx. 61.5 ha). Spreading the supplementary feeders throughout Belleek Forest Park may have encouraged the squirrels to spread throughout the woodland on release. However, the spread of squirrels through Belleek may be more closely related to the size of the woodland compared to Derryclare and the tree species structure. Red squirrels at Derryclare did not have supplementary food to rely upon as the use of feeders had ceased after the first year of translocation (Poole 2007). The connectivity between stands in Derryclare may also have delayed spread, as some sections of mature stands were separated by areas of bog, clear-fell or young stands.

Minimum densities on the trapping grids ranged from 0.17 – 0.29 squirrels per hectare (based on MNP) and 0.18 – 0.63 (based on Fisher-Ford) at Derryclare wood and 0.24 – 0.44 squirrels per hectare (based on MNP) and 0.22 – 1.25 (based on Fisher-Ford) at Belleek Forest Park. These densities estimates correspond to those of other studies (Gurnell et al. 2009), coniferous habitats can range from 0.21 – 0.33 ha\(^{-1}\) (Moller 1986, Lurz, Garson & Rushton 1995), broadleaf habitats can range from 0.5 – 1.3 ha\(^{-1}\) (Tonkin 1983, Wauters & Dhondt 1990) and mixed habitats can range from 0.21– 1.27 ha\(^{-1}\) (Finnegan et al. 2007, Poole 2007). Fluctuations in squirrel density can be attributed to the abundance of tree seeds (Wauters et al. 2004). However, at Belleek Forest Park supplementary feeding was on-going, which may be a reason for the higher density compared to that found at Derryclare. Another reason for the higher density at Belleek may be related to the structure of the habitat, as it has been shown to be affected by the type of trees available (Lurz et al. 1995). Overall, this displays that squirrel densities of translocated populations increase rapidly to densities typical of established red squirrel populations.
Population abundance at Belleek Forest Park was shown to reach a point and plateau, which may correspond to reaching the carrying capacity. Population abundance at Derryclare displays quite a common trend between the different population estimate methods; the population does not show signs of reaching a capacity as each year numbers increase, indicating that the potential population abundance has not yet been reached.

Fluctuations in trapping success did not correspond to the time of the year, with peaks occurring in winter months as well as summer months at both sites. The lowest trapping success usually occurred in the first month in which the trapping grids had changed; this may be due to the squirrels’ having to locate traps. In the following months the trapping success returned to typical levels.

The survival of originally translocated individuals was investigated whilst live trapping was conducted. In June 2008, the first trapping session at Derryclare wood, six of the original translocated stock was caught on the trapping grid. In the wild mean expectation of life at 6 months old is 3 years, although some individuals may live for 6 – 7 years (Harris & Yalden 2008). In 2008 these individuals would have been approximately 4 years old, which is above average for the longevity of wild red squirrels. Three of these individuals were still alive in 2011, reaching the upper limits of a wild squirrel’s life expectancy. This longevity can be credited to the population abundance being below the carrying capacity of the woodland, hence reducing intra-specific competition for food. Of the 15 red squirrels translocated to Belleek Forest Park, only two individuals were still being captured in 2011, which would have made them approximately 4 – 5 years of age. The remainder of the translocated stock were no longer captured at Belleek. This may be related to a lack of site fidelity or higher densities at Belleek. However, it can be argued that longevity was found at both sites. This emphasises the importance of adult survival in the lifetime fitness of the population.

Some studies have found the capture of squirrels to be difficult (e.g. Moller 1986); Gurnell and Pepper (1994) reported that red squirrels can be difficult to trap, especially in some habitats such as mature conifer forests, or certain times of the year when there is seed crop available in the trees. Wauters & Dhondt (1990) showed that trappability of red squirrels in a forest in Belgium could significantly change with season, with trapping success highest in summer months when natural food was scarce and lowest in winter months when food was abundant. Difficulties in maintaining the assumptions of mark-recapture techniques can arise from the live trapping experience itself; animals can become trap shy (with the trapping procedure discouraging them from entering a trap subsequently) or trap happy (habitually seeking out traps to gain the rewards on offer). Trapping was conducted on a bi-monthly format, however, due to un-foreseen events it was not always possible to adhere to a rigid schedule. The gaps between months did not affect population estimation however, as each trapping month shows a
comparative estimate for population size and density session to session. The main problem with gaps in the trapping series was that seasonality of squirrel ecology was harder to predict, it also meant that certain biological and behavioural processes may have been missed. However, as an investigation into post-release monitoring of red squirrels after translocation, the trapping series provided important information into the settlement of squirrels into a once uninhabited woodland.

3.4.2 Population demographics

In comparison to the recruitment at Belleek Forest Park, new recruits in Derryclare were not captured in every trapping month. In general, recruitment occurs when juveniles have weaned and enter the population (and where applicable during the immigration of new squirrels) (Wauters et al. 2004, Wauters & Dhondt 1993). As both study sites are isolated from other squirrel populations, new recruits captured and tagged were the progeny of the translocated stock.

There are a number of factors that can affect the recruitment of squirrels in a population. Size of individual litters can affect total recruitment of young (Gurnell 1987). The probability of locally born juveniles surviving is higher when they are in good condition, that is they have a high body mass at weaning (Wauters et al. 2004). New recruits at both sites were found to be of a high weight, exceeding 230 grams. Another factor effecting juvenile weight is the condition of the mother of the offspring, as heavier mothers produce heavier offspring than mothers of lower body mass (Wauters, Bijnens & Dhondt 1993). Female squirrels in breeding condition were found to be significantly heavier than those that were not at both sites. This in turn relates to the quality of the habitat that the female occupies and how much competition she encounters for that home range (Wauters & Lens 1995). Juvenile growth rate in the American red squirrel (Tamiasciurus hudsonicus) and its survival, but not litter size, were significantly related to annual food supply in studies conducted in Canada (Humphries & Boutin 2000).

Females found to be in a breeding condition at both sites were used to calculate a potential number of offspring. In each trapping year the number of breeding females captured increased, which in turn increased the number of potential young in the woodlands. The number of recruits tagged was similar to the potential young, which indicates that juvenile recruitment was high within both populations. This indicates that the habitat quality was good, or that the populations were below carrying capacity. These findings correspond to those found in a forest in Wales in which red squirrels responded to grey squirrel eradication by increasing recruitment rates (Shuttleworth 2003). Red squirrel recruitment rate is typically 20 – 50%, in Wales recruitment increased to 75% following the reduction in inter-specific competition, this slowly levelled off each year as adult red squirrels expanded into the habitat (Shuttleworth 2003).
On analysis of new recruit’s weight it was found that the majority of individuals captured were of 230 grams or more. Other studies have assigned age classes to individual red squirrels depending on weight (Poole 2007); such as, juveniles classed as weighing equal to or less than 190 grams, subadults weighing between 200 – 230 grams and adults having a lower weight boundary of 240 grams (Tittensor 1970). Adult squirrels have also been described as individuals of 3 – 4 months of age that have molted into their adult coats (Eibl-Ebesfeldt 1951). Age may also be determined by an individual’s ability to breed; Wauters and Dhondt (1995) suggest that juveniles are rarely able to breed until 10 to 12 months of age and that many females only wean their first litter at two years old. Therefore, classifying the age of squirrels especially at a young age can be limited. Many of the new recruits at Derrycclare and Belleek assumed to be juvenile were heavier than 190 grams, which could indicate that young squirrels gain weight quickly before or after weaning from their mothers. The condition of mothers at both sites may have resulted in new recruits being heavier (Wauters, Bijnens & Dhondt 1993) and can be related to the quality of habitat. At Derrycclare new recruits had the potential to have been individuals immigrating into the trapping area from surrounding areas in which squirrels were already dispersed and could also explain the higher proportion of heavy new recruits.

Individual fitness was assessed through a squirrel’s body weight, shin bone length, body condition and the general health of an individual, e.g. whether it had fleas or mites and it’s general appearance. Squirrels at Derrycclare and Belleek had a comparable body weight to those of other studies (Harris & Yalden 2008) and in general showed good body condition. Squirrels at Derrycclare displayed a significant difference in body condition between trapping months compared to those at Belleek that did not show any. Overall squirrels at Belleek were found to be in a fitter condition than those at Derrycclare. This may be related to the differences in habitat type and availability of food, squirrels at Belleek were also supplied with supplementary food. Therefore red squirrels at Belleek had the opportunity to predate upon a wider variety of food resources than those at Derrycclare who were reliant on a smaller number of tree species and their natural resources.

The presence of fleas was occasionally recorded on a few individuals and more frequently in the summer months. Red squirrels can be commonly infested with fleas mainly Monopsyllus sciurorum (Keymer 2008). However, this did not affect the overall health and body weight of a squirrel. No significant seasonal body weight differences were found. This can be related to the persistent availability of food in the wood or the red squirrel’s ability to cache food for use when food is scarce such as winter months (Rice-Oxley 1993).

Body weight is intrinsically linked to body size (Wauters & Dhondt 1989b); squirrels with a larger body size weigh more, irrespective of age (Reilly 1997). At both sites it was found shin bone length had an effect on body weight, with adult squirrels of a larger size weighing more.
However, the regression of shin bone length verses weight displayed at both sites varied between the sexes. Males only displayed significant regression at Derryclare, as opposed to Belleek, in which female squirrels displayed significance but not males. At Derryclare breeding was the overriding determination of weight, as females weighed more when in a breeding condition. However, the opposite was detected at Belleek, this difference may be related to squirrels at Belleek receiving supplementary food as opposed to those at Derryclare. Body weight, body length and habitat quality can all be correlated to survival, as heavier squirrels survive for longer than squirrels with a lower body weight (Wauters & Dhondt 1989a).

The sex ratio at Derryclare wood was found to be male biased with all but one month having roughly twice as many males to females. These results tend to contradict those found at Belleek where the population introduced returned to a 1:1 ratio. Most mammal species produce offspring with a 1:1 sex ratio; that is, on average, there are an equal number of males and females (Gurnell 1987). Gurnell (1987) suggests that this can be explained in terms of a self-correcting system based on natural selection acting on surpluses of males or females. Trivers & Willard (1973) report that data from mammals support the model that as a female’s maternal condition fades she tends to produce a lower ratio of males to females and that natural selection should favour parental ability to affect sex ratio of offspring according to the parental ability to invest. As such, females are more likely to remain within their home range for life and bequeath the area to their daughters (Wauters & Dhondt 1992). The dispersal of red squirrels has been linked to the reduced tendency of intra-sexual competition for resources between parents and offspring as well as an inbreeding avoidance mechanism (Wauters & Dhondt 1993).

Unlike Belleek Forest Park in which the trapping grid occupied the majority of the woodland, the trapping grid at Derryclare occupied approximately 40 ha of a much larger red squirrel range in which not all squirrels were being captured; male squirrels have a larger home range and those from outside the grid were more likely to come into contact with traps and be examined (Lurz et al. 2000). Wauters and Dhondt (1993) reported that male dispersal peaks in spring months and female immigration peaks in autumn months. The new recruits tagged at Derryclare on the trapping grid were mainly male dominant and any patterns in the time of year of dispersal was not seen due to the structure of the trapping series. However, some studies suggest that males have a greater tendency to disperse than females due to the polygynous and promiscuous behaviour of such mammals (Dobson 1982), with larger home ranges and competition for mates. This may explain the fact that more males were being captured at Derryclare than females.

Red squirrels are seasonal breeders, in certain circumstances females can come into a second oestrus and become pregnant a second time in the year, once their first litter has been weaned (Gurnell 1987). At both sites females were captured in which they were found to have bred
twice in one season. A female’s body weight and condition determine the number of young weaned and whether a second litter is possible (Wauters & Dhondt 1989a, 1990). Wauters & Dhondt (1995) reported that a minimum body weight is required by females to enter oestrus and that fecundity increases with age; female squirrels in a breeding condition were found to be significantly heavier than those not in a breeding condition. The results from the current study would agree with those found by Wauters and Dhondt (1995). This may be related to some females captured being pregnant, whilst others are heavier due to the production of milk for weaning offspring (Wauters & Dhondt 1993) or generally being fitter individuals. Unlike the squirrels at Belleek that utilised supplementary feed, the squirrels at Derryclare were completely reliant on the woodland’s natural resources to increase body weight. Female breeding success has also been related to being able to be primiparous as yearlings. This can increase with body mass and the proportion of high quality habitat in its home range (Wauters et al. 2001). In American red squirrels (Tamiasciurus hudsonicus), it has been found that females that initiate breeding as yearlings suffer a decrease in longevity. However, population growth, as well as lifetime fitness can be related to the importance of female survival rather than reproductive output (McAdam et al. 2007).

There was no discernable difference in the duration of breeding seasons between Derryclare and Belleek. Males come into reproductive condition at the start of the breeding season and remain so until the summer and perhaps later. This acts as an important breeding tactic as not all females come into reproductive condition at the same time (Gurnell 1987). Overall, the breeding condition of both males and females was found to be high in the majority of the trapping sessions, proving that the populations were still successfully producing offspring each year, and that conditions for breeding were good.

3.4.3 Red squirrel dispersal

Dispersal in red squirrels is associated with intra-sexual competition for food resources and for mates (Wauters & Dhondt 1992, 1993). In general, the majority of dispersing squirrels are juveniles and sub-adults searching for an area to settle (Thompson 1978) and does not take place all year round but peaks in April - June and October - November (Wauters & Dhondt 1990). It is natural behaviour for young squirrels to seek to disperse to new habitats (Wauters, Somers & Dhondt 1997).

The dispersal of squirrels into new areas of Derryclare can be related to the increase in density of squirrels as new recruits successfully joined the population as well as the high survival rate of adults from year to year. Two main indirect field techniques were used in the monitoring of dispersal at Derryclare. Finnegan (2002) found that there was a positive correlation between the two indirect methods of hair tube surveys and cone core sampling. These methods were used in the investigation of squirrel presence within an area of woodland.
From three different sites Finnegan (2002) estimated a density of 0.11 – 0.7 from cone core sampling. The accuracy of using such methods in low density populations was addressed by Lurz, Shirley and Geddes (2008), whose efforts suggested that these methods are sufficient to detect declines in a population of 50 – 75% but not when they fall below one squirrel for every 20 ha of forest. In the more remote areas investigated at Derryclare a density of 0.006 to 0.01 squirrels per hectare was found in 2010, indicating a very low population density. This technique was not reliable for a true indication of population density as such low population numbers were estimated, but may indicate that squirrels had visited the area and had not yet established themselves in-situ. In 2011, the remote areas of the woodland that were known not to contain squirrels in previous years were visited again; feeding signs were found and a density of 0.01 – 0.18 squirrels per hectare was estimated.

Very low densities have been found to occur in boreal forests of Scandinavia and large conifer forests of northern England and Scotland, these densities ranged between 0.02 – 0.2 squirrels per hectare (Andren & Lemnell 1992, Halliwell 1997, Lurz et al. 1995). These low densities were related to the type of habitat and fluctuations in the availability of seed crop, for example at Kielder Forest, England, red squirrel density dropped from 0.21 squirrels per hectare to zero following a failure in sitka spruce and Norway spruce plantation. Some tagged individuals were found to have survived this failure by moving to an area of lodgepole pine nearby (Lurz et al. 1995). At Derryclare, calculations of potential density were found to be similar to densities of established red squirrel populations, with a range of 0.18 – 1.27.

In the current study estimates made in “frontier areas” were higher in 2011 than in 2010 but were smaller than those for established squirrel populations and hence may again be a sign of exploratory moves. Using the information derived from these indirect techniques, as well as the direct methods of radio tracking and live trapping, the occupied area of Derryclare wood in each year was determined (allowing for the records deduced as exploratory moves only). It showed a relatively uniform spread through suitable habitat, delayed at times by large areas of unsuitable habitat (e.g. block 11, Figure 3.2, which is mainly clear fell and very young stands of trees). These areas are important for the well-being of the population at Derryclare and other similar large wooded areas as they still provide suitable corridors between stands. This prevents fragmentation of stands within the wood and allows free dispersal of squirrels from one area to another.

In the second half of the study at Derryclare the trapping grid was changed to incorporate an area of woodland known not to contain squirrels, to investigate the process of dispersal and the individuals involved. However, apart from one individual (young male) caught during the first trapping session no other squirrels were caught within this section. This may be due to the block being predominantly spruce and within years of high pine availability less attractive to
squirrels. Red squirrels have been found to move through habitat patches that are not preferred (certain tree species or young trees) to preferred patches (Andren & Delin 1994). The ultimate cause of dispersal of both male and female American red squirrel (*Tamiasciurus hudsonicus*) was suggested to be resource competition, thus dispersal patterns are affected by resource patchiness or variability (Haughland & Larsen 2004), the availability of sitka spruce cones in this case.

The situation at Belleek Forest Park was somewhat different to that at Derrycclare wood, mainly due to the difference in size and dynamics of the woodland. In the initial feasibility study of Belleek (Lawton 2006) it seemed that the isolation of the woodland may prevent the red squirrels from dispersing to other suitable habitat. However, during the post-release monitoring red squirrels were seen in areas beyond the forest park by members of the public. Reports also verified that red squirrels had been seen on the eastern side of the river Moy. It is difficult to judge how a red squirrel from the wood may have made the crossing; the bridge is continually crossed by traffic but they may have moved across the river at low tide. This seems to be the most feasible scenario as it was also reported that a red squirrel was seen emerging from the water and climbing up the bank on the eastern side. Pauli (2005) reported sightings of American red squirrel (*Tamiasciurus hudsonicus*) swimming a distance of 2 km and safely arriving to the shore; investigations into this as a dispersal technique were recommended. Swimming however, would require a high amount of energy to be used by individual squirrels. The third possibility is that red squirrels from other woodlands could have made the excursion into the area. However, red squirrels have only been seen since the introduction of red squirrels to Belleek Forest Park. Andren and Delin (1994) recorded dispersal distances of 64 km in grey squirrels and a maximum daily movement of 2.8 km observed in red squirrels. The farthest report of red squirrel dispersal was approximately 6 km away from the woodland at Mount Falcon Hotel, which is surrounded by an area of trees (40.47 ha). At Belleek it was verified the red squirrels that had dispersed away from the wood had found suitable habitat, although invariably it was a small size and therefore would not support more than a minor number of individuals.

### 3.4.4 Habitat quality and seed crop analysis

Vertebrate population dynamics, social organisation and space use are often closely associated with the distribution of critical resources, such as food (Wauters *et al.* 2008). The red squirrel is a specialist feeder and as such relies upon the availability of tree seed to survive. The quality of a habitat has been shown to affect the density of red squirrel populations as fluctuations in numbers are positively correlated with food availability (Wauters *et al.* 2008). It also has been seen to affect the spatial distribution and social organisation of individuals as squirrels track the availability of seed (Lurz, Garson & Wauters 2000). The availability of food affects the
condition of squirrels and thereby the probability of reproduction (Wauters & Dhondt 1989a). Mast years have brought about reproductive waves of squirrels in coniferous forests in Bavaria (Brandl et al. 1991) and positively affected recruitment rates (Gurnell 1983).

In Derryclare wood, the availability of tree seed was investigated to monitor the yearly production of cone crop and to make estimations of squirrel density based on cones eaten. The study was conducted in the later months of each year (Oct – Dec) as the vast majority of cones reach the ground by this time of year (Lurz et al. 2000). There were two main species of coniferous trees available in Derryclare wood; lodgepole pine and sitka spruce. Red squirrels have been found to show a preference towards lodgepole pine over sitka spruce seeds (Lurz et al. 1998) and some studies have shown an avoidance of sitka spruce seeds altogether when there are alternatives (Lurz et al. 2000, Bryce et al. 2005). The small seed size make the sitka spruce seeds an uneconomical source of food when other species are available. Radio-tracking confirmed the lodgepole pine stands and the Nature Reserve to be the key habitats for red squirrels in Derryclare. Although problems were encountered with radio tracking at Derryclare due to the topography, habitat preference was analysed. Throughout the three year study the majority of eaten cones were lodgepole pine cones, however in 2010 this changed and the first sitka spruce cone were found eaten by squirrels. In this year the quantity of lodgepole pine counted declined in comparison to other years, showing a poor crop in comparison to previous years. This can account for the squirrel’s predation upon other food sources such as the sitka spruce crop.

Comparing 2008 and 2009 it was found that per m\(^2\) there was 0.98 kJ per m\(^2\) more energy available in 2008. However, it was found that there was 0.18 per m\(^2\) more cones counted that had been consumed by red squirrels in 2009, indicating more energy was consumed. In 2010, energy consumed was calculated from both tree species and hence there was 0.07 kJ per m\(^2\) more energy consumed overall compared with 2009. However, the availability of lodgepole pine had decreased in 2010 compared to previous years. Lurz, Garson and Ogilvie (1998) conducted a study at Spadeadam Forest in England comparing the cone crop of Norway spruce, sitka spruce and lodgepole pine; they found that a large proportion of pine cones were consumed each year but when spruce cones were available a substantial amount were also predated upon, although Norway spruce was preferred over sitka. The results from Derryclare would confirm that spruce seeds are consumed by squirrels when pine seeds are low, however when pine seeds are in abundance spruce seeds are not preferred by squirrels.

Studies from similar habitat types estimated a density of 0.32 squirrels per ha in a lodgepole/sitka mix plantation (Lurz & Garson 1997). The estimate for actual density was inferred by the counts of cones eaten along transects and therefore gives a more pragmatic figure, however, the value of 0.06 – 0.1 squirrels per hectare was below minimum estimations
made by live trapping data of 0.17 – 0.29 squirrels per hectare (MNP) in 2008. Studies have shown that there can be a time lag of one year between change in cone crop and population response. A rich food supply can increase winter survival, reproduction and recruitment in the following spring - summer influencing population size in the following year (Andren & Lemnell 1992, Lurz et al. 1997).

The estimation of red squirrels from seeds eaten appears too low in relation to known squirrel numbers. It may be a case that not all cores were recorded due to retention of cores in dreys or clumped at feeding stations which were not encountered by transects. Overall, feeding transects were found not to be a reliable method in predicting population estimates but they can be used to monitor and compare food available between stands and years.

During investigation of the seed crop within the Nature Reserve, no oak or beech seed was ever found on the ground. This may suggest that trees were not in mast or producing very little seed, however, as the wood is known to be over 200 years old the age of such trees may have an impact on production of seed (Mitchell 1974). The Nature Reserve still offers the squirrels other food sources such as hazel, fungus, buds and shoots, which squirrels will eat readily when available (Shuttleworth 2000).

Difficulty was found with the technique used for counting seed crop within the Nature Reserve, in order for an estimation to be made, transects must be placed at random throughout the wood. However, by doing this no seed was found to fall within the surveyed area. On inspection, seed was found to fall in a clumped manner directly under trees. Due to the Nature Reserve being a natural wood, the structure and spacing of trees did not suit the technique chosen, and research into other techniques failed to provide an alternative. Therefore, investigations were discontinued and personal observation became the only source of monitoring the Nature Reserve’s crop.

The Nature Reserve offered a good site of release during translocation and of the three originals still captured in 2011, all were caught within or immediately next to the Reserve, indicating a high site fidelity. Derrycclare can be called a mixed habitat, although not all individuals occupy the Nature Reserve, hence do not have the opportunity to use it as a resource. Compared to Belleek which is a completely mixed site, allowing reds there to predate upon a wider variety of foods.

Belleek Forest Park is a mixed habitat with many different tree species. Seed crop surveys confirmed that there were a number of tree species that red squirrels could target when foraging for food. The main species were as Norway spruce, Scots pine, sitka spruce, larch, beech and oak.
Over the course of the study Norway spruce cones were not found on the surveyed areas. Norway spruce covers 25.9 ha of woodland at Belleek, it was planted in the 1950s making the trees approximately 60 years of age. At this age production of cone crop typically slows down (Table 3.22). Another species not producing seed during surveys was oak. Belleek has approximately 4 ha of pedunculate oak (*Quercus robur*) the majority of which were only planted in the last few years and hence are not yet producing fruiting bodies. A 30 year study on Norway spruce in the Italian Alps showed that a mast crop can occur every 3 – 7 years and seed crop failure had an average frequency of once every three years (Mencuccini *et al.* 1995). Therefore, within an average red squirrel’s lifetime (3 – 4 years) it will encounter at least one year of food shortage and probably a mast year (Wauters *et al.* 2005). This indicates that Norway Spruce at Belleek Forest may be beyond cone bearing age. Therefore, the four main species counted as target species for squirrel consumption during the limited two year study at Belleek were beech, Scots pine, sitka spruce and larch which were producing a high amount of cone crop.

Seed crop analysis was not used as a means of calculating density in Belleek Forest Park as not all fruiting bodies can be identified as eaten by squirrels (beech for instance), so an accurate estimation is not possible. The data can be used, however, to examine potential food available over time, and its implication for the red squirrel population.

<table>
<thead>
<tr>
<th>Tree species</th>
<th>Age of first good seed crop (years)</th>
<th>Age of maximum production (years)</th>
<th>Average yield in grams of clean seed/litre of cones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway spruce</td>
<td>30 - 35</td>
<td>50 - 60</td>
<td>13</td>
</tr>
<tr>
<td>Larch – Japanese</td>
<td>15 - 20</td>
<td>40 - 60</td>
<td>14</td>
</tr>
<tr>
<td>Scots pine</td>
<td>15 - 20</td>
<td>60 - 100</td>
<td>6</td>
</tr>
<tr>
<td>Oak (<em>Quercus robur</em>)</td>
<td>40 - 60</td>
<td>80 – 120 onwards</td>
<td>-</td>
</tr>
<tr>
<td>Beech (<em>Fagus sp.</em>)</td>
<td>40 - 60</td>
<td>80 - 200</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3.22: Seed producing capabilities for major tree species at Belleek Forest Park based on age (adapted from Tiernan *et al.* 2009 and Thomas 2000).

Seed crop from the tree species Scots pine and sitka spruce were found to be predated upon, with cone cores found at feeding stations on a regular basis. Wauters & Lens (1995) classified a squirrel territory as good when it contained > 30 beechnuts or pinecones/m² and poor when fewer tree seeds were available; these assumptions were based on energy content per seed species and a squirrel’s daily requirement. Beechnuts were found to be in a good condition, as were many broadleaved species in the woodland. Studies have shown that the hoarding behaviour of certain rodent species, such as the red squirrel, can have a positive effect on the dispersal of seed and influence the population biology and evolution of tree species such as
beech (Jensen 1985). Plans to promote squirrel-friendly species and the management of the wood to replace non-seed producing trees are important, and were included in Coillte’s management plan for the Forest Park (Tiernan et al. 2009).

3.5 Summary and Conclusion

Post-release monitoring showed that both red squirrel populations at Derrycclare wood and Belleek Forest Park were continuing to be successful after translocation. This was observed through the increase in each population, recruitment of new individuals, breeding status each season and the spread of each population into the available habitats.

At Derrycclare, the red squirrel population initially remained close to the site of release. As the population density increased, animals began to spread into new areas. At Belleek, the red squirrel population quickly spread throughout the woodland before increasing population density. In general, squirrel densities were higher at Belleek than at Derrycclare. This difference in spread and density was related to the difference between the two habitats.

Both populations displayed high annual survival rates emphasising the good conditions for both adult retention and recruitment. Survival of originally translocated stock displayed longevity in both woodlands, with some squirrels reaching the upper limits of wild squirrel life expectancy.

Males and females were found to be in a breeding condition in the majority of trapping sessions at both sites, proving that the populations were successfully producing offspring each year and that the conditions for breeding were ideal. Recruitment of new individuals was a common occurrence in trapping months in both woodlands, this can be related to good habitat quality and that the populations were below carrying capacity, thus intra-specific competition for space and resources did not hamper juvenile recruitment into the populations. Red squirrels at Belleek were shown to be in a fitter condition than those at Derrycclare, this was related to the difference in habitat, as squirrels at Belleek had a wider variety of food stuffs to predate upon, as well as supplementary food.

Densities estimated from feeding line transects at the ‘frontier’ areas in Derrycclare displayed very low numbers for established squirrel populations. This shows that these areas were newly reached by the squirrel population and densities were not yet as those found in established areas. This indicates that red squirrels make exploratory moves into new habitat before becoming established within them. The situation of dispersal at Belleek was somewhat different due to the size and composition of the woodland. As Belleek is a smaller isolated woodland, dispersal was limited within the wood, however a number of individuals were found to have moved from the wood to areas around the town of Ballina, Co Mayo.
During studies of habitat quality at Derrycclare, red squirrels displayed a preference towards lodgepole pine, rather than sitka spruce cones. However, in years showing a decline in lodgepole pine seed, sitka spruce became an important food source for the population. The Nature Reserve was also found to be an important resource to red squirrels within its boundaries, but it was not available to the entire population as the most dominant habitat was coniferous. Belleek Forest Park provided a mixed site which allowed the red squirrels to avail of a number of different tree species. However, some seeds i.e. oak and Norway spruce were not found on transects. This was related to the age of the trees, which may limit the production of seed. Management of the woodlands was identified as important to the continued success of the two populations.

Post-release monitoring is an on-going process and determining a suitable time scale for investigations is difficult. The most important aspect of post-release monitoring is to evaluate the continued success of the translocation. Its primary role can assess whether the population of translocated animals may need post-release management and further intervention through the introduction of new individuals, supplementary feeding or habitat manipulation. The current study undertook investigations in the medium term of the translocation process both at Derrycclare wood and Belleek Forest Park; at this stage of the process it is important to assess the population’s spread into its new habitat. It is essential that individual health and overall population fitness is focused upon. The evaluation of the habitat is also an important feature of post-release monitoring, as it allows for the quality and availability of resources to be deduced.
4. The impact of habitat loss on red squirrel populations

4.1 Introduction

4.1.1 Planned and unplanned events and forestry

Major disturbances in forests can be classified as drought, fire, typhoons, landslides (Potts 2003) or non-sustainable clearfelling or logging (Pawson et al. 2006) as well as volcanism and earthquakes in some parts of the world (Ashton 1993). These events may not be a common occurrence but have the potential to be either diversity enhancing or diminishing (Connell 1978) and can be seen to cause an impact on both the abiotic and biotic factors of a forest community. Natural disturbances are predicted to vary under future climate change scenarios (Mirza 2003, Thuiller et al. 2005).

In Ireland, forestry can be impacted by such unplanned events as wildfire, gales, extreme flooding and lightning. Planned events such as clear-felling are used in Irish forests during the production of timber, which can impact upon the forest community. Clear-felling results in the immediate change of a site’s environmental attributes as well as a change in community structure and the overall look of the landscape (Pawson et al. 2006). The removal of trees from an area creates the loss of the buffering effect that the forest canopy provides, hence causing changes to the microclimate. These changes are caused by a difference in the temperature, relative humidity, wind speed and solar radiation subsequently affecting the area (Pawson et al. 2006). Clear-felling can also affect running water environments through the loss of bank-side vegetation, modified hydrological patterns, increased sunlight, increases in soil input or suspended solids, disturbance by machinery, release of nutrients and the input of woody debris (Giller, Johnson & O’Halloran 2002), which all in turn can cause changes in water quality and biology. More timber is harvested and prepared for travel on site, thus producing more woody debris through branches, stumps and leaf litter. Coarse woody debris left behind after clear-cutting can also have an effect on soil characteristics (Tinker & Knight 2001).

Clear-felling can cause a shift in the land-use type and may cause habitat fragmentation (Schmiegelow & Mönkkönen 2002). The approximate size of the area clear-felled may have an impact on biotic communities (Pawson et al. 2006). For example, at forest floor level clear-felling procedures can decrease the level of nutrients in the soil profile which has a knock-on effect on the abundance of soil fungal biomass and forest floor mesofauna (Lindo & Visser 2003). The loss of some insect species after felling gives way to colonisation by open-habitat species, like beetles (Lenski 1982, Heliola et al. 2001). This is also the case amongst plant species, as clear-felling releases resources otherwise dominated by the mature canopy species. In time the surviving understorey plants and new colonisers originating from the soil seed bank
take over (Burton 2002). As such, plant species richness can be greatest in the first few years following felling (Freedman et al 1994). Forest canopy structure determines the availability of nesting sites and foraging resources for bird species (Williams et al 2001). Therefore, felling can influence species richness and abundance of birds (Beese & Bryant 1999); typically more open habitat and generalist bird species are found occupying these areas post-harvest (Pawson et al. 2006). Fisher and Wilkinson (2005) reviewed the response of mammalian abundance and diversity to timber harvest in North American boreal forests throughout successional time. They discovered that the immediate disturbance caused by clear-cutting affected temporal trends in mammal abundance under the influence of vegetation re-growth. Mammals can re-colonise an area successively however different species do so at different rates (Kleener & Sullivan 2003).

Clear-cutting is the main method of harvesting timber from boreal forests and to some extent mimics natural disturbances by fire and wind-felling (Hansson 1994). Fire can cause a major disturbance to forest communities and is heavily associated with anthropogenic influences (Smith 2000). Characteristic changes after fire include canopy consumption, ground charring and soil colour alteration (White, Ryan, Key & Running 1996). Physical, chemical, mineralogical and biological soil properties can also be affected by forest fires (Certini 2005). These effects are usually associated with the burn severity of a fire which is related to several environmental factors that affect the combustion process, such as the amount, type and moisture of live and dead fuel, temperature of the air and humidity, wind speed and the topography of the site. Fire severity consists of two elements, intensity and duration (Certini 2005). Intensity is the rate at which thermal energy is produced. Duration can be the component that transfers the greatest damage as in some cases more heat is irradiated causing huge devastation to the environment. This can lead to changes in soil composition and dynamics (González-Pérez et al. 2004), which in turn can impact the regeneration process. For example, low to moderate severity fires can promote the growth of dominant vegetation species through the removal of undesired plants and increase nutrients, however, severe fires can cause a loss of structure, organic matter and porosity, which will take longer for the area to recover from (Certini 2005). The regeneration of vegetation species depends upon the depth of soil impacted by the fire and the organic content left in the soil (Schimmel & Granström 1996).

The likelihood of tree death from fire is related to the damage sustained by living tissues; the elevation of temperature, flaming and smouldering can impact upon leaves, buds, stems, cambium and fine roots (Stephens & Finney 2002). Injury to tissues can be controlled by the duration of heating that occurs during combustion, the thermal properties of the soil and the spatial distribution of tissues such as roots (Hungerford et al. 1991). Partial basal girdling by the fire around trees in the absence of crown injury has been shown not to seriously affect survival (Kramer & Kozlowski 1979). Coniferous species in the North-Western region of the USA were
studied to show the varying resistance of fire injury; it was found that the probability of mortality increased with the percentage of crown killed and decreased as bark thickness increased (Ryan & Reinhardt 1988). Larger trees are more resistant to fire damage as their bark is thicker and foliage is at a higher position (Martin 1963). It is also the case that tree mortality is more common post-fire when crown injury is accompanied by cambium injury (Martin 1963). The best indicator of crown injury relates to the proportion of crown scorched or killed (Peterson 1985, Ryan & Reinhardt. 1988). Younger trees usually have both thinner bark and their crown is closer to the flames, thus these trees are more susceptible to multiple injuries (Ryan & Reinhardt 1988).

In countries where wildfire is a common occurrence, strategies have been developed in order to combat destructive fires by using management techniques such as prescribed fire (Tiedemann et al. 2000). This minimises the amount of flammable material available as well as mimicking natural events that are important in some ecological processes (Smith 2000, Wood 1988). For example some plant species have come to rely on fire for growth and reproduction (Krefting & Ahlgren 1974). Further studies have shown that fire can create a habitat mosaic of differing successional stages that then has a positive impact on diversity. For example, in arthropods and bird species (Moretti, Obrist & Duelli 2004, Smucker, Hutto & Steele 2005). However, the type and intensity of a fire has an important role in this positive scenario. Animals with a greater mobility are more likely to survive a fire but the destruction of resources such as nests and food can have a severe negative impact on populations into the future. For example, the red-knobbed hornbill (Aceros cassidix) in north Sulawesi, Indonesia was studied after forest fire; it was found that due to its prolonged behaviour of nesting and loss of flight feathers during the event, breeding females and juveniles were affected. Intense smoke and heat reduced recruitment of individuals into the population by 47 % (Cahill & Walker 2000). Post fire effects showed that brushtail possums (Trichosurus cunninghami) in Victoria, Australia survived 100% from the fire, however, there was a reduction in the number of females carrying pouch young in burnt areas (Banks et al. 2011). During a study of fire impact on soil invertebrates (Wikars & Schimmer 2001), invertebrates that live deeper in the soil were found to have a higher survival rate than those in the vegetation and litter layers. Despite these studies little is known about the short term direct effects of fire on animal populations and the long-term implications of its affect on habitat.

4.1.2 Forest management and policy

There is global recognition that forests should be managed to ensure sustainable growth and while the production of timber is an essential commodity, research into forestry management and its impact on the environment is crucial. In accordance with this, governments in cooperation with interest groups and international organisations have come together to form
criteria and guidelines for the management, conservation and sustainable development of all types of forests.

In Strasbourg 1990, the pan-European Ministerial Conference on the Protection of Forests in Europe (also known as the Helsinki Process) produced six resolutions for cooperation on the protection and sustainable use of forests in Europe. In 1993 a second conference was held in Helsinki which produced four resolutions and recognised the principles adopted by the United Nations Conference on Environment and Development 1992. Thus, the first resolution outlined ‘stewardship and use of lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at a local, national and global level, and that does not cause damage to other ecosystems,’ (General declaration from Helsinki Process 1995).

In 1994, in Geneva a follow-up meeting set up six criteria and associated 20 indicators designed as tools to gather and assess how countries have succeeded in implementing the general guidelines produced in Helsinki (Helsinki Process 1995). Finally, in 1998 at a Ministerial Conference in Lisbon the general declaration and resolutions were adopted, 170 countries including Ireland endorsed this document. This is now one of five ongoing international initiatives responsible for producing region-specific criteria and indicators for sustainable forest management. The Pan-European Helsinki Process is the initiative relevant to Ireland.

In forest management there are a variety of reasons for trees to be harvested, these include: improving forest health; attracting certain wildlife species; controlling the type of trees that grow on a site; providing a source of income for the landowner; producing lumber and other forestry products and improving access for hikers and other recreational users. There are a number of methods for harvesting timber, each method has benefits and drawbacks and conditions in which it is most suitably used. These methods include; the shelterwood system (Raymond et al. 2009), a procedure that removes mature trees in two or three harvests over a period of 10 to 15 years, allowing the regeneration of shade tolerant species as a ‘shelter’ is left to protect them. This method is not recommended for trees with a shallow root system as remaining trees can be susceptible to wind damage. Another method, the seed-tree procedure (Franklin et al. 1997) requires five or more scattered trees per acre to be left after harvesting to provide seed for a new forest stand. Again these remaining trees are subject to exposure. The group selection system (Miller, Schuler & Smith 1994), entails harvesting small groups of trees in a given area over many years, so that eventually the entire stand has been cut down in 40 to 50 years. The single-tree selection (Miller & Smith 1993), involves removing individual trees ready for harvest, of low value or that are in competition with other trees. This method is of benefit to wildlife but damage may be caused to remaining trees during operations. Finally, clear-cut/felling, removes all trees in a given area; this is the most commercially efficient
Chapter 4

Introduction

system. This method also allows the forest managers to control tree species that grow on the site through natural or artificial regeneration.

The majority of Irish forestry is managed by Coillte Teoranta, which was established in 1988 and now owns 445,000 hectares of forestry, approximately 7% of the land cover of Ireland. Clear-felling is standard practice on Coillte properties; the dominance of this silviculture system, to the exclusion of any other, is due to experience with wind-throw in open forest canopies, as many of Ireland’s forests are planted on wet soils (Coillte website). However, a programme of testing other methods is in the process of being developed. It is the general consensus that these other methods provide continuous forest cover and multiple age structure, thereby maintaining forest environment, which in turn lessens the impact on landscape, wildlife, soils and water. Despite this, these other methods require more intense and skilled management, but can provide alternatives especially in areas of high sensitivity.

Coillte’s policy has changed over the years and species diversification of trees is now an agenda. In the past, plantations were confined to conifers from North-west America that were capable of growing in conditions such as high exposure, nutrient deficient wet soils and were still capable of producing productive timber. Today, Coillte policy recommends that it is still important to create an economically suitable forest resource, but the knowledge base of site potential and better land quality has brought about the opportunity to diversify species composition in the future. This is being implemented by the reduction of sitka spruce being planted and its replacement by other species such as Norway spruce, larch, broadleaves and native species (Coillte Management Plans).

In general, this type of sustainable management is of great benefit to squirrel species that live within Coillte owned domains. Although clear-felling receives negative press due to its destructive nature, the policy of Coillte to adopt an afforestation plan and a staggered age structure within a woodland should mean that there will always be resources for squirrel populations. Research into the immediate consequences of clear-felling within woodland known to contain an established squirrel population is rare. Although the management of forests in Ireland is conducted in a sustainable manner, other disruptive events can occur, such as fire, which may influence the future of resident squirrel populations.

4.1.3 Background to habitat loss at Derryclare wood

Derryclare wood is a commercial plantation and felling exercises are a common occurrence. During the feasibility study of Derryclare as a site for red squirrel translocation, the felling plan was considered (Poole 2007). It was found that felling was to be conducted in a successive manner and as such enough mature woodland would be available to sustain a healthy squirrel
population. As part of the long-term success of the red squirrel translocation under investigation in this study, the impact of such procedures were to be investigated.

Post-translocation clear-felling began when, in 2007 7 ha of coniferous woodland was felled. Since then no other areas felled were within the red squirrel range, until at the end of 2010, 20 ha of mature woodland were clear-felled from an area in which the population of red squirrels had been established since their introduction to the wood in 2005. This procedure was part of the planned felling programme within the forest and was the first to be conducted within an area inhabited by the squirrels.

In April 2011 due to reported strong easterly winds and dry conditions, Ireland suffered the worst amount of forest fires for 10 years, with four times the national annual average of forest destroyed due to out of control gorse, bog and forest fires. Coillte reported that fires destroyed 985 ha of forest on its properties, with an estimated cost of approximately €5 million. Derrycclare wood was one of the affected areas, on first assessment of the fundamental damage caused by the fire at Derrycclare, it was found that the fire had been contained to the ground and had not affected the tree canopy. Immature stands seemed to be the worst affected, with mature stands mainly burnt around the periphery of each block. However, the impact of the fire on the environment was not fully understood, thus it became essential to investigate this and the knock-on effect to the translocated red squirrel population.
4.1.4 Aims and objectives

As part of the post-release monitoring of red squirrels at Derrycclare wood, the fate of the population after loss of habitat from events such as clear-felling and forest fire was to be investigated. The main aim of this part of the project was to assess the immediate impacts and the long term implications of such events on the squirrel population. It also aimed to determine what impact, if any, such events could have on the general viability of other red squirrel translocations.

The first objective was to determine what level of impact the clear-felling/fire had on the population. This would be investigated by examining:

- the effect of habitat loss on population abundance
  a. In the affected area
  b. In Derrycclare as a whole

- the effect of habitat loss on population dispersal

- the effect of habitat loss on the season’s breeding and recruitment of juveniles into the population

- the effect of habitat loss on individual fitness

The second objective was to assess whether the clear-felling/fire had an impact on the potential carrying capacity of the woodland.

- An assessment of potential K and whether it had been affected was determined by both calculating K per unit area and determining the woodland habitat available on three occasions:
  1. $K_0 =$ Carrying capacity in 2011 if the fire had not occurred.

  2. $K_1 =$ Actual carrying capacity in 2011 after fire and clear-felling (the present)

  3. $K_2 =$ Future carrying capacity predicting possible outcomes in 2020;
     a. If fire had not occurred/has had a limited effect
     b. If the fire has had a devastating effect

- The third objective was to assess seed crop and whether the fire had had an impact on the amount of available food for squirrels at Derrycclare.
4.2 Materials and Methods

4.2.1 Study site

Since the introduction of red squirrels to Derrycclare wood in 2005, 90 ha of mature stands of forest have been clear-cut from the main block of approximately 560 ha of woodland (Figure 4.1b), some of which were cut down from areas where the red squirrel was established (Plate 4.1 and 4.2).

It is not certain how the April 2011 forest fire began but as the ground was very dry due to lack of rain fall it spread quickly through the woodland. Figure 4.2 displays the area of Derrycclare wood in which the fire affected, which was approximately 150 ha. Young stands of trees were devastated by the blaze (Plate 4.3) with the trunk completely scorched and fronds already showing signs of browning, which was an indication that such trees may not survive. Mature stands of trees were mainly affected at the base (Plate 4.4), scorched about two metres from the ground up the trunk. The fire was confined to ground burning which caused the undergrowth to suffer as a result. The areas of woodland that were worst affected include sections 11 and 1 (Figure 4.1a). The fire burnt for approximately 48 hours, Coillte representatives worked to put the blaze out by creating fire breaks and raking out any ground fires, however the main breaks occurred around the forest streams and rivers, preventing further spread.
Figure 4.1a:  Aerial photo (OSI 2005) of Derryclare wood divided into blocks used throughout the study.
Figure 4.1b: Map of Derryclare including areas clear-felled and corresponding years this was conducted.
Plate 4.1: Example of a clear-felled area at Derryclare wood 2010.

Plate 4.2: Example of the on-site collection of timber ready for transportation.
Figure 4.2: Map of Derryclare wood and the area affected by the forest fire (highlighted in orange) adapted from Coillte map.
Plate 4.3: An example of the scorched ground and damage to young trees.

Plate 4.4: An example of damage done to mature trees, scorched from ground to approximately one metre up the trunk.
4.2.2 Live trapping

In order to assess what impact clear-felling and the fire had on the red squirrel population the trapping grid was adapted (Figure 4.3). Trapping was carried out from May 2011 to September 2011, in which four trapping sessions were conducted.

Trapping sessions were carried out as described in section 2.2.4. Due to the clear-felling of section 17 (Figure 4.1a), three of the traps within this coniferous section were removed. This meant that in May 2011 a total of 49 traps were being used for trapping. In June 2011, traps in section 10 (Figure 4.1a) were also removed from the trapping grid as this area was scheduled to be clear-felled. This meant that the three following trapping sessions used a total of 35 traps. During calculations of density section 10 was not included, as no squirrels were ever captured in the area during this part of the study. For clarity in results the trapping grid is described as Sections A, B, C and D. Section A corresponds to the 17 traps situated on the original trapping grid next to and within the Nature Reserve. Section B relates to the six traps in area 8, which were already in use in previous trapping months (Figure 4.1a). Section C corresponds to the 6 new traps placed out in burnt areas (Plate 4.5) and Section D refers to 6 new traps placed in the adjacent unburned area (Figure 4.3). Population estimates and density were calculated using the same techniques undertaken in Chapter 2.

Plate 4.5: Squirrel trap secured in the branches of a tree within the burnt section of the trapping grid. Regeneration of grass occurred within three months of the fire.
Figure 4.3: The new trapping grid used following the fire and clear-felling events. Red dots represent traps omitted due to clear-felling.
4.2.3 Carrying capacity

To further assess the impact of the felling schedule and forest fire on the red squirrel population, potential K was calculated at the end of each year (2008 – 2011). During the feasibility study of Derryclare wood as a target site for red squirrel translocation (Poole 2007), an initial carrying capacity of 115 squirrels was calculated. It was estimated based on the amount of available habitat that was suitable for squirrels at the time multiplied by a red squirrel density of 0.32 squirrels per hectare (Lurz & Garson 1997) for sitka spruce/lodgepole pine forests. Therefore, in order to compare the changing carrying capacity with the initial estimate the same principle was applied.

As well as the amount of clear-felling conducted from year to year, the growth of young stands of trees was assessed. Most conifers have to reach at least 25 years to produce a good seed crop; therefore trees younger than this are unlikely to hold resident squirrels (Gurnell et al. 2009). Thus, these areas were not considered when calculating K. In 2011, the carrying capacity was split into two scenarios; potential carrying capacity, had there been no fire and carrying capacity, after the impact of the fire on the woodland (causes habitat loss).

Future carrying capacity was also examined, this was achieved by assessing forest management plans of the amount of clear-felling to be conducted up to 2020. It also considered the possibility that the fire may have had a devastating effect on the woodland and how this would impact the potential K. Maps were drawn in order to model the long term implications of these events on Derryclare wood.

4.2.4 Habitat quality

In order to assess whether the forest fire had had an impact on cone crop production and/or the quantity of seed available to the red squirrels in mature stands affected by fire, habitat quality was investigated at the end of 2011. This was done using feeding line transects in December 2011. A total of 20 transects were undertaken, ten in section one (Figure 4.1a approx 20 ha), deemed the worst affected area by the fire and ten in section six (Figure 4.1a approx 42 ha) an area unaffected by fire but with a similar tree composition (maturity and species composition). Transects were conducted one per hectare and comparisons were made between the availability of cones in each region of woodland. Comparisons could not be made between the cones consumed within these areas, as although squirrels were identified as being resident at the burnt area before the fire, the unburned area was beyond the ‘frontier’ of the known squirrel range.

Results gathered from the burnt areas were then extrapolated into mature stands known to have been damaged by fire in the whole of Derryclare wood.
### 4.2.5 Work and event schedule

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month</td>
<td>J</td>
</tr>
<tr>
<td>Live trapping</td>
<td></td>
</tr>
<tr>
<td>Feeding line transects</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4.1:** Work Schedule for post-release monitoring including investigations into disturbance by clear-felling (green line) and forest fire (orange line).

Table 4.1 displays the work schedule for 2011 after the described disruptive events took place at Derrycclare wood. The green line in the table represents the felling of 20 ha of forest that was contained within the established red squirrel area in December 2010. The orange line in the table shows the time in which the fire occurred in the wood in April 2011.
4.3 Results

4.3.1 Population and density estimates

<table>
<thead>
<tr>
<th>Trapping session</th>
<th>Minimum Number Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2011</td>
<td>19</td>
</tr>
<tr>
<td>March 2011</td>
<td>26</td>
</tr>
<tr>
<td>May 2011</td>
<td>25</td>
</tr>
<tr>
<td>June 2011</td>
<td>23</td>
</tr>
<tr>
<td>August 2011</td>
<td>22</td>
</tr>
<tr>
<td>September 2011</td>
<td>19</td>
</tr>
</tbody>
</table>

Table 4.2: Population estimates of study area incorporating trapping sessions after the clear-felling and fire (December 2010 and April 2011 respectively).

Table 4.2 and Figure 4.4 show, the population estimates calculated based on the Minimum Number of squirrels caught each trapping month after the 20 ha felling in December 2010. Density estimates from section A are the highest of all three sections. Section B shows a gradual increase in density over each trap session. As traps for Section C and D were only used from May 2011 onwards, four trapping sessions were conducted against six in the other sections for this phase of the project. Section C was based in the burnt area of the trapping grid and displays a low estimate in comparison with the other sections. In the first two months of trapping in this section no squirrels were captured. Section D an unburned area situated alongside section C, displays a higher density of squirrels than the burnt area, indicating more favourable squirrel habitat (Figure 4.4).
Figure 4.4: Density estimates based on the Minimum Number of squirrels captured in sections A, B, C and D of the trapping grid.

Over the course of the four month investigation more individuals were captured amongst the unburned area than within the burnt area. Only two squirrels were caught in the burnt area (section C), one was a new female recruit (August 2011) and the other was an individual male who in the past had usually been captured within the unburned area that had dispersed into the burnt area and been trapped (September 2011). The trapping success within these areas was also calculated, the highest amount of captures were in August 2011 (21.2%), four months after the fire.

4.3.2 Recruitment

Recruitment of new individuals into the population occurred in each trapping month during this stage of the project. Figure 4.5 displays the number of new recruits marked as well as those new individuals captured in the new section of the trapping grid. In March 2011 the highest number of new recruits was captured, the lowest number was caught in August 2011. The expansion of the trapping grid to an area previously not trapped had an effect on the number of new recruits being captured; however, it did not affect the recording of new individuals on the original trapping area.

Previously captured individuals were recorded in areas C and D which were part of the new trapping grid. These individuals were originally marked on section B of the study area and had
dispersed into the newly trapped area. Thus, not all squirrels caught in sections C and D were
ew to the investigation.

**Figure 4.5:** New recruits captured and tagged, recruits captured in sections A and B (black), section C (green) and D (orange).

### 4.3.3 Individual fitness

Squirrel weight was analysed for each trap month, a two-way ANOVA found weight not to be significantly different between trap months ($F = 1.004, df = 5, P = 0.419$). However, there was a significant difference in weight shown between genders ($F = 5.05, df = 1, P = 0.027$). Table 4.3 shows the average weight of adult squirrels in each trap month.

<table>
<thead>
<tr>
<th>Trapping month</th>
<th>Average weight of males</th>
<th>Average weight of females</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2011</td>
<td>$283.57 \pm 16.61$, $n=5$</td>
<td>$265 \pm 30.1$, $n=7$</td>
</tr>
<tr>
<td>March 2011</td>
<td>$266 \pm 14.36$, $n=15$</td>
<td>$270.71 \pm 24.68$, $n=7$</td>
</tr>
<tr>
<td>May 2011</td>
<td>$265 \pm 13.11$, $n=13$</td>
<td>$277.86 \pm 17.27$, $n=7$</td>
</tr>
<tr>
<td>June 2011</td>
<td>$251.25 \pm 8.51$, $n=16$</td>
<td>$286 \pm 26.12$, $n=5$</td>
</tr>
<tr>
<td>August 2011</td>
<td>$262.92 \pm 15.3$, $n=11$</td>
<td>$258.33 \pm 20.1$, $n=6$</td>
</tr>
<tr>
<td>September 2011</td>
<td>$253.33 \pm 7.21$, $n=12$</td>
<td>$277.86 \pm 27.21$, $n=7$</td>
</tr>
</tbody>
</table>

**Table 4.3:** Average weight (grams) of male and female adult squirrels each trap month.
Chapter 4

Results

Of the two squirrels captured within the burnt area of the wood in August 2011 and September 2011, both weighed 250 grams, which is only just below the average for squirrels at this time.

The number of male and female squirrels captured on the trapping grid during this phase of the study was determined. Males remained dominant throughout the study, as found with previous months of the project. The average proportion of animals captured that were male for the entire study area was calculated as 0.67. The dominancy of males was also encountered during trapping sessions on areas C and D of the trapping grid. However, one female was captured in area C (August 2011) and one was caught in area D (September 2011), no males were caught in these sections at these times. The sample size was too small to consider significant.

Adult female squirrels were found to be in a breeding condition in every trap month apart from January 2011 (Figures 4.6 and 4.7). The highest number of breeding females was caught from May to August 2011, males were found to be in a breeding condition in every trap month.

![Breeding status of adult female squirrels of all trapping sections at Derryclare wood.](image)

**Figure 4.6:** Breeding status of adult female squirrels of all trapping sections at Derryclare wood.
Figure 4.7: Breeding status of adult male squirrels of all trapping sections at Derryclare wood.

Of those individuals captured on the new section of the trapping grid (Section C), all were found to be in a breeding condition, apart from one juvenile male captured in June 2011 and one female in September 2011.

4.3.4 Carrying capacity

The ever changing dynamics of the commercial woodland at Derryclare through clear-felling and forest fire has altered the carrying capacity. Table 4.4 shows the potential K from 2008 onwards incorporating areas of woodland that are habitable for the red squirrel population.

<table>
<thead>
<tr>
<th>Year</th>
<th>Felled (ha)</th>
<th>Suitable area for squirrels (ha)</th>
<th>Potential K</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>33</td>
<td>301.38 + NR</td>
<td>104</td>
</tr>
<tr>
<td>2009</td>
<td>17</td>
<td>284.38 + NR</td>
<td>99</td>
</tr>
<tr>
<td>2010</td>
<td>20</td>
<td>264.38 + NR</td>
<td>93</td>
</tr>
<tr>
<td>2011 (after fire)</td>
<td>13</td>
<td>251.38 + NR</td>
<td>88</td>
</tr>
</tbody>
</table>

Table 4.4: The potential carrying capacity in Derryclare wood and the Nature Reserve (NR) over four years incorporating clear-fell and forest fire incidences.

Due to clear-felling procedures the carrying capacity drops each year, the potential K after the fire has also been calculated. The figures used are generated from Coillte’s management plans,
it is their policy to re-plant these areas with both conifers and broadleaves, producing a sustainable habitat.

The potential $K$ can be compared to the area in which the squirrels actually occupied each year extrapolated into a potential number of individuals (Table 4.5).

<table>
<thead>
<tr>
<th>Year</th>
<th>Area occupied by red squirrels (ha)</th>
<th>Number of squirrels (based on 0.32 squirrels per hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>61</td>
<td>20</td>
</tr>
<tr>
<td>2008</td>
<td>104</td>
<td>33</td>
</tr>
<tr>
<td>2009</td>
<td>120</td>
<td>38</td>
</tr>
<tr>
<td>2010</td>
<td>140</td>
<td>45</td>
</tr>
<tr>
<td>2011</td>
<td>181</td>
<td>58</td>
</tr>
</tbody>
</table>

Table 4.5: Area occupied by squirrels from 2007 to 2011 through dispersal of individuals and the potential number of individuals within the given area based on 0.32 squirrels per hectare.

By 2020, another 57 hectares is planned to be felled at Derryclare (Table 4.6), 90 hectares of the areas now clear-felled will have been re-planted with conifers and broadleaves. The 37 hectares of young stands will have matured. Hence the amount of woodland habitable for the squirrels will have changed, affecting the potential carrying capacity. If the potential impact of the forest fire is also considered, two sets of figures for potential $K$ can be calculated (Table 4.7). Taking this into account, the amount of suitable woodland available to the squirrels by 2020 if the fire hadn’t happened would be approximately 231.38 ha plus the Nature Reserve, which gives $K$ value of 74. If the woodland is subject to detrimental effects due to the fire the amount of woodland available is less, approximately 154.38 ha, giving a $K$ value of 49.

<table>
<thead>
<tr>
<th>Time period (years)</th>
<th>Area planned to be felled (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011 - 2015</td>
<td>45</td>
</tr>
<tr>
<td>2016 - 2020</td>
<td>12</td>
</tr>
<tr>
<td>Period total:</td>
<td>57</td>
</tr>
</tbody>
</table>

Table 4.6: The amount of scheduled clear-felling due to take place according to Coillte’s forest management plan for Derryclare wood.
Table 4.7: The amount of suitable habitat available to the red squirrel population (without the fire but after clear-felling procedures and with the fire if the event had been destructive) by 2020.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Areas to be felled (ha) by 2020</th>
<th>Suitable area for squirrels (ha)</th>
<th>Potential K 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without fire</td>
<td>57</td>
<td>231.38</td>
<td>74</td>
</tr>
<tr>
<td>With fire</td>
<td>57</td>
<td>154.38</td>
<td>49</td>
</tr>
</tbody>
</table>

Figure 4.8 displays Derrycclare wood after various felling events but without the fire. Figure 4.8a represents the present if the fire had not occurred and Figure 4.8b displays the potential outlook for Derrycclare in 2020 had the fire not taken place or if the fire had negligible impact. These scenarios clearly show a sustainable forest with clear-fell sections being replanted and maturing.

The actual areas due to be felled by 2020 are not known, however Coillte have undertaken not to clear from blocks in the southern section of the woodland (12, 13, 14, 15, 16), the area shown to be taken corresponds with the amount planned for felling (Table 4.6).

Figure 4.9 displays Derrycclare wood after the fire. 4.9a represents the present with a large section of burnt ground. 4.9b shows the scenario if the fire had devastated the trees in this area and what the outcome may be in 2020. Planned felling events have also been incorporated in Figure 4.9b. This shows that the amount of actual mature forest would decrease in this scenario and succession of stands would be hindered by immature trees being burnt. It also displays a more fragmented habitat with corridors of trees missing.
The diagrams illustrate the effects of a fire that occurred in 2011. Figure 4.8 indicates that, in 2020, had the fire not occurred (A), the area would resemble the current state (B). Had the fire not occurred or had only a minimal effect (B), the mature stands would still be present, and the immature stands would be unaffected. The clear-fell and bare areas would be minimal, indicating a lesser impact on the forested region.

**Legend**: Mature stands, Immature stands, Clear-fell, Bare

**Figure 4.8**: 2011, had the fire not occurred (A), 2020, had the fire not occurred or had only a minimal effect (B).
<table>
<thead>
<tr>
<th>Legend</th>
<th>Mature stands</th>
<th>Immature stands</th>
<th>Clear-fell</th>
<th>Bare</th>
<th>Burnt</th>
</tr>
</thead>
</table>

Figure 4.9: 2011, assuming the fire devastated all areas (A), 2020, assuming the fire had a devastating impact (B).
4.3.5 Habitat quality

Table 4.8 displays the results of line transects carried out in burnt and unburned areas of Derrycclare wood. It shows that more than twice as many lodgepole pine cones were counted on transects in the unburned area than in burned areas. The amount of energy available along transects and hence per m$^2$ is therefore higher in unburned areas than in burnt areas at this time. More sitka spruce was counted in unburned areas. During counts of cones on burnt areas, burnt cones were also counted, table 4.8 shows that by adding this number to the number of unburned cones counted in the same area the total amount of cones is comparable to that found in the unburned area. By extrapolating data gathered in the study area to the 150 ha affected by the fire, a figure of 2,925,000 kJ of energy is estimated to be available to squirrels. This figure is based upon lodgepole pine and sitka spruce counted. The amount of energy available that is lodgepole pine is 1,890,000 kJ.

During the feeding transects, cones that had been consumed by squirrels and other animals were also counted. However, numbers of eaten cones were not large enough to calculate squirrel density within the area. In the burnt area only 15 consumed lodgepole pine cones were counted, 13 of these were eaten by squirrels and two were eaten by other animals. Within the unburned area only 29 lodgepole pine cones were found to be consumed; only four of these were by squirrels, however this area is on the periphery of the known squirrel range at Derrycclare.
<table>
<thead>
<tr>
<th>Tree sp.</th>
<th>Unburned area</th>
<th>Burnt area</th>
<th>Total (150 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Line transects (500 m²)</td>
<td>Per m²</td>
<td>Line transects (500 m²)</td>
</tr>
<tr>
<td>Lodgepole Pine</td>
<td>Cones available</td>
<td>474</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>Energy available (kJ)</td>
<td>1393.56</td>
<td>2.79</td>
</tr>
<tr>
<td></td>
<td>266 (B)</td>
<td>0.53 (B)</td>
<td>-</td>
</tr>
<tr>
<td>Sitka Spruce</td>
<td>Cones available</td>
<td>542</td>
<td>1.08</td>
</tr>
<tr>
<td></td>
<td>Energy available (kJ)</td>
<td>2872.6</td>
<td>5.72</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Total energy available (kJ) in burnt region 150 ha</td>
<td>2,925,000 kJ</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.8: Cones available and energy available (kJ) for lodgepole pine and sitka spruce in burnt and unburned regions of Derryclare wood. Burnt cones (B) were also counted. Total available energy extrapolated over the entire area affected by fire (150 ha) based on cones counted that were not burnt.
4.4 Discussion

4.4.1 Impact of clear-felling on squirrel populations

Clear-felling procedures are a common technique in Irish silviculture, thus animals living within commercial plantations must adapt to the felling of trees from sections of forest. Prior to translocation, the choice of a potential target site for red squirrels should consider a forest’s sustainable management plan. Poole (2007) determined that the size of Derrycclare woodland and the felling plans would not impact the squirrel population detrimentally.

In 2010, twenty hectares of forest was clear-felled from an area in which the red squirrels had been established for at least three years, an area adjoining the Nature Reserve. Procedures were conducted in consideration of the time of year in which it would least affect the squirrel, thus felling commenced in the month of December.

Clear-felling removes habitat directly and can cause degrading of remaining habitat by edge effects, decreasing squirrel activity and potentially increasing vulnerability to predation (Wolff 1975, Anderson & Boutin 2002). Densities of the American red squirrel (Tamiasciurus hudsonicus) decreased from 1.2 to 0/ha in clear-fell areas of a spruce forest in Alaska (Wolff 1975). In Sweden it was discovered that the red squirrel (Sciurus vulgaris) was never observed on clear-fell areas (Hansson 1994). This shows that clear-cuts of tree stands can be detrimental to local populations of tree squirrels, however, if the landscape is only impacted by small but temporary fragmentation with connection to other areas of forest the impact may be minimal (Koprowski 2005). The grey squirrel (Sciurus carolinensis) in Ohio, USA, was found to be less adversely affected by clear-felling when clear-cuts were small, narrow and when 40 – 60% of the stands were retained in a seed producing stage (Nixon, McClain & Donohoe 1980).

Alternatives to clear-felling have been suggested by some studies (Carey 1995), however, these techniques such as tree thinning, have also shown to have an impact on squirrel populations causing a decline in squirrel density (Koprowski 2005, Sullivan & Moses 1986) and a reduction in reproduction (Shuttleworth 1997b). This may be due to the preference of squirrels to a closed canopy, with a number of squirrel species favouring denser sites (Gurnell et al 2002). However, as trees respond to thinning, the increase in crown volume 12 – 14 years post-thinning, may offset the initial reduction in cones from reduced densities of crop trees (Ransome et al. 2004), which in turn is beneficial to squirrel populations. Shuttleworth and Gurnell (2001) recommend that thinning operations should seek to maintain canopy integrity as much as possible, as open canopies reduce foraging efficiency and increase predation risk, as squirrels are forced to move across the ground. This can be achieved by thinning across rows of trees rather than along rows to minimise gaps created in the canopy layer.
At Derryclare, squirrel density of the area surrounding this fell site (section A) was at its highest in March 2011. At this time of the year, the first of the year’s young are born (Gurnell 1987) and dispersal of males is more prevalent in conjunction with the search for mates (Wauters & Dhondt 1992). However, those recruited were not young squirrels from 2011’s breeding season, as their weight and breeding status suggested more mature animals. Hence, it is feasible to say that these individuals may have entered the trapping grid from the area clear-cut as this area is the closest for them to occupy. These results show that squirrels react to clear-felling by moving away from the danger into surrounding residual forest. This highlights the importance of areas of connecting forest for individuals to move through. Studies have shown that the important aspect of clear-fell is not how much is felled but how much residual forest is left for animals to utilise (Potvin, Courtois & Béllanger 1999). The implications of forest operations for red squirrels were considered by the Forest Commission in the UK (FCS 2006), with particular reference to Scottish forests in which red squirrels still have strongholds. In this report, recommendations for the law and good practice during felling operations were outlined. These included a detailed summary of procedures in order to create the least amount of impact to red squirrels during such felling scenarios. A detailed plan of harvesting methods includes a review of the area to be felled, the time of year felling should commence (preferably not within breeding season) and a review of harvesting methods. It was recommended that felling should not occur within the richest squirrel habitat, which is areas that have good seed crop, and those active areas should be marked and avoided where possible. These practices are in place to ensure the conservation of the red squirrel especially as Scotland is one of the few areas of Britain to have strong red squirrel populations. The distribution of red squirrels is somewhat different in Ireland, which is still fairly widespread (Carey et al. 2007), however, Coillte do take protected species into consideration when planning forest operations. At Derrycclare wood, a forest management plan is in place with the caveat that the red squirrel is a protected species and forest procedures are conducted in knowledge of this.

Coillte have planned to replant the clear-felled areas, as it is their policy to re-generate these regions in a sustainable manner. Recent Coillte procedures for replanting trees has changed, with the type of tree species now being planted differing from those planted in previous years. For example, the 20 ha felled in squirrel established areas is now due to be replanted with broadleaf trees which will provide a wooded buffer to protect the core of the old oak wood in the Nature Reserve. There is also a policy to create an ecologically sensitive riparian zone, which is 30 metres wide along the banks of main streams and 50 metres wide along the shores of Derrycclare Lough and Lough Inagh. These plans relate to the 20 ha section felled but also to other areas of the woodland. Trees affected by this will be felled on their scheduled fell date and left unplanted or else replanted with native tree species such as birch, rowan and willow (Coillte 2003).
4.4.2 Impact of forest fire on squirrel populations

Forest fires occur on a much smaller scale in Ireland compared to those in the USA, Canada and Australia, which can occur from 9,000 to 100,000 events per year (Coillte website). However, every year several hundred hectares of forest is destroyed by fire in Ireland, the highest risk period occurs between February and June when ground vegetation is dead and dry following winter (Irish Forestry website). In Ireland, forest fire is usually an accidental incident that occurs due to gorse/land burning by farmers becoming out of control, or the mistake of people discarding cigarettes, matches or else illegally setting a fire in a woodland. The fire at Derrycclare wood was believed to be due to one of the latter. Approximately 150 hectares of wood was affected by the fire at Derrycclare. Although the fire itself was confined to the ground level, it managed to scorch many of the mature and immature stands of trees.

The impact of the fire on the squirrel population at Derrycclare was examined using the technique of live trapping, in which traps were placed in burnt and unburned areas of the woodland, as well as incorporating areas previously trapped throughout the study. Twelve new traps were placed on a new section of the grid which allowed the direct comparison of squirrel dynamics between burnt and unburned forest. Tree squirrels have been found to be negatively impacted in the short-term by forest fire, as it reduces available food, nests and cavities (Kirkpatrick & Mosby 1981). Small mammals are known to flee wildfires but direct mortality has been reported (Geluso et al. 1986). At Derrycclare the number of squirrels caught in burnt areas was lower than those caught in unburned areas. These areas were only separated by a small stream that was the breaker during the fire and saved further stands of the forest from being damaged. Findings on the impact of wildfire on Mount Graham red squirrels (Tamiasciurus hudsonicus grahamensis) in Arizona, reported that the survival of red squirrels over a period that included the fire was lower in areas that were burnt than unburned areas, however, the majority of squirrels within the study area survived (Koprowski et al. 2006). The scale and intensity of a fire are potentially of high importance in determining the possibility of survival of fauna (Silveira et al. 1999). If fires remain on the ground (as was the case at Derrycclare) and are not of a high temperature, shelter in burrows and nests in the canopy can serve as refuges. In comparison if the fire extends into the crown it is likely to lead to higher devastation not only for survival of tree squirrels and other fauna but the trees as well.

At Derrycclare wood, a high number of breeding females were found on the trapping grid during this time in comparison to other years and recruitment of individuals was also high in relation to this. Studies of post-fire forests in Austraila found that the proportion of mountain brushtail possum (Trichosurus cunninghami) females carrying pouch young in burnt areas was significantly lower, but there was no short-term post-fire population decline (Banks et al. 2011).
Overall, it would seem that the fire at Derryclare did not have a direct effect on population density, meaning that if there was any mortality due to the fire it was a very small amount. As the fire remained on the ground, refuges were more than likely found in dreys or squirrels fled certain areas during this time. The most important aspect post-fire is the impact of the fire on trees and whether this may affect seed production or growth. As only two individuals were captured on the burnt area at Derryclare it is not possible to make a comparison with female breeding condition of burnt sites against unburned sites; this may be due to the small area being trapped but may also be an indication that squirrels were not utilising these burnt sections regularly and could possibly be using them as a corridor between other patches of forest or simply making exploratory moves.

4.4.3 Derryclare wood as a sustainable habitat

During Poole’s study (2007) it was important to determine the potential carrying capacity of the woodland in order to determine if Derryclare wood was a good potential target site for translocation. Carrying capacity is a fundamental principle of modern wildlife management, and inherent in this principle are factors encompassing the environmental limitations of an environment. These can include, quantity, quality and distribution of food, cover and water which regulate wildlife populations (Decker & Purdy 1988). The carrying capacity of squirrel populations can be determined by calculating the amount of squirrels a habitat can support. At Derryclare the density used to calculate carrying capacity was 0.32 squirrels per hectare based on literature for lodgepole pine/sitka spruce habitat (Lurz & Garson 1997), previously used by Poole (2007). According to Gurnell et al. (2009) this can be typical of low-medium carrying capacity based on British data.

As Derryclare is a commercial woodland the amount of habitat available to squirrels is subject to change, hence a carrying capacity was calculated for each year based on the amount of clear-felling conducted and the potential amount of habitat affected by the fire. As it is Coillte’s policy to re-plant trees after felling the future of Derryclare remains sustainable. However, as the fire affected a large amount of woodland, the amount of habitat available for squirrels had the potential to change. It was also possible that the fire may have negatively impacted upon the tree cone crop which may have caused the loss of cones from the 2011 crop.

Lodgepole pine forests are native of western north America; fire has been singled out as the factor responsible for the establishment and structure of most of the lodgepole pine forest today (Brown 1975). Lodgepole pine has occurred in fire-dependent ecosystems for centuries; it has been shown to be the predominant postglacial tree invader (Hansen 1943). Fire has an important biological role as changes occur in the soil and biotic activity which can then lead to new species and life forms appearing, as succession begins (Ahlgren & Ahlgren 1960). Lodgepole pine’s success as a pioneer species comes from a number of physiological attributes
such as bearing serotinous cones. Serotinous cones do not open at maturity rather they open after exposure of temperatures of 45 – 50 degrees C, which breaks the resin bond and permits scales to flex so the seed can be released (Lotan 1976). Fire favours an increase in lodgepole pine in single and mixed species stands due to this closed cone habit (Brown 1975), which can then be released in large numbers all at one time (Lotan 1976). Pioneer species such as the lodgepole pine can extend their phase in to a tenth year after the fire, depending on the microclimate created (Bloomberg 1950). Regeneration of spruce comes late in the successive pathway (Chapin et al. 1994), at which point the young plants can thrive on fire-disturbed soil and the shade and leaf litter of the pine stand (Bloomberg 1950).

Feeding line transects at Derryclare were used to assess the amount of cone crop available to the red squirrels after the occurrence of the fire. Transects were not conducted until the late autumn/early winter to ensure that the majority of cones had fallen to the ground (Gurnell et al. 2001). The comparison between a burnt stand and an unburned stand was made using the same amount of transects in each area. It was found that the unburned stand had twice as many pine cones available as the burnt stand but when the amount of cones found burnt on transects was added to the unburned ones, this total was similar to that found on the purely unburned area. However, this may not be truly indicative of cone loss from the overall crop in the burnt area, as the fire did not penetrate the crown region and the nature of lodgepole pine to retain cones in the canopy after maturation. Therefore, cones will still be retained in the canopy for squirrels to feed upon.

During this investigation into seed crop, the area burnt by the fire could be clearly assessed and it was found that the burning within the mature stand was very patchy and that some small areas had not been touched by the fire. Koprowski (2005) reported that fire that devastates a stand of trees is likely to have a greater impact on squirrel populations, as they experience them as clear-cut areas. This is not the case at Derryclare, where the fire was not able to penetrate all the way into mature stands but rather remained on the periphery. The presence of eaten cone cores, although few and the capture of squirrels in traps on burnt areas, suggest that squirrels still reside in the burnt area or may use burnt sections as corridors to more favourable habitat. The fire may have initially driven red squirrels within its vicinity away into unharmed regions of the forest, but the fact the resources still remain within the burnt areas may mean individuals will re-occupy the area in time.

4.4.4 Mapping the future of Derryclare wood for the red squirrel population

This study showed that it was not the foreseen events such as clear-felling but rather the unforeseen events such as forest fire that constitute the major threat to the forest habitat and therefore the red squirrel population. Through the use of maps (Figure 4.8a,b) the current study showed that, as a commercially run woodland, Derryclare can be maintained as a successive
Chapter 4  

Discussion

habitat, with enough mature forest to sustain a healthy red squirrel population into the future. Clear-fell sections re-planted trees will be producing cones within 25 years (Gurnell et al. 2009). As the fire at Derryclare impacted upon a large section of the woodland, the use of maps (Figure 4.9a,b), presented the worst case scenario, with the entire area burnt assumed destroyed. In this scenario, Derryclare a large area has to be removed and replanted. This includes areas of young and mature trees, which impacts on the ability of the woodland to remain a successive forest for red squirrels. Initially a fragmented forest landscape is created and squirrels in different regions are separated by large areas of clear-fell. However, by 2020, this large area is replanted and an immature stand of trees replaced it. In either scenario, the carrying capacity of Derryclare wood is affected, as the amount of mature habitat is reduced.

The actual implications of the fire may be derived from evidence from the literature (see section 4.1), which suggests that due to the nature of the fire, many of the trees will recover in time. Recently, correspondence with the Forestry Manager has confirmed that there is currently no intention to fell any of the burnt areas as many were only scorched by the fire (Barry Rintoul pers. comm.). The actual outcome may be more closely related to Figure 4.8b with some degree of the young stands in block 11 (Figure 4.1a) being lost, but this will not affect the successive nature of Derryclare woodland overall. It has also been confirmed that sections in the southern end of the property of Derryclare will be retained on the long term. Therefore, the outlook for Derryclare wood in the long term is unlikely to be as devastating as predicted by the worst case scenario assessed for 2020. The co-operation between the current study and forestry management means Derryclare will remain a sustainable habitat in the future.
4.5 Summary and Conclusion

The red squirrel population at Derrycclare wood was not detrimentally affected by clear-fell procedures. Red squirrels are capable of adapting to clear-felling when there is enough residual habitat for the population to disperse into. Managing the forest in a sustainable nature and undertaking felling exercises out of the red squirrels breeding season is essential in the high survival rate of squirrels living within commercial plantations.

It is important for forestry managers to be aware of where squirrel populations can be found in their properties. This may then influence their intention to fell or retain certain areas of forest. The forestry plan of differing aged stands of trees is essential in the succession of growth and the continued availability of natural resources. Therefore, any disruption to this routine may cause a knock-on effect to the future health of a squirrel population. Hence, if such events occur it is essential the impact is assessed.

As the fire at Derrycclare wood was confined to the ground, the red squirrel population was not affected detrimentally. Squirrels were still found to be utilising the space that was scorched by the fire but were not caught often enough to indicate they were still established in the area trapped. Therefore, red squirrels had not yet re-established themselves in burnt areas and may have been using them as corridors to favourable habitat. The area burnt by the fire was a part of a much larger environment, hence squirrels could escape and use resources in other regions. However, if the fire had happened in a smaller woodland the outcome may have been different. Therefore, the extent of the fire relative to the size of the woodland was a positive factor in the survival of the red squirrel population. The seed crop was not affected by the fire, as cones retained in the canopy were not reached by the fire.

Analysis of carrying capacity showed that it is subject to change due to the various felling exercises impacting upon the availability of mature habitat. However, a healthy red squirrel population can be maintained as was predicted by Poole’s (2007) feasibility study. If the fire had had a destructive impact on the area that was burnt, carrying capacity would have taken a major decline, both in the short term and into the future. In actuality, the fire did not destroy the area in which it impacted upon. Therefore, the carrying capacity and successive nature of Derrycclare will remain in the long term.

Carrying capacity varies from year to year, regardless of habitat area due to annual variations in seed crop. When assessing the sustainability of squirrel populations, the assessments should allow for poor seed crop levels, higher amounts are then a bonus.
This section of the post-release monitoring of red squirrels at Derryclare wood has emphasised the importance for maintaining sustainable habitat. During the first stages of planning an animal translocation a comprehensive assessment of land-use plans should be conducted. In forests this may include planned felling exercises and replanting programmes. This information can therefore be used to predict the target site's potential carrying capacity, but also its potential future capacities subject to change due to changes to the landscape. This may then clearly determine whether a target site has the viability to be a successful habitat for the translocated population, not just in the immediate future but in the long term.
5 The potential threat of grey squirrel infiltration into Belleek Forest Park

5.1 Introduction

5.1.1 Habitat fragmentation and its effects on squirrel populations

Habitat fragmentation is a process by which large, continuous habitat is broken into smaller patches (Delin & Andrén 1999). Fragmentation of habitat can be caused through natural events like fires, or by human activities such as agriculture, urbanisation and forest management. For species dependent on a particular kind of habitat, the landscape in which this fragmentation occurs is a maze of suitable habitat surrounded by unsuitable environment (Celada, Bogliani & Maracci 1994). Wauters (1997) described three main components to habitat fragmentation; loss of original habitat, reduction in habitat patch size and the increase in isolation of the remaining habitat patch. Habitat fragmentation can cause a major threat to the survival of natural populations: population size can become reduced due to changes in the availability of resources such as food; it can cause predation pressure; cause a loss in genetic integrity; or reduce the ability of a species to re-colonise a site following local extinctions (Wauters 1997). For small rodent populations the proportion of occupied patches in a fragmented landscape has been related to the isolation of patches and the density of subpopulations (Gottfried 1979).

Tree squirrels rely on the presence of forested habitats; hence forest fragmentation has an influence on their distribution, space-use and dispersal (Wauters, Casale & Dhondt 1994, Koprowski 2005). In western Europe, there are large areas that no longer contain forests and as a result many woodlands have now become isolated (Opdam 1988). Whether or not these woodlands are occupied by a squirrel species depends on a number of factors, for example, regional squirrel distribution and population dynamics, size and quality of woodland and the presence of connecting corridors such as hedgerows and tree-rows between patches (Wauters 1997).

Wauters, Casale and Dhondt (1994) studied the space use and dispersal of red squirrels in fragmented habitats in Belgium. They found that space use and home range size in these habitats are strongly influenced by size and the structure of the woodland and that dispersal was aided by the presence of connecting tree-rows. Social organisation of red squirrels in fragmented landscapes has also been found to be similar to those found in continuous woodlands, adult survival and reproductive rates have also been found to be similar (Wauters 1997). However, fragmented habitat has caused a lack of immigration and can result in lower densities and loss of genetic diversity (Barratt et al. 1997). There is no evidence that the loss of
gene-flow and the potential threat of extinction via inbreeding issues cause a problem in small red squirrel populations (Wauters, Casale & Dhondt 1994). In fact, population processes and environmental issues have a far greater potential to cause extinction through the decrease of immigration rates, and this combined with a poor tree seed year could drive a population into a bottleneck, which in some cases can lead to extinction (Wauters 1997).

5.1.2 Squirrel habitat in the west of Ireland

Centuries ago Ireland was a country covered in forest. By the 19th and early 20th century only 1% of the total land area was under trees and only scattered remnants of old forests or planted woodland remained (Hickie 2002). Around 5,700 years ago the large influx of people to the island brought about the new activity of agriculture, and woodland began to be clear-felled to make way for farming. To begin with this was a gradual process with small plots of trees removed. When the land became exhausted the next area of trees would be felled. As the human population grew, a demand for food put an increased pressure on the land and more areas of trees were felled to grow crops instead.

Before the Industrial Revolution, in 16th Century England, timber was an extremely sought after commodity; it was used as a source of energy and a raw material for economic development. The political powers of Europe relied on the continuous supply of timber for the building of wooden ships, for carrying goods, people and for their navies. Since Ireland was colonised by that time, it was seen as a valuable source of timber, hence, a large quantity of wood was being harvested from Ireland. Management of woodland was non-existent during this time, however, in the 18th and 19th century, the Royal Dublin Society provided a grant scheme for planting trees in recognition that woodlands of Ireland were diminishing. Today, the importance of Ireland’s forests and woodlands and the need for their enhancement and management has become important. As such, moves have been made to promote Ireland’s woodlands and sustain them into the future (Hickie 2002).

In Carey et al.’s (2007) survey of squirrels in Ireland, a detailed report of landscape connectivity was published (Figure 5.1). It showed that in the western region of Ireland (region of Connacht, Figure 5.1), there was poor suitability for squirrel dispersal due to the type of land and connectivity available. It was classified as unfavourable due to the presence of willow dominated hedgerows, limestone walls and unenclosed peat and upland areas. Natural barriers such as lakes, mountains and open peat-lands have made it difficult for squirrels to occupy this region. The isolation of woodland in this landscape has created patches of forestry that are unoccupied by squirrels, this is most prevalent in far western regions of counties Galway and Mayo.
Figure 5.1: The composition of field boundaries by O’Sullivan and Moore (1974) adapted to illustrate the favourability of boundaries for squirrel dispersal (Carey et al. 2007).

As such, the red squirrel populations found within this region should not to be under immediate threat by grey squirrel invasion. This is due to the difficulty that squirrel populations find in traversing the region. As a result of the natural barrier provided by the river Shannon, lack of corridors and suitable habitat (such as deciduous forest) immediately west of the river. Therefore, the difficulty for red squirrels to disperse in an isolated region is counter balanced by the difficulty for grey squirrels to invade.

5.1.3 Grey squirrel management and control methods

In mainland Britain, the decline of the red squirrel through competition by the grey squirrel is at a much more advanced stage than in Ireland. The red squirrel now only occurs in a few areas around the UK. In order to combat the influence of the grey on red populations a UK action plan (1995) for conserving the species was developed. Different methods of protecting lasting red squirrel populations were developed. Pepper and Patterson (2001) described the main
principles of this plan as; increasing awareness and understanding for red squirrel conservation, deciding where and how to plan for red squirrel conservation and providing a guide of sources for more detailed advice and information. Through this plan conservationists and scientists in the UK have been able to set conservation aims and investigate ways of achieving them. Two of these principles are; to maintain or improve habitat to sustain viable populations of reds and to minimise competition from greys (Pepper & Patterson 2001).

In 2007, the UK biodiversity action plan (BAP) reviewed its approach and published a detailed report of a shared vision for UK biodiversity adopted by all 4 UK countries (Wales, Scotland, England and Northern Ireland), this report re-enforced the commitment of conservation in the UK and as such, the red squirrel remains a priority species for protection (JNCC 2010).

The National Parks and Wildlife Service and the Department of Environment and Heritage Northern Ireland, has recently addressed this problem between the two species and drawn up its own Action Plan (2008) for the conservation of red squirrels. The Irish situation lends itself to conservation management deployment more readily as the situation on the island is not as far advanced as in the UK. As such a number of recommendations were made, these were; to sustain populations of red squirrels where they are healthy, to expand populations where possible, to re-introduce to areas where they don’t occur (e.g. far west) and to control the infiltration of greys into the area.

In general, there are three traditional methods for grey squirrel control. One is to shoot grey squirrels on sight and in the past has also consisted of drey poking to increase the number of squirrels killed. In Ireland the National Association of Regional Game Councils, have introduced bounties for grey carcasses. Another method is cage trapping which can be used to reduce the numbers of grey squirrels over a short period of time (Rowe 1983, Lawton 2003). The third method is the use of poison, namely Warfarin, which is an anticoagulant and has been used in Britain to remove greys but is banned from use in areas containing reds or pine marten (Mayle et al. 2007). The use of these control methods must be monitored as they pose a danger of removing animals that are not targeted and may be protected. Shooting remains the least effective of the three methods, as squirrels are quite elusive and this method provides little impact. Cage trapping is very effective as it ensures the targeted species is removed, but it is labour intensive and can prove costly (Lawton 2003). Poisoning can be difficult to ensure the targeted species is removed, however, in Britain grey squirrel-only feeding hoppers with poisoned bait have been found to be effective (Mayle et al. 2007). Control programmes must have the backing of the relevant authorities.

Another method of conserving red squirrels is habitat management, research has shown that the proportion of large-seeded broadleaf trees should be minimised in areas managed for red squirrels, a threshold of 10% large-seeded broadleaves has been proposed (Pepper & Patterson...
1998). This is due to the grey squirrel’s ability to out-compete the red squirrel for such resources (Bryce, Cartmel & Quinie 2005). In general, grey squirrels have been found to out-compete red squirrels in mixed and broadleaved habitats, however, in coniferous-only habitats grey squirrels lose their advantage and red squirrels can survive more readily (Lurz et al 1995).

Therefore, habitat re-structuring can influence the potential for grey squirrels to fully establish themselves or out-compete the red squirrels in an area. Such habitat management has been recommended within red squirrel nature reserves such as Kielder Forest in the north of England (Lurz, Rushton & Gurnell 2003) in order to sustain the red squirrel population and hinder any grey squirrel establishment.

A fundamental part of squirrel conservation work is to monitor the distribution of the two species geographically. This enables information to be gathered on habitat use, population dynamics and where any overlap between species occurs. It can highlight any future problems that could arise (Pepper & Patterson 2001) and can determine the effectiveness of conservation management. Knowledge of the distribution of species can enable the implementation of conservation tactics on a manageable scale. For example, the use of buffer zones through which a red squirrel population within a woodland can be protected from the invasion of grey squirrels (EWGS 2005). The refuge is managed to promote red squirrel development and the buffer zone deters the grey squirrel, and grey squirrel control methods can be used in order to prevent the species from entering into the forest.

Regional or national elimination of grey squirrel populations is not feasible, however, control on a local level is sometimes a practical aim (Pepper & Patterson 2001). The difficulty of removing grey squirrels from an area in which they have been established for a long time is their ability to re-colonise rapidly after control, especially in areas that sustain a high population in the surrounding environment (Pepper & Patterson 2001, Lawton & Rochford 2007). However, in situations where site management is feasible and red squirrel populations can be protected, control is a viable choice for planning the preservation of that population.

In Italy, the grey squirrel was introduced on a number of occasions through the 20th century and since then has expanded to cause a threat to the country’s red squirrel population. In 1997, a trial eradication programme was begun as it was seen to be feasible to remove grey squirrels from the particular region. However, animal rights activists took the co-ordinator of the programme to court, in which a lengthy three year trial ensued. Within the intervening years the grey squirrel population was left; hence in the year 2000 the grey squirrel population was found to have significantly expanded its range and thus eradication was no longer an option (Bertolino & Genovesi 2003). This example proves public perception is a key consideration. It also emphasises the difficulty in eradicating grey squirrel populations once they are established.
5.1.4 Modelling the spread of an invasive species

Approaches to modelling the spread of invasive species include explicitly spatial and non-spatial techniques. Diffusion models are widely used as a non-spatial model suitable for describing spread over a single habitat type (Pysen & Hulme 2005). They require few input variables and can be applied quickly with limited data. However, they can often under-estimate spread (Hengleveld 1994). In contrast, spatially explicit models such as the spatially explicit population dynamics model (SEPM), combines spatial variables with species’ life history traits (fecundity, mortality, dispersal distances and density) to determine current and future distribution and population size, effects of inter-specific competition and spread of disease (Tattoni et al. 2004, Bertilino, Lurz & Rushton 2006).

These models tend to be GIS (Geographical Information System) based, which allows computer software to store, manipulate, analyse and visualise spatially referenced data. When a link has been made between landscape features and species occurrence, it can potentially be used as a tool to predict species distribution (Gough & Rushton 2000). When the ecology of a species is well researched, models can be applied to habitat based on its structure and age and its influence on the distribution of a species within, e.g. the red squirrel at Thetford Forest, England (Gurnell et al. 2002).

Cost-Surface Analysis and Least Cost Pathways (LCP) is a spatially explicit method for modelling the permeability of complex landscapes for organism movement (Gonzales & Gergel 2007). LCPs have been used to identify cost effective routes for roads (Atkinson et al. 2005) and pipelines (Feldman et al. 1995), but have also been developed for use in conservation planning. For example, LCP analyses can provide a GIS-based approach for wildlife managers to assess potential landscape linkages that can aid in the conservation of wide-ranging animals such as the black bear in America (Larkin et al. 2004), predict potential dispersal corridors for cougars (Puma concolor) in Midwest America (LaRue & Nielsen 2008), and/or identify connecting patches of suitable wolf (Canis lupus) habitat and factors that influence patch occupancy in Poland (Huck et al. 2011).

5.1.5 Background to this section of the study

During the feasibility study of Belleek Forest Park as a target woodland for red squirrels (Lawton 2006), it was recognised that due to the size and location of the woodland that the squirrel population would be isolated from other woodlands and red squirrel populations. Despite these concerns the other benefits for translocation and the long-term commitment from the local woodland committee, made the project feasible (Chapter 2). As part of the current study, the isolation of Belleek Forest Park was to be investigated and the long-term success of translocation was to be determined. This was achieved by investigating the potential threat of
grey squirrel invasion to Belleek and re-evaluating the absence of the grey squirrel from the surrounding area.

5.1.6 Aims and Objectives

The first aim of this part of the study was to determine the red/grey squirrel distribution in the North-western region of Connacht, including Belleek Forest Park and its surroundings.

The second aim was to determine a likely route of invasion using the Least Cost Pathway model.

- The model allowed us to identify potential bottlenecks or sentry posts (areas which can be observed to detect grey squirrel invasion), which could be used to monitor grey squirrel spread and used as areas of control to prevent spread to Belleek.

- To examine the potential of Least Cost Pathways for future translocation projects or protecting red squirrel refuges.
5.2 Materials and Methods

5.2.1 Study area

In order to investigate current squirrel distribution and whether the grey squirrel poses a threat to the red squirrel population at Belleek Forest Park, the areas targeted for survey work were; Sligo, Leitrim and north Roscommon (Figure 5.2a and b), as these areas represented the likeliest route of invasion. During the survey, reports were also received from counties Mayo and Cavan.

Figure 5.2a: The area targeted during the squirrel survey (examined in 10 km² blocks) including the river Shannon and the Erne waterway. The red dot represents location of Belleek Forest Park
Figure 5.2b: Counties of Ireland.
5.2.2 Survey work

The appropriate personnel from Coillte Teoranta, NPWS and other land owners were contacted in order to gather information. Public participation was achieved by issuing posters in the region. Ordinance Survey maps (16, 24, 25, 26, 32, 33, 34) of areas of interest were consulted and various towns and villages were targeted for the deployment of posters. Areas targeted were based on a 10 km$^2$ grid of the proposed area (Figure 5.2a) and at least two town lands in each 10 km$^2$ block were visited. During each visit to a town or village, posters were distributed either at local post offices, newsagents or libraries. The poster asked the simple question ‘have you seen a squirrel recently?’ with a professional photograph of each species of squirrel (Appendix 1). A telephone number and email address were given as points of contact.

Sightings were recorded using a questionnaire (Appendix 2) with the following details recorded:

- Squirrel species present
- Location the squirrel was seen in
- Type of habitat the squirrel was seen in
- Date of the sighting
- Type of sighting, i.e. visual sighting, road kill or other
- Contact details of the person reporting the sighting

Where possible an exact location of the sighting and a grid reference were gathered. Sightings recorded by members of the NPWS were taken to be correct based on the profession of such individuals. All reports were scrutinised and verified through contact with the respondent.

Posters were distributed to the targeted areas at the beginning of June 2011. Certain key areas were targeted to maximise returns.

5.2.3 Squirrel habitat suitability

In order to take a detailed look at the suitability of habitat in the regions mentioned above, land cover data was obtained. This land cover data was acquired in a digitised format at 500 m resolution (CORINE Land Cover, EPA 2006). Land cover and vegetation type data were presented in a single habitat map. Each 500 m by 500 m cell was characterised by a single habitat type, thus due to the resolution, some small suitable woodlands may not have been recognised (Tattoni et al. 2004). This results in making model predictions more conservative as the total available habitat was reduced (Lurz et al. 2001).

Corine land-use cover was edited to assess the potential amount of habitat available for squirrels and the land cover available for grey squirrels to infiltrate. Grey squirrel carrying capacity for each type of habitat was derived from published estimates (Table 5.1). Although some land-cover and vegetation types are not suitable habitats for squirrels, individuals can move through
them whilst dispersing (Tattoni et al. 2004). Therefore, habitat preference for grey squirrels was broken into five categories. These categories were; optimal, sub-optimal, favourable for dispersal, uninhabitable and barrier. The optimal category included forestry that was ideal for grey squirrels, such as mixed stands and broadleaf woodland (Harris & Yalden 2008). The sub-optimal category included woodland in which greys are known to occupy, such as coniferous stands, but density is known to be limited (Lurz et al. 1995). The “favourable for dispersal” category included land in which hedgerows and other modes of land connectivity were available (Wauters et al. 1994). “Uninhabitable” described everything that was not habitable to grey squirrels, such as grassland, bog, marsh etc but could potentially be crossed. The final category was “barrier” which described areas posing a considerable mortality risk for grey squirrels, such as, airports, construction sites etc.

<table>
<thead>
<tr>
<th>Land-cover type</th>
<th>D&lt;sub&gt;max&lt;/sub&gt;</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coniferous forests</td>
<td>0.2</td>
<td>Smith &amp; Gurnell 1997</td>
</tr>
<tr>
<td>Transitional woodland scrub</td>
<td>0.2</td>
<td>Current study</td>
</tr>
<tr>
<td>Non-irrigated arable land</td>
<td>0.013</td>
<td>Bertilino, Lurz &amp; Rushton 2006</td>
</tr>
<tr>
<td>Pastures</td>
<td>0.013</td>
<td>Current study</td>
</tr>
<tr>
<td>Complex cultivation patterns</td>
<td>0.013</td>
<td>Bertilino, Lurz &amp; Rushton 2006</td>
</tr>
<tr>
<td>Mainly agriculture with natural vegetation</td>
<td>0.013</td>
<td>Bertilino, Lurz &amp; Rushton 2006</td>
</tr>
<tr>
<td>Sports and leisure facilities</td>
<td>0.013</td>
<td>Bertilino, Lurz &amp; Rushton 2006</td>
</tr>
<tr>
<td>Natural grassland</td>
<td>0</td>
<td>Lurz et al. 2001</td>
</tr>
<tr>
<td>Moors and heath-land</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Sparsely vegetated areas</td>
<td>0</td>
<td>Bertilino, Lurz &amp; Rushton 2006</td>
</tr>
<tr>
<td>Inland marshes</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Peat bogs</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Salt marshes</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Stream courses</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Artifical surfaces</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Beaches, bare rocks</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Water bodies</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

**Table 5.1:** Habitat description and maximum grey squirrel densities (D<sub>max</sub> =Squirrel/ha) based on published literature for suitable landcover types, adapted from Bertilino et al. 2006, Lurz et al. 2001. Barriers are indicated by ‘X’.
5.2.4 Least Cost Pathway model

Having assessed the suitability of land for dispersal for the grey squirrel, a Least Cost Pathway (LCP) could be conducted. This analysis was achieved in a number of steps (Figure 5.3):

1. The creation of a digital landscape.
2. The creation of a cost-surface, based on the habitat preferences described in section 5.2.3.
3. Conducting cost-surface analysis, determined by assigning friction values to habitat and the accumulative distance from an origin.
4. Determining a LCP, that calculates routes with the accumulation of the lowest values from the origin to a specified endpoint (Douglas 1994).

This analysis was conducted using ArcGIS 10 and all available digital land-cover (CORINE 2006) was converted to raster format (Figure 5.3, (1)). For this simulation all land-cover was reclassified and given friction values based on its suitability for grey squirrels (2). Friction values were based on a scale of 1 to 4. For example, optimal habitat was given the smallest value of 1 as it was the most favourable to the squirrels and provided a base cost. Sub-optimal habitat was given the value of 2 and so on. Barriers such as water bodies and construction sites were given a value of 50, in order to display a magnitude above other values that indicate major barriers to movement or mortality risks (Adriaensen et al. 2003, Gonzales & Gergel 2007). Once these values had been assigned to each pixel a cost-surface was produced (3). The next step was to create a distance dataset (4) where each cell contained a value representing the accumulated least cost of travelling from that cell (6 and 7) to the final site (Belleek, 5) and a direction dataset (8) that gave the direction of the LCP from each cell back to the source (9). Sources were developed from areas identified in survey sightings as containing grey squirrels. A Cost Path (10) was then created from the data input.
Figure 5.3: Flow diagram of the LCP model. Circles represent input or output, rectangles represent processes.

1. Digital Landscape
2. Reclassify according to grey squirrel preferences
3. Cost Surface Map showing squirrel permeability
4. Cost Distance Created
5. Final Site Location
6. Cost Backlink Created
7. Output Cost Distance Created
8. Cost Path Calculated
9. Source Site Location
10. Output Cost Path Created
5.3 Results

5.3.1 Survey responses

A total of 92 responses were gathered during the west of Ireland squirrel survey. Table 5.2 displays the number of responses recorded for each targeted county, as well as a number reported from other neighbouring counties Mayo and Cavan. Counties Leitrim and Sligo produced the most feedback. This is illustrated further in Figure 5.4.

<table>
<thead>
<tr>
<th>County</th>
<th>Number of reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sligo</td>
<td>27</td>
</tr>
<tr>
<td>Leitrim</td>
<td>37</td>
</tr>
<tr>
<td>N. Roscommon</td>
<td>17</td>
</tr>
<tr>
<td>Other</td>
<td>11</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>92</strong></td>
</tr>
</tbody>
</table>

**Table 5.2:** The number of responses gathered for each targeted county during survey work.

Reports were received mainly by telephone (38%) and email (42.4%), although a number were also gathered in person (19.6%). The majority of reports were made by members of the public. Other sources included NPWS, Coillte and members of gun clubs.

**Figure 5.4:** Locations of all squirrel survey returns
Figure 5.5 shows the areas in which positive records for red and grey squirrels were received, as well as the areas in which no sightings were received. Records show that the red squirrel has a widespread range for the area under investigation. The majority of areas surveyed showed positive sightings for the red squirrel especially in the eastern half of the survey area. During the survey, only five reports of grey squirrel sightings were made. All reports of grey squirrels were historic and were at least one year previous to the current survey. Two of the five were made in areas not targeted by the survey in eastern county Cavan. The other reports were received in counties just west of the river Shannon. Grey squirrels were not seen on a regular basis in any of the areas investigated. Those reports received from Roscommon were based around the Lough Key Forest Park area, while one was received by a member of the public, the other was made by a forester.

![Map of survey results](image)

**Figure 5.5:** Summary map of survey results displaying the records in 10 km$^2$ of both species. Red squirrels represented by red dots and grey squirrels by yellow dots, green dots represent negative returns. Belleek Forest Park marked by a box around its location.

Both red and grey squirrels occurred in the same area in three 10 km squares. Two of the five grey squirrel reports were from the same locality (Lough Key Forest Park). Although the reports suggested that red and grey squirrels had been seen in the same locality, red squirrel sightings were more common and more recent within these areas.
Chapter 5

5.3.2 Land-use in the western region of Ireland

The land-use cover for counties Mayo, Sligo, Leitrim, Roscommon and Cavan as collated by the Corine land-use cover map 2006 show that the majority of the land in these regions is made up of pastures, arable land and peat bogs. Table 5.3 displays the legend for Figure 5.6 and details how the land was categorised.

<table>
<thead>
<tr>
<th>Legend</th>
<th>Optimal</th>
<th>Sub-optimal</th>
<th>Favourable for dispersal</th>
<th>Uninhabitable</th>
<th>Barrier</th>
<th>Figure 5.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous urban fabric</td>
<td>√</td>
<td></td>
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<tr>
<td>Discontinuous urban fabric</td>
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<tr>
<td>Industrial and commercial units</td>
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<tr>
<td>Road and rail network</td>
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<tr>
<td>Airports</td>
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<td>Mineral extraction sites</td>
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<td>Construction sites</td>
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<tr>
<td>Sport and leisure facilities</td>
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<td>Non-irrigated arable land</td>
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<tr>
<td>Pastures</td>
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<tr>
<td>Complex cultivation patterns</td>
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<td>Mainly agriculture with natural vegetation</td>
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<tr>
<td>Broadleaved forests</td>
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<tr>
<td>Coniferous forests</td>
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<tr>
<td>Mixed forests</td>
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<tr>
<td>Natural grassland</td>
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<tr>
<td>Moors and heath-lands</td>
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<td></td>
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<tr>
<td>Transitional woodland scrub</td>
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<td></td>
<td></td>
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<tr>
<td>Beaches, dunes, sand</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bare rocks</td>
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<tr>
<td>Sparsely vegetated areas</td>
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<tr>
<td>Inland marshes</td>
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<tr>
<td>Peat bogs</td>
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<td>Salt marshes</td>
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<td></td>
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<tr>
<td>Intertidal flats</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Stream courses</td>
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<tr>
<td>Water bodies</td>
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<tr>
<td>Estuaries</td>
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<td></td>
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<tr>
<td>Sea and ocean</td>
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</tr>
</tbody>
</table>

Table 5.3: Five categories for grey squirrel habitable preferences, plus colour code for Figure 5.6.

Figure 5.6 displays the Corine land-use as designed for grey squirrel preferences. It shows that the majority of land coverage in the western region targeted is either favourable for dispersal (land described as arable land and pastures that are potentially surrounded by hedgerows) or
uninhabitable. The actual amount of land that is entirely habitable by grey squirrels is very limited and fragmented. However, it would seem that these areas could be accessed via more moderately favourable habitat.

5.3.3 Least Cost Pathway analysis

Least cost pathway (LCP) analysis is illustrated by three main maps. Figure 5.7 presents the four potential routes or cost paths through the landscape. Route A displays the LCP constructed from Lough Key Forest Park in which two sightings of grey squirrels were potentially witnessed. In this pathway, the cheapest cost for the squirrels to traverse would take them through a ‘barrier’, namely Boyle town. After which the route follows a landscape littered with fragmented optimal and sub-optimal habitat. Route B displays the LCP constructed from Killyvoggy, Dromahair, Co Leitrim. This pathway travels more than 20 kilometres north of route A at the widest point and crosses larger optimal and sub-optimal areas. Routes C and D from Co Cavan must contend with at some stage the crossing of the river Shannon. However, within county Cavan itself there are very small patches of optimal and sub-optimal habitat surrounded by a much broader area of favourable for dispersal patches. The two routes converge at Altcrock, Co Cavan. Approximately 40 km later they also converge with route B at Carrownagh, Co Sligo.

All four routes combine in the Ox Mountains about 20 km from Belleek Forest Park. Before the combined routes reach the forest a ‘barrier’ must be crossed, namely the river Moy. The LCP finds the cheapest route to Belleek via bridging the Moy rather than navigating around Ballina town.

<table>
<thead>
<tr>
<th>LCP Route</th>
<th>Length of pathway (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>70.25</td>
</tr>
<tr>
<td>B</td>
<td>66.22</td>
</tr>
<tr>
<td>C</td>
<td>165.60</td>
</tr>
<tr>
<td>D</td>
<td>149.42</td>
</tr>
</tbody>
</table>

Table 5.4: Length of each LCP (km).

From the LCP analysis certain areas can be identified as potentially viable for grey squirrel control. Four main areas have been identified as possible locations for sentry posts (Figure 5.8). These posts will initially be used in a concentrated monitoring programme, as they have been recognised as the areas that grey squirrels may establish themselves.

1. Lough Key Forest Park, Co Roscommon
2. Altcrock, Co Cavan
3. Carrownagh, Co Sligo
4. The Ox Mountains, Co Sligo
Figure 5.6: Corine land-cover data categorised by grey squirrel habitat preference. For legend see Table 5.3. ‘X’ represents the location of Belleek Forest Park.
Figure 5.7: Four Least Cost Pathways displayed on habitat preference map for grey squirrels. Route A represented by a black dot, Route B by a grey dot, Route C by a blue dot and Route D by a purple dot.
Figure 5.8: Sentry post locations. Zones 2, 3 and 4 are based around the areas in which the LCPs converge and are set at a 5 km radius around these areas.
5.4 Discussion

5.4.1 Survey results

The squirrel survey was successful in gathering information on squirrel distribution in the region. The majority of the responses came from members of the public and corresponds with other surveys that found this to be an important group when carrying out surveys (Poole 2007). Although places were not visited to verify results, as much information as possible was gathered via telephone from the respondent.

The first aim of this study was to determine what the distribution of grey squirrels was in relation to red squirrel populations in this region, with particular emphasis on the translocated population in Belleek Forest Park, Co Mayo. Previous studies have shown that natural barriers such as the river Shannon and the lack of suitable habitat immediately west of the Shannon have prevented the grey squirrel in the east from establishing itself in the west (Poole 2007). However, in the past breaches of the Shannon and reports of grey squirrel sightings have been published (Carey et al. 2007). Those sightings were located close to Leitrim town and Drumshanbo, county Leitrim. Apart from these reports of individual sightings no other records have shown discernable evidence that the grey squirrel has established itself in this region. The current survey agrees with these findings.

During the current survey, five reports of grey squirrels in the region were received which potentially lead to an invasion of Belleek. However, there is a possibility that locations of other grey squirrel sightings were not made and therefore other routes of invasion may be missed. Some of the grey squirrel sightings in the current study were questionable due to the nature of the report made. The two sightings received from Cavan are from areas east of the river Shannon known to contain established grey squirrel populations and are therefore not in question. The two sightings received from Lough Key Forest Park, Co Roscommon are under scrutiny. After consultation with the Forest Manager of the woodland in which it was reported, it became evident that the sighting of grey squirrels may have been misidentification due to the variation in coat colour that red squirrels can go through (Martin Ruane pers. comm.). No grey squirrels were seen either during the trapping sessions that occurred at Lough Key during the translocation of red squirrels to Belleek Forest Park (Chapter 2) or detected during the post-removal monitoring of the forest via hair tube analysis (Goldstein 2009). Therefore, it was seen to be unlikely that grey squirrels reside in that location. It is worth noting that Lough Key is a well managed forest and that any other such sightings would be reported. Poole (2007) highlights that if the grey squirrel is able to establish itself at Lough Key, a vibrant grey squirrel population would flourish in the mixed habitat. The final grey squirrel sighting was received
from county Leitrim in an area well represented by red squirrel populations. There is no evidence to suggest that this sighting may not be grey but only one report was received from the area. Despite the uncertainty of some of the grey squirrel reports, all were examined in the model.

It is likely that any grey squirrels witnessed west of the Shannon may be individuals on exploratory movements and not established in a population, or else present at very low density which make them difficult to detect. The closest established grey squirrel populations are in counties Cavan, Longford and Fermanagh (Carey et al. 2007). However, if grey squirrels are to arrive at Belleek Forest Park, then the locations of grey sightings may be likely areas for them to colonise en-route. None of the sightings of grey squirrels gathered in the current study, corresponded to those reported in the previous survey (Carey et al. 2007). This implies that those previous grey squirrels described were not able to establish themselves within the areas they were reported.

5.4.2 Land-use and its impact on squirrel dispersal

The structure of land and its uses can have an effect on the distribution of squirrel species (Rushton et al. 1997). In the west of Ireland there are three main factors that can limit squirrel dispersal in this region: fragmentation of habitat, woodland habitat available and landscape connectivity, and the feasibility for squirrels to disperse from one wood to another. The grey squirrel has evolved from broadleaved forests of the United States, thus in England where rapid replacement of red squirrels by grey has been witnessed, the dominance of broadleaved woodlands in the landscape aided its establishment and dispersal (Shuttleworth 2003). In Connacht, an area of 7.46 % to 12.94 % is forested depending on the county (adapted from Carey et al. 2007), of which the majority is coniferous habitat. If this is compared to four counties of Leinster (east of the country, where grey squirrels are more prevalent), an area of 5.43 % to 13.05 % is forested. Three of these counties are predominately forested by conifers, but one (Kildare) is predominately broadleaved. The amount of land forested doesn’t seem to vary a great deal from region to region. However, the forestry within the region of Connacht is very fragmented and there are still woodlands that do not contain any squirrel species (Carey et al. 2007).

Hedgerows are important to squirrel dispersal as they act as corridors adjoining woodlands, as well as a food source (Wauters et al. 1994). Table 5.5 displays the average density of hedgerows per county in the region of Connacht and compares it to the average density of hedgerows found in Leinster.

Hedgerow densities are relatively similar between the two regions, with two counties (Leitrim and Laois) displaying a higher density for both areas compared to other counties. It has been
purported that the western half of the country does not facilitate squirrel dispersal well due to the lack of connecting corridors (Carey et al. 2007). This may be related to county Mayo and west Galway which have a lower hedgerow density compared to other counties. In certain parts of county Mayo (mainly western part of the county) hedgerows were recorded as scarce, this was associated with upland and blanket bog regions of the county. The county of Galway is only surveyed in the eastern half; this is due to the fact that the western region of Galway has significantly less hedgerows. Both Mayo and west Galway are more mountainous regions with extensive peat-lands; hedgerows are replaced by stone-walls.

<table>
<thead>
<tr>
<th>County</th>
<th>Average density of hedgerow (km/km²)</th>
<th>Mean Species diversity</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mayo</td>
<td>2.24</td>
<td>2.70</td>
<td>Foulkes 2007a</td>
</tr>
<tr>
<td>East Galway</td>
<td>5.88</td>
<td>2.8</td>
<td>Foulkes 2006a</td>
</tr>
<tr>
<td>Sligo</td>
<td>5.33</td>
<td>2.71</td>
<td>Foulkes 2008</td>
</tr>
<tr>
<td>Roscommon</td>
<td>5.43</td>
<td>2.8</td>
<td>Foulkes 2007b</td>
</tr>
<tr>
<td>Leitrim</td>
<td>7.31</td>
<td>3.93</td>
<td>Foulkes 2006b</td>
</tr>
<tr>
<td>Westmeath</td>
<td>5.82</td>
<td>2.8</td>
<td>Foulkes 2004</td>
</tr>
<tr>
<td>Kildare</td>
<td>5.92</td>
<td>3.48</td>
<td>Foulkes 2006c</td>
</tr>
<tr>
<td>Offaly</td>
<td>5.81</td>
<td>3.81</td>
<td>Foulkes &amp; Murray 2005a</td>
</tr>
<tr>
<td>Laois</td>
<td>7.28</td>
<td>4.00</td>
<td>Foulkes &amp; Murray 2005b</td>
</tr>
</tbody>
</table>

Table 5.5: Average density of hedgerows in counties of Connacht and four counties of Leinster.

The quality of hedgerows was determined through the mean species richness of both native and non-native species analysed by each hedgerow survey. Species rich hedge was defined as ‘one that contains four or more native woody species on average in a 30 m strip’ (Foulkes 2007a). Counties Laois, Leitrim, Offaly and Kildare displayed the highest amount of diversity, with counties Mayo and Sligo displaying the lowest. The other counties (East Galway, Roscommon and Westmeath) displayed a comparable amount of species rich diversity in hedges. In general, there isn’t a large amount of difference between the east and west hedgerow species diversity, many of the surveys most dominant species were found to be hawthorn (Crataegus monogyna). Two counties were also recorded as having hedges with a low proportion of trees; these were Mayo and Laois. The assessment of the quality of hedgerows was based on species richness, but the condition of hedges can also involve other qualities such as; bank/wall erosion, tree age composition and height etc (Foulkes 2007a). However, it was felt that the makeup of hedges would be important in squirrel dispersal due to the availability of resources.
From Corine land-use data gathered in 2006, the entire western region displays a similar trend, with larger coniferous areas than mixed or broadleaved. Studies have suggested that red squirrels are better suited than greys to living in conifer forests, whilst greys outcompete them in broadleaved and mixed forests (Kenward & Tonkin 1986) and that purely coniferous forest may be used as sanctuaries for red squirrel populations (Kenward & Holm 1989). However, both species predate upon conifer seeds and broadleaf mast alike (Harris & Yalden 2008). Lurz et al. (1995) reported that grey squirrels will do better in conifer plantations that contain oak (Quercus spp.), or where oak is available no more than 500 m away from a conifer dominate woodland. In Britain, grey squirrel densities in conifer plantation can range from 0.15 – 1.8 squirrels per hectare (Kenward & Walls 1991), compared to broadleaved areas where it can range from 2 – 8 squirrels per hectare. Relative densities have been related to seed availability and weather (Gurnell 1996). In Harris and Yalden (2008) red squirrel densities are reviewed from various areas of Europe and given a range in coniferous forests as 0.2 – 1.3 squirrels per hectare, compared to broadleaf forests of 0.3 – 1 squirrels per hectare. Thus, in forests that contain coniferous species without the larger seeded broadleaves such as oak, red squirrels can maintain their numbers, whilst grey squirrel may lose their competitive advantage. However, the risk to red squirrels from SQPV is cause for concern when the two species reside in the same habitat (Lurz, Rushton, Shirley & Gurnell 2005).

Due to the demand for timber, it has been Coillte Teoranta’s policy in the past to plant the faster growing conifers; as such the most dominant species planted was sitka spruce. However, in recent times with the focus being on sustainable forestry management and biodiversity, Coillte’s policy has changed (Coillte website). As such, less sitka spruce is being replaced by conifers and at least 10% of their plantations are now being planted with broadleaves. These procedures create mixed habitats for squirrel populations. Although, the introduction of broadleaves is beneficial to red squirrel populations due to the availability of more varied food types, this may cause a problem in the long-term as regards to the grey squirrels ability to outcompete reds in such habitats. When the west of Ireland’s coniferous forests take on such change in composition, this may have a causative effect on the ability of grey squirrels to infiltrate more successfully into the area. There is scope for forest management however to plant smaller seeded broadleaves (such as birch Betula spp., rowan Sorbus aucuparia, willow Salix spp. and aspen Populus tremula), rather than the larger seeded species of oak and beech hence protecting red squirrel populations from competition with the grey.

5.4.3 Least Cost Pathways

The second aim of the study was to assertion the potential movement of grey squirrels through the landscape from those areas identified by the squirrel survey. This was achieved by using a Least Cost Pathway model through GIS.
For this study, the primary factor determining movement of the grey squirrel was landscape data, which has been described as the best primary factor to use when investigating such scenarios (Gonzales & Gergel 2007). Other studies have incorporated other factors into their surface layers such as, slope (Ganskopp et al. 2000) or road and river networks (Huck et al. 2011). However, merging coarse data with finer scale data such as road networks with landscape cover can become problematic and result in loss of fine scale information (Gonzales & Gergel 2007). Therefore, for this study land-cover data only was used.

In the format of the model it is important to apportion a value of suitability, in this case to land-use by grey squirrels. These values were assigned in accordance with expert opinion from the literature and our own discretion; it has been suggested that this is a weakness associated with LCP models (Sawyer, Epps & Brashares 2011). However, red and grey squirrel ecology and habitat preference is well studied and therefore it is reasonable to suggest that the assumptions made were reliable.

The highest friction values were given to land-use such as the urban environment, construction sites and water bodies, as these areas pose the greatest threat to grey squirrel dispersal and are the most difficult to traverse. However, it does not rule them out completely from LCP routes as it may still be cheaper for the potential corridor to go through these areas than around them. This was the case in the routes created by the LCP in this study. Route A from Lough Key Forest Park to Belleek requires dispersal to occur through the town of Boyle. All four routes also require the crossing of the river Moy in order to infiltrate Belleek Forest Park. This is not impossible as squirrels can swim (Pauli 2005) and translocated red squirrels from Belleek have been seen doing so by members of the public. Grey squirrels are also known to have established themselves in town-lands, using parks and gardens for resources (Lurz et al. 2001). Therefore the red zones do not create an absolute barrier to movement but do pose a greater risk of mortality.

The next two categories ‘uninhabitable’ and ‘favourable for dispersal,’ were given friction values based on their suitability for grey squirrel dispersal, the main difference between the two groups was the potential availability of hedgerows, which are known to facilitate squirrel dispersal. None of the routes created caused the dispersal route to go through these two categories for more than 10 km before touching a sub-optimal or optimal habitat. Tattoni et al. (2004) used a SEPM to predict spread of a grey squirrel population in northern Italy, in which a maximum distance of 10 km through unfavourable habitat was allowed before dispersers were assumed to have perished. However, the likelihood of grey squirrels to make such lengthy excursions and the use of an arbitrary figure such as 10 km for all unfavourable habitat, including areas without hedgerows is subject to further research. Rushton et al. (1997) varied the maximum dispersal distance using a SEPM to 10 and 20 km in order to produce different
outcomes. Therefore, it may be important to adjust the dispersal distances in which grey squirrels would move through over the three categories (‘favourable for dispersal’, ‘uninhabitable’ and ‘barrier’) before favourable habitat must be found. If the dispersal distances are altered to lower than 10 km then none of the four LCPs created in the current study allow a feasible route to Belleek Forest Park.

On further analysis of each LCP (Figure 5.9), routes C and D in county Cavan (the farthest away from Belleek Forest Park) show a difference in potential for grey squirrels to navigate across them. Route C has a lot more ‘barriers’ to cross than route D, due to a large area of lakes encountered approximately 30 km west of its source. It is not impossible for these lakes to be skirted around, as the area in between is made up of forestry. However, of the two routes, route D is the least detrimental to the grey squirrel. Route B provides the grey squirrel with a good opportunity to reach its destination at Belleek due to the large amount of forestry within the region. All three LCPs eventually converge within this area of Leitrim and Sligo; it contains many forests and small woodlands within which the grey squirrel is capable of establishing populations. Finally route A; although grey squirrel would have to push through a town-land (Boyle), there are no more ‘barriers’ along the route before the river Moy alongside Belleek. Thus, the routes in this study show that there is a potential risk for grey squirrels to invade the region studied and could potentially threaten the red squirrel population at Belleek Forest Park in the future. However, grey squirrels need to establish themselves along the routes in order to potentially invade the region. Routes A, B and D may be more likely routes of invasion.

As cost-surface analysis and LCP is GIS-based, it is suitable for users familiar with GIS software and therefore may be used by land managers to be applied for rapid assessments. In regards to managing and monitoring the grey squirrel as an invasive species, best practise shows that the most effective control is to stop new populations in advance of the population front (Sharov 2004). LCP can provide predicted information of where this front may occur, the nodes of LCPs, areas prior to branching or overlapping sections of pathways give likely encounter areas for monitoring (Gonzales & Gergel 2007). This is the case of analysis conducted in this study and as such the application of the monitoring of grey squirrels can be recommended in certain areas. It also may provide another potential tool during feasibility studies to translocate other red squirrel populations, by analysing the potential threat from encroaching grey squirrels into the targeted area.

5.4.4 Implementation of grey squirrel monitoring and control

The implementation of grey squirrel monitoring will be essential in the west of Ireland. As there is no established grey squirrel population in the west, the region lends itself to the promotion and conservation of the red squirrel. Keeping the grey squirrel at bay or absent from the region will require the use of planned monitoring and control methods.
In the current study, analysis of LCPs has determined that it is possible for greys to infiltrate the area and eventually become a threat to the red squirrel population at Belleek Forest Park. However, through this analysis a number of locations were recognised as areas that the grey is most likely to travel through en-route to Belleek. The first location identified was Altcrock, Co Cavan, an area situated against the Iron Mountains, encompassing a large area of forestry. The second location is at Carrownagh, Co Sligo, which adjoins Union wood in Ballysadere (the second donor site used as part of the translocation of red squirrels to Belleek, Chapter 2). The third location is at Lough Key Forest Park, which is a 200 ha mixed forest in Co Roscommon. Lough Key would provide grey squirrels a strong location to establish themselves from and in fact, was one of the source sites examined in this study. The fourth and final location is situated in the Ox Mountains approximately 10 km east of Belleek Forest Park. It is similar to the second location as there are many patches of forest within quite a mountainous area. Much of the forestry in this area is owned by Coillte and is predominately coniferous.

It is the recommendation of the current study that a monitoring programme should be established within these locations. It will be important that monitoring programmes are assisted by land owners, relevant governing bodies (i.e. NPWS) and the public. Therefore, these bodies must be made aware of the locations of sentry posts. A radius of approximately 5 - 10 km around the locations will be necessary, as grey squirrels may not take the exact route indicated by the LCP. Although a least cost path has been derived by the model, it is not guaranteed that greys will follow the exact path. Huck et al.’s (2011) study to identify the connection of suitable wolf habitat using LCPs, created buffers of 500 metres either side of the path (total of 1 km) in order to incorporate other habitat types and landscape features affecting their analysis.

It will also be in the interest of future monitoring, to follow-up sightings of more than one report in an area of grey squirrels to determine the reliability of a claim. The use of field techniques such as, hair tubes or live trapping will be required. Based on the results, a management programme can be implemented; this action will need to be swift in order to prevent establishment or spread of grey squirrels.

Within these zones the management of woodlands could be addressed, by keeping woodland that are not protected or native, to conifers or mixed sites but using small seeded broadleaves as a compromise for biodiversity of tree species. Monitoring will not have to involve work at each sentry post identified but beginning with the farthest away, for example Altcrock, Co Cavan. However, if grey squirrel sightings become more common place, then a judgement of the next sentry post to be used must be made.

The continued promotion of current red squirrel populations in the west can be maintained by on-going public awareness. The involvement of forestry owners will also enhance red squirrel habitat in a sustainable manner. In the event that grey squirrels are sighted within an area, the
appropriate field methods should be used to confirm sightings and the necessary control methods should be applied in consultation with relevant authorities.

5.5 Summary and Conclusion

Survey results show that red squirrels have a wide spread distribution with the majority of areas surveyed displaying the presence of reds. Grey squirrel sightings were only reported in four locations within the survey area. In each case, sightings of greys were historic (more than a year old) and no more than one individual seen on each occasion. This suggests that grey squirrels seen within these areas were not established and may have been making excursory movements or found at low densities and hence low detectability.

Grey squirrel sightings were not found in the same locations as those reported by recent previous squirrel surveys (Carey et al. 2007). This suggests that those grey squirrel sightings of the past, were not able to establish themselves fully in the habitat in which they were reported.

The majority of survey results were gathered from members of the public, this emphasises the importance of involving the public in such investigations. It also enhances the public’s awareness and is beneficial on an educational level.

Analysis of landscape in relation to favourability for grey squirrels showed that optimal and sub-optimal habitat in the region of Connacht is quite fragmented. Favourable habitat is surrounded by large areas of unfavourable habitat.

The overall assumption that the lack of suitable habitat/corridors for squirrel dispersal in the west may be preventing grey squirrel dispersal or establishment in the region may not be the only features to be influencing this distribution. It would be the recommendation of this study that research of grey squirrel populations located on the eastern side of the river Shannon (counties Longford, Cavan and Fermanagh) should be investigated. To determine in what locations grey squirrels have strong-holds and the potential for dispersal into the west from those locations.

Through Least Cost Pathway analysis, four feasible routes of invasion by grey squirrels to Belleek Forest Park were determined, of which three are likely. However, in order for greys to infiltrate Belleek ‘barriers’ would have to be crossed, for example, the river Moy. To invade the region successfully, grey squirrels would have to establish themselves in favourable habitat along each route. Otherwise a dilution effect would occur the further from established grey squirrel populations that individuals got.
Identification of four potential sentry posts was made using LCP results. These areas would incorporate a 5 – 10 km radius around each point to ensure that other favourable habitat were not overlooked during monitoring, as grey squirrels may not take the exact route produced by GIS. The involvement of the public, land owners, NPWS and other relevant groups will be essential in the implementation of monitoring programmes. Any potential control methods will also have to be done in compliance with the relevant governing bodies.

The Least Cost Pathway model has proven to be successful in the identification of grey squirrel dispersal corridors and application of this method for future translocation feasibility studies may provide essential information on how to protect areas from grey squirrel invasion.
6 General Discussion

6.1 Overview of red squirrel populations at Belleek Forest Park and Derryclare wood

Overall, the translocation of red squirrels to Belleek Forest Park was a success, with two out of two short-term criteria to measure success being met. Initially, the translocation was designed as a soft release, however, due to problems with enclosure construction it fundamentally became a hard release with nest boxes and supplementary food. This situation did not affect the overall success of the translocation but may have had an influence on red squirrel site fidelity, with some squirrels leaving the woodland, making excursions to neighbouring gardens and/or smaller wooded plots. It was found that squirrels translocated in phase one of the programme were captured for a longer period after release than those translocated in phases two and three. As no report was made of the failure of the enclosure until phase two of the project, this apparent longevity of squirrels from phase one may be linked to the use of a soft release. Soft release has a number of advantages associated with its use: it allows for the close monitoring of individual health, which is important especially in stock taken from grey squirrel areas; it allows for individual squirrels to become accustomed to using feeding hoppers; it allows squirrels to lose their original site fidelity and remain within the site of release. However, this does not rule out the use of hard release procedure in future squirrel translocations and it may be appropriate to consider the technique used on a case by case basis. Soft release can add to the expense of a translocation and other studies have also proven hard release to be successful (e.g. Fornasari et al. 1997).

Red squirrels translocated to Belleek showed an increase in weight initially and therefore were in good condition to breed. These results correspond to other translocations in which weight was gained (e.g. Poole 2007). Squirrels that increase their weight from the time of release to the first initial monitoring session, have more chance of breeding within that season, as squirrels with healthy weight breed more consistently than those with a low weight (Wauters & Dhondt 1995). This emphasises the importance of using supplementary food during translocation, to ensure squirrels have access to food whilst they are still in an exploring phase.

The settlement of red squirrels at Belleek Forest Park displayed the importance of supplementary food with feeders present in all individual home ranges. Some squirrels were
also witnessed re-entering the soft release enclosure, which was being supplied with food at the
time. Not all squirrels established a core area immediately after release, but continued to utilise
their home range uniformly. Some individuals also established home ranges in other areas of
the wood, away from site of release. These results correspond to those reported in other studies,
in which individuals were found to move away from area of release to unoccupied areas of
woodland (Poole 2007, Wauters et al. 1997a). Those home ranges that were investigated 18
months later, showed that individuals were utilising other areas of the wood including parts
without supplementary food, suggesting that a pattern more consistent with established squirrel
populations had been reached.

The post-release monitoring of the red squirrel population at Derryclare wood confirmed that
the translocation continued to be successful. Six of the original individuals translocated were
captured within the area in which they initially settled (within or close to the Nature Reserve),
displaying longevity and site fidelity to the area. The population was found at the start of the
current study to have spread further into the woodland since the completion of Poole’s study
(2007). This spread continued over the course of the current study as the population increased
in size.

The spread and establishment of the two red squirrel populations was influenced by the
structure of the two different habitats. Although Derryclare contains the broadleaved Nature
Reserve (Poole 2007), this is a relatively small area, and many squirrels did not include the
reserve in their home range. Therefore, Derryclare can be considered predominantly coniferous,
compared to Belleek which is a true mixed site. Density of the two red squirrel populations was
found to also correspond to the type of site; previous studies also show the structure of the
habitat and seed availability influenced the number of squirrels present (Lurz et al. 1995, 1998).
Overall, recruitment was consistent with the number of breeding females at both sites and led to
annual growth of each population. Therefore, when the post-release monitoring of both
populations came to an end, both populations were continuing to survive.

The future of each population was considered and their survival was questioned. At Belleek
Forest Park carrying capacity was reached at a quicker rate, due to the relative size of the wood,
recruitment rate and high adult survival rate. The planned management of the woodland is to be
carried out with red squirrels as a top priority in the scheme. Promotion of a staggered age
structure, closed canopy and ‘squirrel-friendly’ tree species will enhance Belleek for future
generations of squirrels. The main threat to the red squirrel population at Belleek was
considered to be from the potential incursion of the grey squirrel. The use of Least Cost
Pathway (LCP) modelling provided the most likely routes for grey squirrel infiltration to
Belleek Forest Park. However, it also provided valuable information on possible sentry posts
for grey squirrel control where and when necessary. It is the recommendation of this study that
land-owners of the sentry posts identified be notified and a request to be vigilant for greys made. Another recommendation is that grey squirrel distribution west of and immediately east of the Shannon be studied in detail to further enhance the information gathered and to create a clear picture of grey squirrel invasion. The use of LCP models will play an important role in identifying possible routes of infiltration by grey squirrels to areas of the west, as well as identifying areas suitable for grey control in order to protect the red squirrels in the west of Ireland.

At Derrycclare the future of the red squirrel population is subject to the commercialism of the woodland itself and the impact of one off events, such as forest fire, which threaten to cause the loss of habitat. The potential red squirrel carrying capacity of Derrycclare had not yet been reached by the end of the current study. However, this capacity was changing from year to year due to the clear-felling that occurs in a commercial wood such as Derrycclare. Overall, it was found that these procedures had not impacted upon the red squirrel population detrimentally, which corresponded to predictions made by Poole (2007) during his feasibility study of Derrycclare as a site for translocation. The time of year of felling was a key consideration being made to minimise the impact on the red squirrel population. The future for red squirrels at Derrycclare wood will be greatly influenced by the sustainable management of the habitat and consideration of the squirrel populations by Coillte will be highly important to the population’s continued success. Investigations into the forest fire at Derrycclare showed that the fire was contained to the ground which meant it had not severely impacted upon the population.

6.2 Post-translocation management: What role does it play?

Adaptive management is an approach to wildlife management that attempts to enhance the understanding of conservation strategies and best practices by investigating experimental outcomes over time and using models to predict the future (Rout et al. 2009, Wilhere 2002).

Post-translocation management is a form of adaptive management as it provides intervention, where needed to translocated populations or species, identified through post-release monitoring.

Once a translocation has been deemed a success many translocation programmes close with no further monitoring (White et al. 2003, Fisher & Lindenmayer 2000). It has already been reported that post-release monitoring is essential to call translocation a continued success (Seddon 1999). However, the duration and frequency of such monitoring is not clearly defined.

In the current project for the translocation of red squirrels, three terms of monitoring were identified, short, medium and long (Figure 6.1). It is the view of the author that these terms can be used as a template for other translocations to help define duration and frequency of projects. Short-term monitoring is defined as the programme related to measuring the initial success of a translocation. It investigates the animal’s settlement into its new environment and potential breeding success. Once the criteria to determine translocation success have been met, short-
term monitoring comes to a close. Medium-term monitoring is defined as the programme to investigate the development of a population or species. This includes monitoring of establishment of a population or species and its spread through the new habitat, and an assessment of individual health and/or population fitness. It also includes an examination of quality of the new habitat and how this may affect the status of the translocated population or species. A lot of important information about the ecology of a species can be gleaned from the medium-term stage; this may then be fed into possible models and/or predictors, which can be used to assess long-term success. Once a population has reached a density consistent to those of established populations, and recruitment and breeding are annually successful then medium-term monitoring can be concluded. Long-term monitoring is defined as the programme by which the future success of the translocation is determined and any inhibitory factors influencing success are identified.
Figure 6.1: Flow-chart of stages of species or population post-translocation monitoring.
As IUCN guidelines (1987, 1998) are followed during the initial phases of a translocation, it is important that they are followed throughout, which means long-term monitoring is a prerequisite to translocation. This does not necessarily mean undertaking a comprehensive assessment every year but may involve an indirect field technique to be used at periodic time intervals. The use of hair-tubes and/or feeding surveys can provide a cheap alternative to more direct methods such as live trapping. Where possible local interest groups can undertake this continued assessment (e.g. Belleek Forest Park Enhancement Committee). The information collected can then be compared with results that were predicted in models and an assessment of the actual fate of the translocation can be made.

This continued assessment of translocation projects allows the identification of the potential need for intervention to be made. Intervention can mean the management of the translocated population or species and/or its habitat. Techniques available include the introduction of more animals to the target site, the use of veterinary care, the use of supplementary feeding or the enhancement of the habitat. However, this does raise questions: when is post-release monitoring ever complete and is intervention ever considered not feasible? This may only ever be the case if a translocation starts to fail and intervention may no longer be appropriate. This may happen for a number of reasons for example, the original reason for a species’ demise in an area returns or the area/habitat no longer being viable. In these cases intervention may be more detrimental than beneficial and remaining individuals of the translocated population may need to be relocated to ensure their survival.

The continued assessment of Derrycclare wood and Belleek Forest Park red squirrel populations should be maintained as discussed in the long-term. Derrycclare will require an assessment by NPWS wildlife officers and/or a biologist as it is isolated from public use. Belleek will benefit from the vigilance of the general public and the involvement of the Enhancement Committee who will employ the correct expertise in order to monitor the red squirrel population. These bodies have the potential to take on important aspects of management and may be able to identify problems quickly. This assessment may only require an indirect field approach, through feeding sign surveys or hair tubing at regular time intervals (e.g. every two years). Intervention may be necessary on occasion for example, Poole (2007) suggests the introduction of new individuals to red squirrel populations every 8 years for genetic enhancement. Habitat modification may also need to be made in order to create a sustainable environment.

In general, post-translocation management has an essential role to play in the continued success of a translocation. Without its assessment a translocation cannot be monitored in the long-term and continue to be called a success.
6.3 Translocation and its role in the conservation of the red squirrel in Ireland

One of the key threats to the native red squirrel in Ireland, above predation pressure and habitat loss, is competition from the American grey squirrel. This has caused a 20% decline in its range since 1911 (Marnell et al. 2009). There are a number of reasons why it is important to conserve the red squirrel in Ireland. The Irish government has committed to a National Biodiversity Plan, which includes red squirrels, through the maintenance and enhancement of Ireland’s flora and fauna. The red squirrel is important at a habitat level, as squirrels aid the dispersal of tree seed through their caching behaviour, which helps promote sapling growth (Jensen 1985). Tree squirrels are also excellent indicators of forest health and structure (Carey 2000); the presence demographics and habitat use of tree squirrels can indicate the status of forest ecosystems (Koprowski 2005). The red squirrel also can be used as an educational tool, demonstrating the impact that an introduced species can have on a native species.

At an economic level, the red squirrel has been linked to eco-tourism, providing a role in attracting visitors to an area. Since the introduction of red squirrels to Belleek Forest Park, the park has received a large amount of publicity. This has drawn visitors to the woodland and surrounding area, which has helped boost the local economy, both at Belleek Castle and Ballina town. It can be difficult to estimate a value that red squirrel eco-tourism creates but in England, the North West Development Agency (NWDA 2005) estimated that red squirrels at Formby Nature Reserve attract a tourist spend of £1 million per year.

In general, the distribution of red squirrels in Ireland is still fairly widespread, however it is important that any conservation efforts be made before a further contraction of the Irish population occurs. In Britain, the red squirrel is only found in limited a number of places and conservation is vigorous to ensure these areas remain refuges for the reds. Although the situation is different in Ireland, lessons must be learnt from other countries.

The All Ireland Species Action Plan (2008) set out several means by which the red squirrel may be conserved. The advantages of using translocation, which was listed in the plan as a conservation tool, are: ‘it is a long term solution that requires a small amount of management into the future, and it is a clear way of expanding red squirrel distribution and creating strong holds against the grey squirrel.’ Unlike techniques such as culling, translocation can be promoted to the public positively, as well as enhancing the biodiversity of the target site without detrimental effects. The main disadvantage associated with translocation is the financial cost. Poole (2007) outlined the total cost including equipment, employment of a biologist and other related costs to be between € 93,290 - 115,172 to conduct a translocation. This may not be prohibitive compared to immune-contraceptives if and when they become available or concentrated control costs. However, more than one translocation would need to be conducted in order to make an impact. The cost of translocation can be offset if an income attached to eco-
tourism can be raised. Another issue involved with red squirrel translocation is who undertakes the project, if the required expertise is available and can the long-term monitoring commitment be guaranteed.

A number of recommendations can be drawn from this work and are important for the future of translocation. Initially, a detailed feasibility study is essential in order to predict the potential of a target site for translocation. This includes an estimation of carrying capacity and the future management plans for the site that could affect this capacity. An investigation into how remote the target sites are, and whether there is potential of infiltration by grey squirrels will be essential for long-term success.

On review of other red squirrel translocations, introducing reds to an area within the grey squirrels distribution would not be cost or time effective, especially when there are other sites available to the conservation of reds. In areas such as Thetford forest, East Anglia, England or Anglesey in Wales, where red squirrel translocation has been successful and the eradication of grey squirrels implemented, red squirrel populations can still come under threat from the spread of the SQPV and stress related disease such as the adenovirus. Schuchert et al. (2012) reports that over a thirteen year eradication programme of grey squirrels from Anglesey, Wales, SQPV rates declined. In this study, the highest SQPV seropositive (75%) proportion was found in 2002 coinciding with the highest total catches of grey squirrels that year. This proportion of SQPV seropositive grey squirrels decreased constantly from 2003 to 2010 when only 4% of sampled animals were found to be seropositive. This shows that eradication of grey squirrels is potentially a viable option, reducing the risk of SQPV, if the habitat permits control, however to date not all grey squirrels have been removed from Anglesey. This type of programme would add to the expense of an already expensive procedure. Until recently, Ireland had not yet had a reported case of SQPV in the country, but there have now been four confirmed cases (Dr Declan Looney & Ferdia Marnell pers. comm.). The situation in Ireland lends itself to the continued success of translocation as there are areas in the western regions that do not contain grey squirrels; counties Kerry, Clare, Donegal, Sligo, Galway and Mayo represent areas favourable for red squirrel translocation. This is based on the 2007 (Carey et al. 2007) survey and squirrel distribution in Ireland needs to be continuously updated to look for grey squirrel invasion into the area.

Other Irish translocation projects funded in the recent past include the reintroduction of native birds of prey. These include, the golden eagle (Aquila chrysaetos, O’Toole 2002), the red kite (Milvus milvus) and the white-tailed sea eagle (Haliaeetus albicilla) (Golden eagle website). Unfortunately, efforts made to reintroduce these species have been hampered by birds being poisoned on a number of different occasions. However, some individuals have survived and the
white-tailed sea eagle has recently been reported as breeding on an area of Lough Derg, Co Clare (Irish times, 2012).

Translocation is feasible and should be used as one of a number of types of methods to promote red squirrel populations. Other methods may include the habitat modification of forests in the west to deter grey squirrel dispersal but promote red squirrel populations. This can be achieved by planting small seeded broadleaves rather than large seeded ones. Keeping the west as a haven for red squirrels must be a priority. This will be aided by monitoring programmes and communication of grey squirrel sightings in the area and the implementation of grey squirrel control where necessary.

6.4 Translocation and its role as a conservation tool for animal populations in general

Once a translocation has taken place it is important to report either success or failure and the difficulties that may have been encountered during the process. Often only the successful projects are reported. There is an opinion that not all species that could benefit from translocation are suitable for what the programme entails. In a review of amphibian and reptile translocation, Dodd & Seigel (1991) suggested that, due to the lack of successful translocations rigid criteria should be set before future attempts are made. Other reviews of amphibians and reptiles have found these findings to be extreme (Burke 1991). This has caused some debate amongst herpetologists (Seigel & Dodd 2002). However it is clear that success can be found in some cases (Tuberville et al. 2005). Another group shown to be problematic to translocate are bats. According to a review of bat translocations (Ruffell, Guilbert & Parsons 2009), none have been fully successful. It was determined that existing guidelines for translocation were not directly transferable to bat species. This is due to differences found in morphological, physiological and behavioural characteristics to those in which translocation has been developed. In these cases translocation may not be a feasible management tool for conservation and any attempts should clearly be planned to ensure that success is maximised. Despite these examples, translocation has been a valuable tool in conservation in a wide range of taxa.

Besides the IUCN published guidelines on translocation (1987, 1998), specialised guidelines are also produced by the IUCN for specific translocations including placement of confiscated animals (2000), primates (IUCN 2002), the African elephant (*Loxodonta Africana*) (IUCN 2003), grey partridge (*Perdix perdix*) (IUCN 2008) and Galliformes (IUCN 2009). These specialised guidelines have been published for a variety of reasons, for example the need for the placement of confiscated animals from illegal trade worldwide to new areas. In order to protect the African elephant, which has suffered from the degradation of habitat and human conflict and to develop best practise techniques with leading experts. It may not be possible to produce a
Guidelines for post-translocation monitoring and long-term strategies are more difficult to acquire. It may be the case that not all long-term monitoring is published once the initial success has been reported on. However, some projects do report on the continued success or failure of translocations by other means. For example, the re-introduction of native birds of prey in Ireland are being monitored in the long-term. Information of how birds are being monitored and results being found are available for public consumption on an active website set up by the Golden Eagle Trust Ltd (Golden eagle website). This site allows the continued monitoring of birds including the golden eagle, red kite and white-tailed sea eagle to be interactive. Cameras have been set up at red kite nesting sites, GPS locations have been mapped for the sea eagle and up-to-date information of each individual’s status is recorded. Each species’ project employs a full time project manager who is responsible for the monitoring of the birds. Thus, the re-introduction of these birds of prey is being monitored in a long-term programme.

Long-term maintenance of translocation projects may be difficult to determine or even facilitate but some studies have used a protocol based on GIS to assess the changing status of translocated species. For example, following the re-introduction of 153 river otters in central and western Pennsylvania, USA, spraint and foot-print analysis was used to track their distribution (Hubbard & Serfass 2004). This information was gathered in collaboration with wildlife officers, and future changes are continuing to be monitored. In another example of long-term monitoring, a review of boreal caribou (Rangifer tarandus) in Quebec (St-Laurent & Dussault 2010), found that since their introduction in the 1960s alongside a wolf control programme that continued to 1980, the population is now under threat of extinction. Although, initially the introduction was reported as being the first successful translocation of caribou in the presence of predators (Bergerud & Mercer 1989), the small population size, its isolation and low recruitment rate, and pressure from habitat loss and predation have now put it under threat. This example shows that long-term monitoring is important in the identification of possible threats to translocated species or populations.

In general translocation is a lengthy conservation technique as monitoring is an on-going procedure. The expertises required make the procedure more expensive beyond the simple initial translocation costs. Therefore financial feasibility could potentially add to the complexity of its use as a conservation tool. However, there is also potential for long-term monitoring using already-employed individuals such as wildlife officers and/or the development of voluntary organisations that may be able to provide the future stability of projects.
6.5 Conclusions

The project fulfilled all the aims that were set out initially. The translocation of red squirrels to Belleek Forest Park was completed and was successful. Post-release monitoring was undertaken both at Belleek and the previously translocated population at Derrycclare wood.

The project set out a three distinct time periods in which translocated population should be monitored; short, medium and long-term phases.

The project identified the need to incorporate habitat management plans at the feasibility study level of translocation to ensure that habitat is kept at a sustainable level essential to habitat obligates such as red squirrels. The use of LCP models was also identified as a useful tool in establishing the potential route of invasion of grey squirrels to the target site; this may also be incorporated at the preliminary stages of translocation. However, it was recommended that further analysis of grey squirrel distribution be made in the near future to compliment predictive models.

The ecology of red squirrels in two environments provided evidence for the establishment and spread of populations through different habitat structures. Population demographics provided a basis to monitor the on-going health of individual squirrels as well as the overall fitness of the population during establishment. High recruitment rate and adult longevity produced a high survival rate in both populations which showed conditions to be favourable for squirrels.

Finally, the project enhanced the research already undertaken for red squirrel translocation and displayed that translocation can continue to be a successful tool for conservation in the absence of the grey squirrel in Ireland and further afield.
7 References


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222


8 Appendices

Appendix 1: Survey Poster

West of Ireland Squirrel Survey 2011

Have you seen a squirrel recently?

If you have we’d like to hear from you.

A survey on the distribution of squirrels in the west of Ireland is being conducted. If you have seen a squirrel recently in your area please contact us.

Email: squirrelwest@gmail.com

Phone: 087 3575176.
Appendix 2: Survey questionnaire

West of Ireland Squirrel Survey 2011

Email: squirrelwest@gmail.com

Phone: 087-3575176

Name: ________________________________________________________________

Address: ________________________________________________________________

______________________________________________________________

______________________________________________________________

Phone no: ________________________________________________________________

Email: ________________________________________________________________

Where was the squirrel seen? (Forest, woodland, town land)

_________________________________________________________________________

Where is the closest town/village?

_________________________________________________________________________

Grid Reference

_________________________________________________________________________

Woodland type: Coniferous [ ] Broadleaf [ ] Mixed [ ]

What type of squirrel: Red [ ] Grey [ ]

What type of sighting was it? (Road kill, personal observation)

_________________________________________________________________________

When was the most recent sighting of red squirrel?

Within 3 months / 3 months to 1 year / more than 1 year ago

When was the most recent sighting of grey squirrel?
Within 3 months / 3 months to 1 year / more than 1 year ago

Any other information?
_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________

How did you find out about the survey?
Newspaper  ☐  Poster  ☐  In the post  ☐

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