Red Squirrel Translocation in Ireland

Irish Wildlife Manuals No. 51

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

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Citation:

Waters, C. and Lawton, C. (2011) Red Squirrel Translocation in Ireland. *Irish Wildlife Manuals*, No. 51. National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin, Ireland.

Keywords: Red squirrel translocation, *Sciurus vulgaris*, post release monitoring, donor site, source population, density estimate, breeding, recruitment, dispersal.

Cover photo: Red squirrel © Joe Kilroy

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Irish Wildlife Manuals Series Editors: F. Marnell & N. Kingston

ISSN 1393 – 6670

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EXECUTIVE SUMMARY

This report details the findings of research conducted in the west of Ireland on the use of translocation as a conservation tool for the red squirrel (*Sciurus vulgaris*). Translocation is the establishment of a population of wild animals in an area where they have become locally extinct or were not found historically. The red squirrel has suffered a 20% decline in range since the introduction of the grey squirrel (*Sciurus carolinensis*) to Ireland, due to competition for resources. This study fulfilled criteria set out by the IUCN guidelines for re-introductions (1998). The main aims of this research were to complete the translocation of red squirrels to Belleek Forest Park, Ballina, Co Mayo and carry out long-term post-release monitoring there and in Derryclare, Connemara, Co Galway, where squirrels were translocated in 2005. The donor site populations, from which the translocated squirrels were sourced, were also examined to investigate any impacts experienced through the removal of the animals.

The translocation was completed using a soft-release technique. Settlement patterns of squirrels were examined using radio-tracking methods and direct and indirect field techniques such as live trapping, radio-tracking, line transects and hair tube surveys were used to further monitor the new populations. The results studied the demographics of each population and the colonisation of these once uninhabited woodlands.

Despite problems encountered with the release enclosure, the translocation of 15 red squirrels to Belleek Forest Park was deemed a success with 67% of the individuals surviving to the breeding season and young animals being born in the new woodland. The population in Belleek quickly spread through the wood, and then population density increased as the monitoring continued. Recruitment rate was high, reflecting the high percentage of individuals found to be in a reproductive condition. Squirrels maintained a healthy body condition, linked to the excellent habitat at Belleek Forest Park and the supplementary food provided.

The population at Derryclare has continued to increase since its 2005 translocation with three of the original 19 red squirrels still occupying the wood despite their advanced years. The population was found to have established itself in the vicinity of the release site and only dispersed into other areas of the large wood once the carrying capacity of the stands they occupied was reached. Differences between the settlement patterns in the two woods can be explained by the quality of squirrel habitat available (Derryclare having a poorer seed crop than Belleek).

No detrimental effects to the populations at the donor sites could be attributed to the translocations; source populations had recovered quickly after removal of red squirrels. It is a requirement of translocation that the removal of individuals must be balanced with safeguarding source sites.

A number of recommendations are made regarding any future translocations:

- Several areas in Ireland are suitable for future translocations including counties Donegal, Sligo, Mayo, Galway, Clare and Kerry.
- Translocations consistently fail if grey squirrels are present or disease affects the new population. Red squirrel translocation cannot be used in areas within the grey squirrel range, even where a grey squirrel eradication programme has been carried out.

- Potential translocation sites should be carefully assessed to ensure they have sufficient resources to sustain a viable red squirrel population into the future. For isolated woods there should be enough habitat for at least 60-80 squirrels.
- The cooperation of landowners, and in particular a commitment to a long-term strategy of sympathetic woodland management, is essential.
- Use of local conservation groups is encouraged, but great efforts are required to educate, train and manage the individuals involved.
- Donor sites must be carefully assessed and given a chance to recover following removal of squirrels; the same site should not be used for a series of translocations. Using more than one site will also boost the genetic integrity of the new populations.
- Hard releases can be successful as a whole but may lead to more individuals leaving the area.
- Supplementary food is beneficial, but should be phased out before the new population reaches an artificially inflated carrying capacity of the new area.
- Long term commitment is essential in undertaking translocations, particularly where extra animals are required in future years to reduce inbreeding.
- Costs of a translocation study are an important consideration as are the individuals carrying out the work. Much training is required if individuals do not currently have the required expertise.

ACKNOWLEDGEMENTS

Thanks to Nicola Condell, Emily Goldstein, Emma Sheehy and Maria Duddy whose research contributed to this study. Thanks to Eoin MacLoughlin, John Galvin, Albert Lawless and other staff and students of National University of Ireland, Galway for their assistance in the field and in preparing equipment. Thanks to Dr Alan Poole and Dr Laura Finnegan who worked on earlier phases of this study, but continued to help and advise throughout. Special thanks to the Belleek Forest Park Enhancement Committee, and especially Cyril Collins, for their long term commitment and support to the project. Thanks to Ordnance Survey Ireland for permission to use the maps herein. Thanks to Coillte and National Parks and Wildlife Service for their assistance and permission to use field sites, and especially to the staff of NPWS for their expertise and support in this study. CW and CL.

INTRODUCTION

Squirrel biology

Squirrels belong to the Order Rodentia, which is considered the most diverse order of extant mammals with over 2100 species or 41% of all mammal species (Harris & Yalden 2008). The rodents are divided into six different families: Sciuridae (squirrels), Castoridae (beaver), Gliridae (dormice), Cricetidae (voles), Muridae (mice and rats) and Myocastoridae (coypu). The family Sciuridae is a large family with 278 species in 51 genera (Wilson & Reeder 2005), which includes a mix of arboreal and gliding squirrels, terrestrial marmots and ground squirrels. Tree squirrels include the genus *Sciurus* and are found on all continents apart from Australia and Antarctica.

The Eurasian red squirrel (*Sciurus vulgaris* Linnaeus 1758) inhabits forests throughout the Palaearctic from Ireland in the west to Sakhalin Island 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 and the Altai mountains in central Mongolia (Gurnell 1987).

The red squirrel is diurnal (i.e. mainly active during daylight hours). In the winter the squirrel has a short, uninterrupted active phase which is an adaptation for conserving energy in cold months; in the summer it has a longer active phase that is usually broken by a rest period (Tonkin 1983, Wauters & Dhondt 1987). Most of this active time (75 – 91%) is spent foraging, regardless of the season (Tonkin 1983). Tree seed makes up the majority of the red squirrel's diet; 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).

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 summers 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). 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).

Red squirrels do not defend individual territories as strongly as other squirrel species do and can be thought of as having individual home ranges controlled by a social hierarchy within the population (Wauters and Dhondt 1992). Generally, dominant females maintain nearly exclusive core areas within their home range against other females (intrasexual 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).

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 gone 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 introduced. The red squirrel features in scripts by Augustin, an Irish writer of the 17th century, through the word "*sesquivolos*" (Barrington 1880). However, the red squirrel became extremely rare in Ireland if not extinct in the late 17th and early 18th century (O'Teangana 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*, 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 competitor of the native red squirrel species (O'Teangana *et al.* 2000). The grey squirrel is the larger of the two species - adult females can weigh between 480 – 720g and males 500 – 650g (Lawton 1999) - and is distinguishable from the red squirrel by its brown-grey coat and lack of ear tufts.

Fifteen surveys have been carried out on the distribution of squirrels in Ireland; the first field based survey took place in 1968 in response to damage caused to trees by squirrels in commercial plantations (NPWS 1968). Carey *et al.* (2007) carried out the most recent survey of squirrels in Ireland (Figure 1 displays the expansion of the grey squirrel range up to 1997). The grey squirrel's range includes 26 of the 32 counties (except for Cork, Kerry, Clare, Galway, Mayo and Sligo (Figure 2)). The average rate of spread from the site of release has been approximately 3km/year. Grey squirrels have advanced into counties Wexford and Wicklow at a rate of 50km in the past 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.

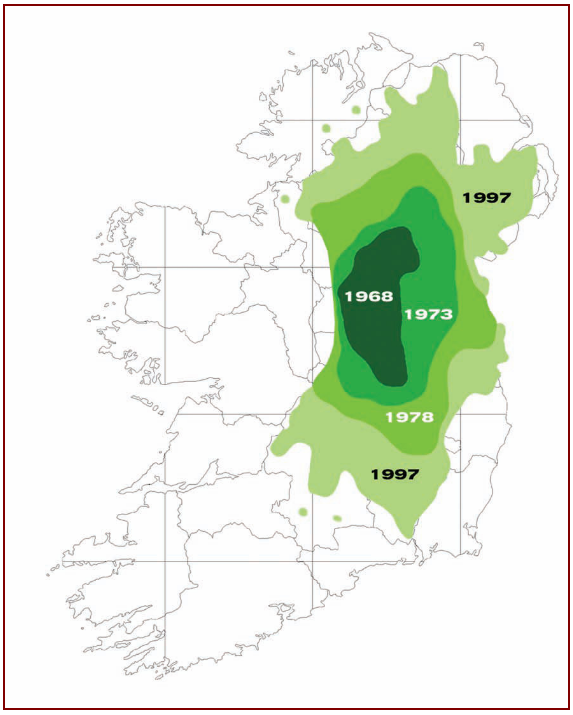

Figure 1: Spread of the grey squirrel following its original introduction to Co Longford (Carey *et al.* 2007)

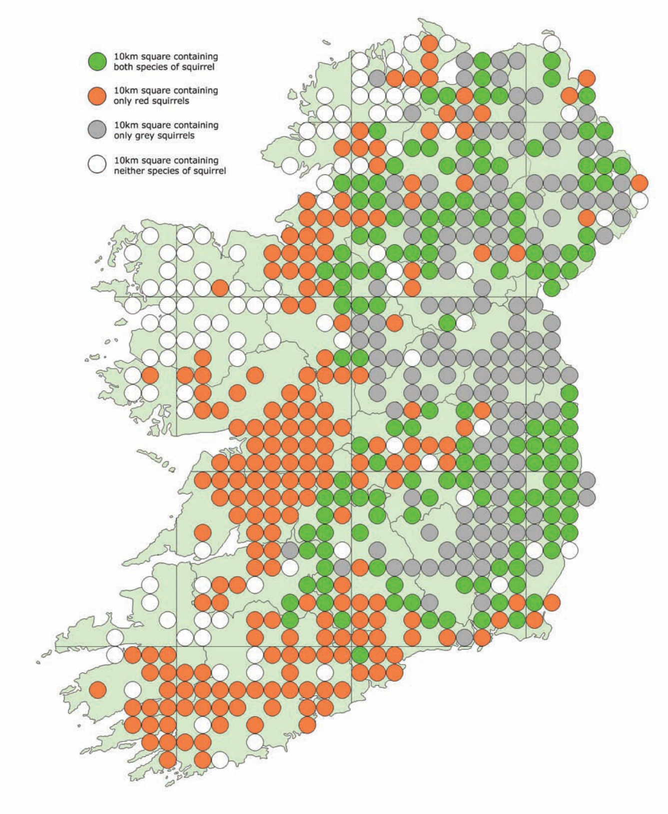

Figure 2: Squirrel distribution in Ireland showing areas with grey squirrels only (grey), with red squirrels only (red), with both species of squirrel (green) and with neither species present (white) (Carey *et al.* 2007)

The river Shannon has acted as a natural barrier preventing the grey squirrel in advancing into the west, however, there have been reports of breaches in three locations in counties Leitrim and Roscommon in the most recent survey, but other earlier reports also. 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 have 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. 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 remain inaccessible to the populations due to lack of dispersal corridors to reach them.

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.

In Britain the grey squirrel was introduced from America in the late 19th century and 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. Competition 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 probably will 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 (Skelcher 1997) with the two species show similar dietary preferences (MacKinnon 1978). 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). Another factor is the grey squirrel's ability to exploit acorns earlier in the season (Kenward & Hodder 1998) at a time when the tannin levels are indigestible to the red squirrel. In broadleaved woodland, allopatric 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 population density by interspecific competition acting primarily during the growth phase of the red squirrel (juveniles and sub-adults), causing reduced growth and hence smaller adult size in sympatry with greys (Wauters *et al.* 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 was attributed to the introduction of the grey squirrel (Sainsbury & Gurnell 1995), however, diseased reds are rarely observed apart from localised epidemics (Reynolds 1985). 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 (McInnes *et al.* 2009) no infected squirrels had been found in Scotland but reports now suggest that the virus has appeared in south Scotland. To date, there have been no reports of SQPV in red squirrels in Ireland, however, the antibodies have been found in grey squirrel populations in Northern Ireland (McKay *et al.* 2004). 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.

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), *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.

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.

Translocation

Translocation is the intentional release of animals to the wild in an attempt to establish, re-establish or augment a population (Griffith *et al*. 1989). Translocation is used as a tool for the management of the natural and man-made environment, which can bring great benefits to natural biological systems and to 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 habitat at release sites, genetic out-breeding and hybridisation, impact on donor sites, unwanted competition and/or out-break of disease and predation. Therefore the IUCN have published stringent guidelines to follow when undertaking translocation (IUCN, 1998).

Many studies have undertaken the use of translocation in the conservation of the target species, such as the re-introduction of the golden eagle (*Aqulla chrysaetos*) in Ireland (O'Toole *et al*. 2002), the hazel dormouse (*Muscardinus avellanarius*) in the UK (Bright & Morris 1994), tuatara lizards (*Sphenodon guntheri*) in New Zealand (Nelson *et al*. 2002) or the field cricket (*Gryllus campestris*) in northern Germany (Hochkirch *et al.* 2008). These studies are examples of the use of translocation as a means to re-introduce an extinct species, to re-establish a threatened species or to aid in the dispersal of the species into 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 habitats have been restored or recovered (Griffith *et al*. 1989).

There have been seven main translocation studies of red squirrels carried out in the past 25 years in Britain and Europe. Bertram & Moltu (1986) re-introduced red squirrels to Regent's Park, London, an area in which the grey squirrel had become established. A soft release technique (using a release enclosure to acclimatise squirrels to the woodland) was used and selective-species feeding hoppers were designed to allow reds-only access to the supplementary food. However, although in the short term the red squirrels seemed to establish themselves, the translocation failed in the long term as the squirrels could not compete with the already established grey squirrel population.

Venning *et al*. (1997) carried out four translocations in Thetford Forest, East Anglia, in the UK. Each one helped in refining the methodologies for translocation. A soft-release method was adopted using a release enclosure to acclimatise squirrels to the woodland. Of the four studies, three succeeded and one failed due to SQPV, highlighting the need for awareness of squirrel general health and fitness during translocation.

Red squirrels were re-introduced to Parco Groane, northern Italy by Fornasari *et al*. (1997). Suitability of both the donor and release sites were assessed before translocation took place and population estimates were made to determine the impact of removing individuals from the source site. The availability of natural food sources was also assessed at the release site and squirrels were released in a hard release programme (immediate release of squirrels into the woodland). The translocation was a success with all wooded habitats being inhabited by squirrels.

Wauters, Somers & Dhondt (1997) translocated red squirrels into a park in Antwerp, Belgium, with post-translocation monitoring continuing for six years thereafter. Squirrels were removed from three source sites and released in a hard release method; supplementary feeding was used in order to help the squirrels to become established. Although mortality was high up to the first breeding season the population survived and grew steadily until reaching the carrying capacity of the habitat.

Another red squirrel translocation, to conifer woods at Poole Harbour, Dorset, England (Kenward & Hodder 1988), was to an area where grey squirrel populations were established. Individuals were radio tracked in order to assess the settlement patterns, however, none of the 14 red squirrels released survived past four months, due to predation, disease and loss of weight.

Jackson *et al*. (1998 & 2002) undertook two translocations, one of which was undertaken at Colwyn Bay, Wales and the other on Anglesey Island, Wales. Grey squirrels were present at both sites and both studies used a soft release technique. However, the translocation at Colwyn Bay used captive bred individuals, which contracted SQPV and ultimately caused the failure of the translocation. The Anglesey translocation was a success with a breeding population present during post-release monitoring.

In total, therefore, ten red squirrel translocations have been reported, with four ultimately failing. Two of these failures were in woods with grey squirrels present and squirrel pox virus was considered the cause of failure of a third. Both grey squirrels and the disease were implicated in the fourth. Each translocation advanced the methodology for the technique, with recommendations being taken on board in subsequent translocations.

During each translocation, the practicalities of making it a success were considered. Five of the projects used a soft-release method and two used hard release. Each of the soft release programs used a different sized enclosure and the amount of time the squirrels remained in the pen varied. There was no correlation between release method used and success. In theory, using a soft release ensures the translocated animal's original site fidelity is lost meaning they are less likely to flee the new area upon release. They also become accustomed to feeding stations and thus when released recognise supplementary feeding platforms which can continue to be used for several months. However, soft release may cause problems when animals become reluctant to leave the release enclosure (Venning *et al*. 1997) or if disease is an issue. The use of soft release may still be an advantage as it can help to impress on the public the importance and scope of the project, and also increase the survival prospects of individual squirrels, if not the whole population.

Jackson *et al*. (2002) and Venning *et al*. (1997) included important information on the selection of donor and release sites, logistics on transportation, releasing and the monitoring of squirrels. Venning *et al*. (1997) set targets for survival and success, with an initial target of >75% survival in the enclosures and further survival of 50% through to the following year's breeding season. During the soft releases the red squirrels were provided with excess food in the enclosures and supplementary food was provided in the woodland surrounding the release site. Squirrels utilised supplementary feeders in all studies (except in the successful hard release translocation in N. Italy (Fornasari *et al.* 1997), where no supplementary food was made available). In the Bertram & Moultu (1986) study where grey squirrels were also present, selective hoppers were used, designed so only red squirrels could access food. In general, supplementary feeding allows a strong increase in recruitment, primarily of juveniles (Klenner & Krebs 1991). However, the available seed crop in the woods remains an important source of nutrition for red squirrels even where supplementary feed is provided (Shuttleworth 1997).

Up to 2005, no red squirrel translocations had taken place in Ireland since the 18th century (Barrington 1880). Other animal translocations had included red deer (*Cervus elaphus*), which became very rare in the 19th century in county Donegal and were re-introduced from Britain and private collections in Down and Wicklow (de Buitlear 1993). Red deer were also translocated in another study from Killarney to Connemara National Park (Fairley *et al*. 1995). The pine marten (*Martes martes*) was translocated from counties Mayo and Clare to Killarney National Park by the NPWS in the mid 1980s after persecution had severely reduced its range in Ireland (Lynch *et al*. 2006). The most recent translocations have involved large birds of prey (e.g. O'Toole *et al.* 2002).

Translocation of red squirrels to Derryclare wood, Connemara

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

The donor site chosen was Portumna Forest Park, Co Galway, a mixed wood dominated by Scots pine *Pinus sylvestris* and Norway spruce *Picea abies*. In keeping with the IUCN guidelines for re-introductions (IUCN 1998) the donor site was investigated in order to make sure that removal of animals would not endanger the population. Through direct and indirect field techniques it was found that the woodland contained a population with a density of 0.93 squirrels/ha (giving a total population estimate of 244 squirrels) with no signs of disease. Monitoring of the population continued post-removal; it recovered quickly from the removal of relatively few (19) squirrels.

The recipient woodland was sourced from a shortlist of five potential woodlands in the Connemara area. 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 of the grey squirrel 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 (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 and 3.9 m high and enclosed with 25mm x 25mm, 1.6mm gauge galvanised welded mesh walls and roofs. They were equipped with branches, platforms containing food and water, four nest boxes and supplementary feeders. In total, and under NPWS licence, 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 batches with no more than five squirrels in an enclosure at any one time. They were held for three to ten weeks before being released.

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 radio-tracking and live-trapping to assess settlement patterns and monitor the 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%). 68.4% (13 of 19 squirrels) survived to the following breeding season (against a target of 50%). By May 2006, 11 of 12 surviving squirrels were reproductively active and at least 9 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 the supplementary feeders. Only two squirrels established initial home ranges which were completely separate from the rest. The main habitat used by squirrels outside the deciduous region was lodgepole pine *Pinus contorta* (Poole & Lawton 2009).

Translocation of red squirrels to Belleek Forest Park, Ballina, Co Mayo

Following on from the success of the translocation of red squirrels to Derryclare, a second translocation was initiated in 2006.

An assessment of Belleek Forest Park's suitability for 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). The report found that Belleek woodland is a very isolated woodland, the nearest substantial block of woodland is 13km south, 15 km west or 16 km east. It resides alongside the river Moy and Ballina town is situated to the south of the wood. Although isolated the habitat offered was deemed highly suitable and a carrying capacity of approximately 65 red squirrels was estimated for the woodland. Furthermore it was considered that the education potential and knowledge gained on translocations would be worthwhile for conservation benefits.

Once again, the source of red squirrels was an important factor in the translocation process as the removal of animals from donor sites must have no impact on the source population (Lawton 2006, IUCN 1998). It was considered that translocated squirrels should be Irish and following findings on the origins of Irish red squirrels (Finnegan *et al*. 2008) they should be taken from the west of Ireland. Such considerations would ensure genetic integrity of squirrel populations in the region and also satisfy logistic requirements, that is reducing transportation time and the risk of stress related disorders. Squirrels sourced from the west of Ireland, which is free of grey squirrels, also have not been exposed to the SQPV, a major factor in determining the success or otherwise of a red squirrel translocation.

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 translocation began in March 2007 by Dr Laura Finnegan (2007) under NPWS contract (D/C/214) and licence; this was to become phase one of a three phase translocation. Finnegan chose two potential donor, or source, sites based on their size (a larger source site would be less likely to be impacted by the translocation) and distance (within 50km) from Belleek Forest Park. The first woodland chosen was Lough Key Forest Park (G825 075), just outside Boyle, Co Roscommon. It is approximately 200ha of mixed wood, managed as an amenity forest. The second woodland chosen was Union wood, Ballysodare, Co Sligo (G685 285). It is approximately 300ha of mainly sitka spruce (*Pinus sitchensis*) and is managed for commercial purposes. The work was carried out with the permission and cooperation of the woodland owners Coillte Teoranta.

The source woodlands were assessed using mark recapture techniques through live trapping. In the first phase of translocation, five individuals, two males and three females were moved to Belleek Forest Park.

According to models conducted by Poole (2007) a minimum of 14 squirrels are required for translocation as seven females are required at the start of the breeding season. The current project was commissioned by the National Parks and Wildlife Service to complete the Belleek Forest Park translocation, as well as carry out post-translocation monitoring in both Belleek Forest Park, and Derryclare wood.

Aims & 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). In order to understand this, the behaviour and survival of released animals needs to be monitored intensively (IUCN 1998) and the effects of translocation must be monitored and reported on (Hodder and Bullock 1997).

This project aimed to investigate the post-translocation settlement, spread and ecology of the red squirrel populations at Derryclare wood and Belleek Forest Park.

The first task was to complete the translocation of red squirrels to Belleek Forest Park, Ballina, Co Mayo. This was to develop into a post-release monitoring phase which tracked changes in the population as it became established. The same criteria for success of the Belleek translocation as outlined by Venning *et al*. (1997) and used by Poole (2007) were adopted in the current project:

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

The second task was to re-visit the site at Derryclare woodland, Connemara, Co Galway and assess the status of the red squirrel population two years after the previous study had come to an end. The population was then monitored for a further three years to observe changes and determine the long-term prospects for the population. Population size, density, range, dispersal, recruitment and individual health are key components to this assessment.

As well as the recipient woodlands, the donor sites were revisited to ensure there was no long-term impact of the translocation on the source populations.

The final aim was to derive recommendations on the use of translocations in the conservation of red squirrels in Ireland and further afield. The overall suitability of the technique together with best practice methodologies were considered.

METHODOLOGY

Belleek Forest Park

Translocation

Belleek Forest Park (G 25 21) is situated alongside the river Moy, approx one mile from Ballina town, Co Mayo (Figure 3). Originally the woodland belonged to the Knox-Gore family whose estate covered almost 750 hectares in 1701 and as a result many historical features can be seen in the woodland today. 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 woodland has been used for recreation by the adjoining town of Ballina and the wider community. Over the last eleven years (1999 – 2010) 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.

The main block of Belleek Forest Park is approximately 61.5ha of mature woodland with 18.1ha of adjacent blocks, giving total available woodland habitat of 79.6ha. The woodland is predominantly coniferous trees (61%), with 30% broadleaf and 9% open space. Norway spruce *Picea abies* is the most dominant species occurring in 25.9ha 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 species group is beech *Fagus sylvatica* which accounts for 7.6ha. 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; some hazel *Corlyus avellana* has also been planted recently. Invasive species such as laurel *Prunus laurocerasus* is found within the woodland but rhododendron *Rhododendron ponticum* has almost been completely removed.

Coillte have devised a management plan to thin certain areas of woodland to promote growth of remaining trees and allow the undergrowth to develop. Saplings will also be planted with squirrel friendly species such as Scots pine and hazel.

Once the source woodlands had been assessed by Finnegan (2007), red squirrels were chosen for translocation. This was based on the condition of the individual. Individuals were chosen by their weight, breeding condition and health and fitness assessment before being moved. Only squirrels with a weight of 210g or greater were translocated, making sure juveniles and potentially unhealthy individuals were not moved; pregnant or lactating females were not considered. All squirrels were marked with a Trovan Passive Integrated Transponder ID-100 PIT tag.

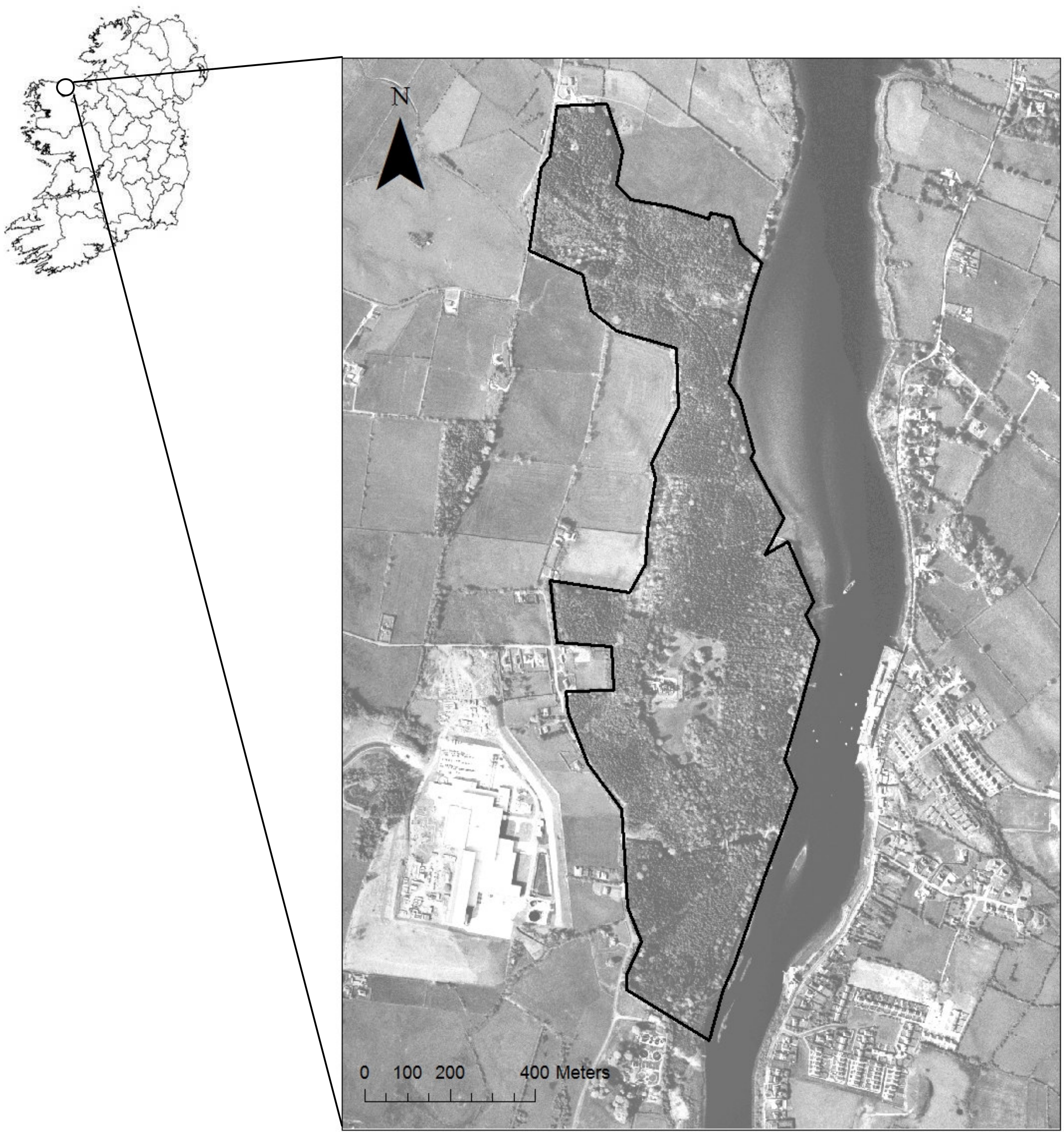

Figure 3: Belleek Forest Park situated to the western bank of the river Moy, approximately one mile from Ballina, Co Mayo.

A soft-release programme as described by Poole & Lawton (2009) and Venning *et al*. (1997) was used. Squirrels were transported from the source wood 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 approximately 10m in height. The wire mesh was buried 30cm under the ground and six nest boxes and a feeding platform were placed inside. A mixture of peanuts, maize, sunflower seeds and some walnuts, hazelnuts and pine cones were provided at all times. Sliced apple and water were also made available and were replenished every two days. Individuals were to be kept in the enclosure for four weeks with no more than five squirrels in the enclosure at any one time.

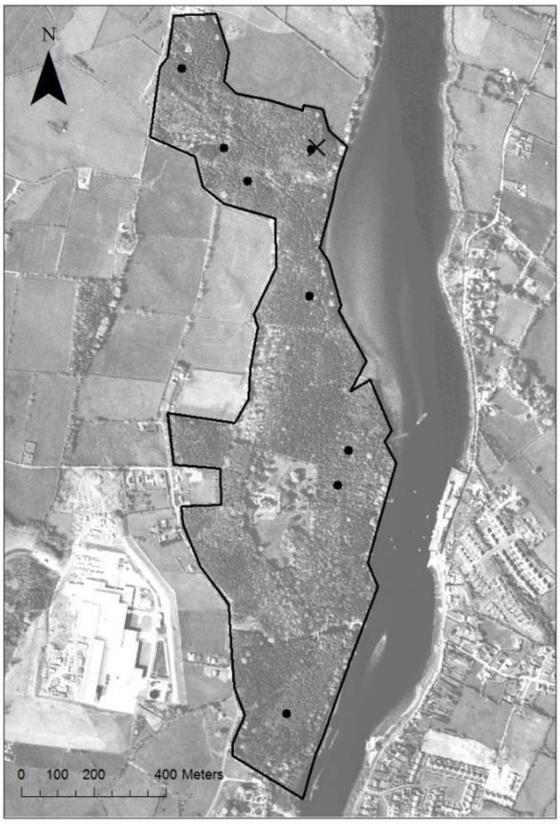

Figure 4 Locations of the enclosure (x) and supplementary feeders (•) at Belleek Forest Park

In the first phase of translocation (Finnegan 2007), five individuals were translocated, with a 2:3 ratio of male:female.

Phase two of the translocation was undertaken in February 2008. During this time four individuals were taken from Lough Key Forest Park (two females and two males).

Phase three of the translocation took place in July 2008, with the movement of six individuals from Lough Key to Belleek (five females and one male).

In total 15 red squirrels were translocated to Belleek Forest Park (Table 1). Eight supplementary feeders were positioned throughout the woodland and were filled with a mix of peanuts, maize and hazelnuts and replenished twice a week.

Post-release monitoring

Monitoring of released animals must be an integral part of any re-introduction programme. Where possible there should be long-term research to determine the changing status of the new population, the need for further releases and identification of the reasons for success or failure of the programme

(IUCN 1987). In order to follow this procedure, post-release monitoring techniques must be used after translocation of the red squirrels is complete.

Post-release monitoring can be conducted using direct (live trapping and radio telemetry) or indirect field techniques (feeding/sighting line transects and hair tube surveys). Other translocation projects have used a combination of direct methods to monitor populations (Wauters, Somers & Dhondt 1997, Kenward & Hodder 1998, Venning *et al.* 1997). These procedures allow health checks to determine whether squirrels have lost weight or show signs of disease during the initial release stages and throughout the study. Settlement patterns after release and establishment within the woodland can be monitored. Later in the study it can provide evidence for breeding and population dynamics. Indirect methods can be used to determine the dispersal of squirrels by investigating feeding signs (Gurnell 1983) on line transects. The density of squirrels can be related to hair left in hair tubes (Garson & Lurz 1998), and the quality of habitat can be measured by the amount of seed fall (Lurz *et al.* 1995, 2000).

Other IUCN guidelines that must be adhered to post-release are possible interventions in veterinary care, supplementary feeding and habitat modification. These can only be instigated if the population has been monitored in the first place. Decisions for revision, rescheduling or discontinuation of the programme can be made if unforeseen circumstances should arise.

In April 2008 after the second phase of translocation of the red squirrels was complete, the initial settlement patterns of six individuals were monitored via radio tracking. Three females and three males were chosen. Each squirrel was fitted with a collar approximately 5.3-6.6g in weight with an estimated lifespan of 230 days (SOM-2190, Wildlife Materials International Illinois, USA). Each collar had a specific frequency by which that individual could be recognised.

Fixes were recorded, with a gap of at least three hours between fixes to avoid auto-correlation, until 30 fixes in total were gathered for each individual. Signals were picked up using a TRX-1000s receiver and Yagi antenna. The squirrel's position was recorded using a Garmin Etrex Venture GPS. Individual home ranges and core areas (areas of intensive use within the home range) were analysed using Arcview GIS 9.3 and was presented using peeled minimum convex polygons (MCP) (Bath *et al.* 2006). Core areas were determined by plotting the percentage home range against the percentage of fixes (peeled MCPs).

Eighteen months after the initial radio-tracking was undertaken, another session was conducted in September 2009. Six individuals were fitted with collars, four females and two males. Individuals were collared randomly from those captured during live-trapping sessions.

Nine live trapping sessions were conducted between August 2008 and July 2010. Thirty five traps which were placed at a density of one per hectare around Belleek Forest Park (Figure 5A) and their location marked on a Garmin Extrex GPS. In February 2010, the trapping grid was expanded, through a redistribution of the traps and the addition of two extra traps, to incorporate areas that were previously untrapped (Figure 5B). The traps were of a wire-mesh design and had a wooden base and wooden nest box attached. The traps worked from a treadle system, which snapped the door shut once the occupant had entered the end of the trap. Traps were placed at a height of approximately 1.5 to 2m in a tree (Plate 1) and secured between branches or with rope if necessary. Each trap was baited with a 3:1 mix of whole maize and peanuts and hazelnuts. Visibility of traps to the squirrels was highly important; the yellow maize was placed on top of the nest box, at the entrance of the trap and inside. Hazelnuts were only placed behind the treadle at the end of the trap.

Before each trapping session, each trap was pre-baited three times in a week with the trapping mechanism disarmed. Three or four trapping days were undertaken following the last day of pre-baiting depending on the season and daylight hours available. Each trap was set just after dawn and left for at least four hours before being checked.

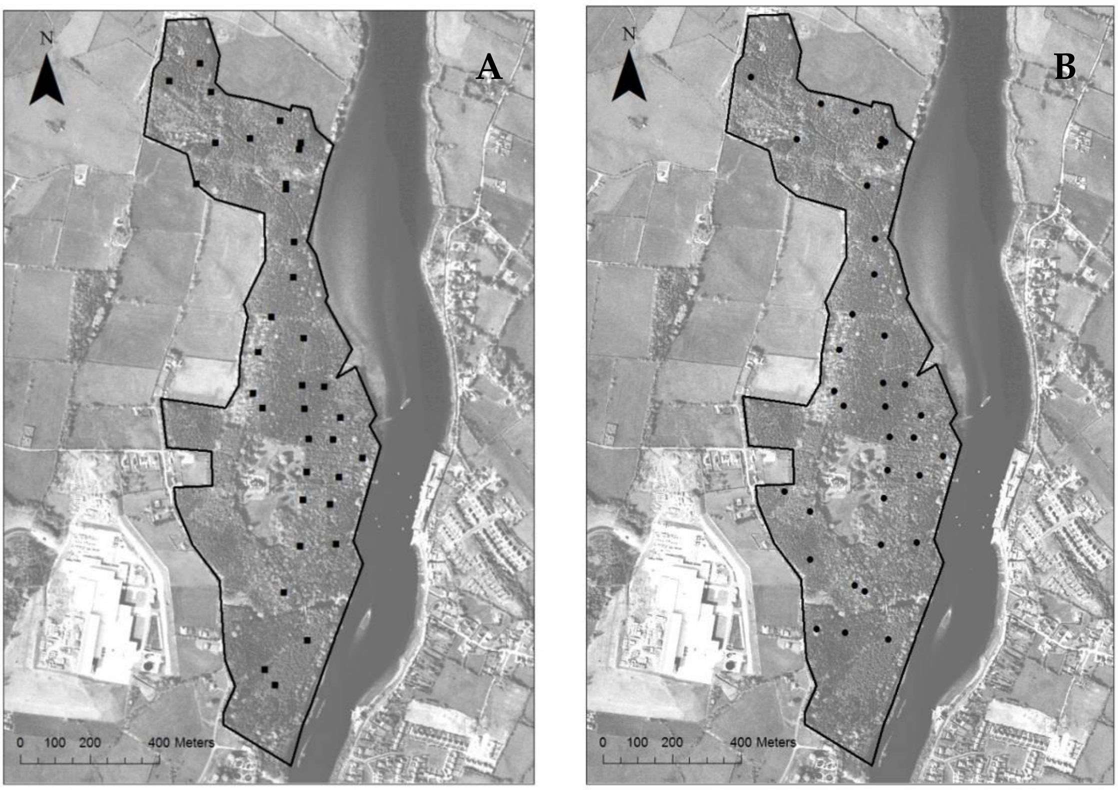

Figure 5: Location of live squirrel traps at Belleek Forest Park; A - August 2008 to November 2009 and B - February 2010 to July 2010

When a squirrel was caught in the trap, it was transferred into a handling cone (Plate 2) by way of a hessian sack. Squirrels were then examined; sex was determined, it was weighed to the nearest five grams using a 500g Pesola precision spring balance and its shin bone length was measured using callipers to the nearest 0.1mm. Each squirrel was marked using a passive integrated transponder (PIT tag) which was injected into the scruff of the neck. When squirrels were re-captured they could be scanned for the presence of a tag using a Trovan PIT tag reader, which then displayed an individual code.

The breeding status for each squirrel was also considered. In males, the size and location of the testes was ascertained. Juvenile and sub-adult males tended to have abdominal testes with no scrotal sac. Adult males had scrotal testes which were judged to be in reproductive condition or not 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- or post-lactation (prominent nipples, no signs of hair loss)).

Plate 1: Live squirrel trap secured in branches of a tree

Plate 2: Red squirrel held safely and securely in a handling cone

Population estimates were made using a number of different techniques based on the mark-recapture data collected. When using these techniques there are a number of assumptions that are made: all marks are permanent; being captured, handled and marked has no effect on an individual's chance of being recaptured, dying or emigrating; all individuals have an equal chance of being caught and that sampling periods are short in relation to total time (where the model does not assume that there is birth, death, emigration or immigration) (Begon, 1979).

The first estimate used was 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).

As each trapping period in this study lasted for three to four days, the final day trapping was taken as the second sample and the earlier days were taken as the first sample. This means that a separate estimate was derived for each month trapping 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 second technique used was the Minimum Number Present (MNP). This calculates the animals known to be present in the wood at any one time, and is based on the individuals captured in each 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 third model 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.

These population estimates are then 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.

In 2009 and 2010, the amount of natural resources available to the red squirrels was assessed. This was studied using eleven line transects placed randomly throughout the Forest Park. Each transect consisted of three 1m^2 quadrats placed on a 40 metre line approximately 20 metres apart. Quadrats were marked using wooden stakes painted white in order to locate them easily each session. The quadrats were also marked with a Garmin GPS in case stakes became lost. Each trapping month, fallen seeds were counted on each quadrat and debris removed. Tree seeds such as beech mast, ash, sycamore and pine cones (Scots pine, Norway spruce, sitka spruce and larch) were counted; cones eaten by squirrels were also recorded. These values were then extrapolated to give the overall seed available and eaten throughout the Forest Park. Although feeding signs were recognisable in the cone 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 woodland could not be fully quantified. However, the seasonality of tree seed was assessed and the amount available in the woodland was recorded.

Supplementary feeding was on-going at this time by members of the Belleek Forest Park Enhancement Committee. However, in June 2010 feeding was phased out in order to allow the red squirrels to rely on the natural resources of the woodland.

Derryclare Wood

Derryclare wood (OS: L 83 50) is situated in Connemara, west Co Galway (Figure 6). The woodland resides alongside Lough Inagh and Lough Derryclare and at the foot of the mountain ridge Derryclare-Bencorr, one of the twelve pins. Derryclare consists of a 789ha Coillte-owned commercial conifer forest and a 19ha broadleaf Nature Reserve owned by the National Parks and Wildlife Service.

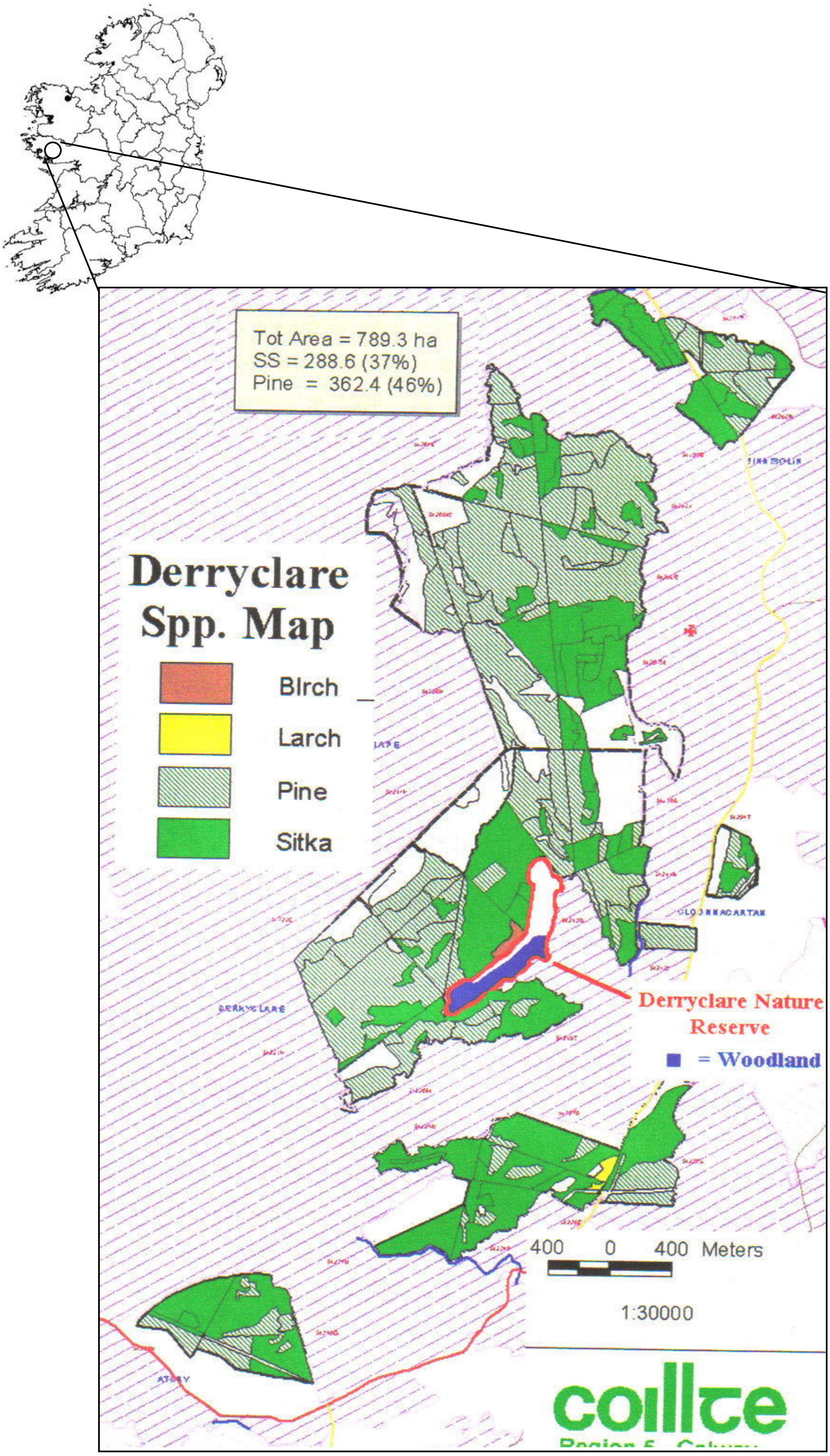

Figure 6: Derryclare wood including the Nature Reserve and tree species composition (Coillte, 2004)

The conifer forest is mainly dominated by lodgepole pine *Pinus contorta* (63%) and sitka spruce *Picea sitchensis* (36%) (Poole & Lawton 2009). The 789ha forest has a 570ha area contained in one large block which adjoins the Nature Reserve. Of the 570ha, 276ha are lodgepole pine and 156ha are sitka spruce; of the remainder 83ha are felled, 49ha are bare and 6ha are other tree species. The commercial forest has a well managed felling plan with a variable age structure.

The Nature Reserve is made up of 8ha of wooded area and 11ha of pond, wet moorland and lake shore habitats. 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, Quercus robur*, Ash *Fraxinus excelsior*, birch *Betula* sp. and hazel *Corylus avellana*. The Nature Reserve has developed over the last 200 years and is protected under Article 2, Section 15 of the Wildlife Act 1976. The oldest oak tree recorded was given an approximate age of 148 years (Fahy *et al*. 1999).

The Nature Reserve was the site of release for the 19 red squirrels in 2005 during the first translocation of red squirrels in Ireland (Poole 2007).

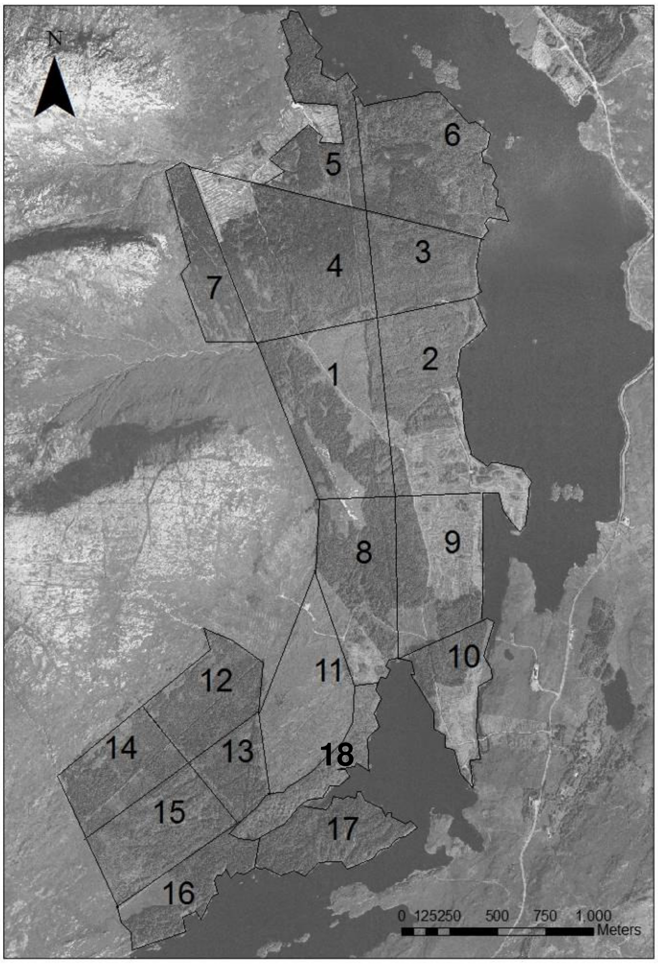

Figure 7: Derryclare wood divided into the sections used in the baseline line transect survey.

In May 2008, a baseline survey of the woodland was conducted to examine changes to the squirrel population since the end of Poole's study in 2006. The 789.3 hectares were divided into different sections, 18 blocks in total (Figure 4.1). Each block was examined and searched for the presence of red squirrels, using feeding signs or sightings. The Nature Reserve (block 18) was included, as this area was the site of release during the translocation.

In those areas identified as positive for squirrel presence during the baseline survey, a trapping grid of 40 traps was set out (Figure 8, Phase A). Traps were placed at one per hectare and incorporated the Nature Reserve and the immediate surrounding coniferous areas. The trapping procedure was carried out as described above for Belleek Forest Park. The number of traps was later reduced to 33, for logistical reasons.

Figure 8: Trapping grid incorporating the Nature Reserve and surrounding coniferous woodland (Phase A)

In March 2010, the trapping grid was adjusted to incorporate other areas of the woodland (Figure 9, Phase B). Twenty traps were kept in place on the original trapping grid and twenty were placed in new areas of woodland.

Figure 9: New trapping grid incorporating areas that red squirrels have dispersed in to (Phase B)

As Derryclare is a commercial woodland clear-felling is an on-going process. However, operations are carried out by Coillte with regeneration plans and comprehensive reports. Since the introduction of the red squirrels to Derryclare approximately 72 hectares have been clear-felled (Forest management report). However, this has not affected the trapping grid. Population estimates were converted into population density as described for Belleek Forest Park.

Radio telemetry was undertaken in March and April 2009. The methods were carried out as described 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 the difficulty in traversing it that gathering the fixes needed to investigate home range was not possible in a reasonable amount of time. 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.

Hair tube surveys were conducted in two areas adjacent to the trapping grid. They were made from 300mm lengths of 65 x 65mm 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 $1cm^2$ patches of strong glue. Tubes were secured to the trees at about head height on suitable branches at the trunk with coloured twine (Plate 3).

Plate 3: Squirrel hair tube

Each tube was baited with a 3:1 mix of maize to peanuts. Bait was placed on the top of the tube to attract the squirrel down to the tube and four hazelnuts were placed inside to entice the squirrel in. Hair tubes were then 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 area 12 (Figure 7). Twenty-four tubes were placed at intersections of a grid at 100m apart. After examination of squirrel dispersal a second survey took place in July 2009 in area 8 (Figure 7). Again 24 hair tubes were placed out but at a density of two per hectare.

Hairs were removed from the glue squares by soaking them in vegetable oil, as this has been found to help in removing the hairs from the glue without damaging them. Hairs were then 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.

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 the gelatine had hardened. The hairs were then removed using 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 4).

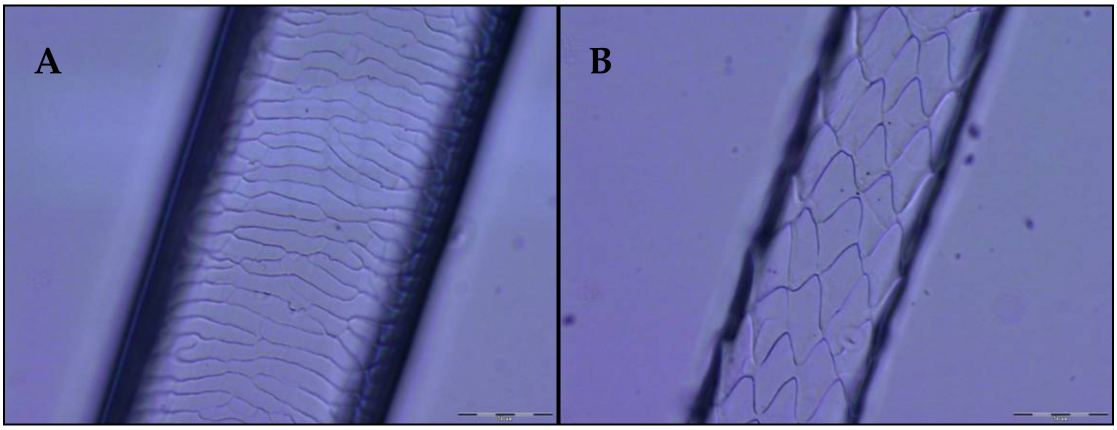

Plate 4: Impressions in gelatine left by red squirrel hair shield (A) and shaft (B) (as viewed under x400 magnification)

The proportion of hair tubes used by squirrels was investigated to estimate the density of the squirrels in these sections of Derryclare woodland. Calculations were made using the following equation adapted from Garson and Lurz (1998).

$$\frac{(0.955 \times \text{No. of tubes used}) - 0.77}{\text{No. of tubes set out}}$$

In the case of other species of mammals entering the hair tube, it was assumed that such a hair tube was only available to red squirrels on average for half the sampling time (one week) and therefore that tube was counted as half a tube. Since other animals entering the tubes interfere with the bait and perhaps leave discouraging scents behind it was assumed that a squirrel would not visit a tube after another mammal. This was taken into account when calculating the density of the squirrels.

Up to this point hair tubes had been used to investigate dispersal of the red squirrels. In order to examine a larger area in a shorter period of time, line transects were used.

A transect of 50m² was walked, one transect for every four hectares (Gurnell, Lurz & Pepper 2001). The length of each transect was measured using a 50m tape and the width with a metre stick (Plate 5). Along each transect, all lodgepole pine and sitka spruce cones were identified and counted. Cones eaten by squirrels were taken as a sign for red squirrel presence in that area. In total nine transects were conducted, three in section 1, three in section 4 and three along the border of sections 1 and 2 (Figure 7). Cones consumed by squirrels were counted and information on energy value per unit area was estimated, this was then converted into squirrel density.

Plate 5. Lodgepole pine cone (A), whole (top) and eaten by squirrel (bottom) and typical line transect (B), measured by 50m tape and metre stick

Line transects were also used to assess food availability and energy consumption in the coniferous areas of Derryclare woodland in 2008 and 2009.

In 2008, this was undertaken by an undergraduate in their degree year (Emma Sheehy B.Sc). Thirty-one transects were examined along 50m x 1m 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 100m distance from other transect locations.

Information on food availability and consumption along transects (1550m²) was then extrapolated to the entire survey area (670,000m²). The energy content of a lodgepole pine cone seed was obtained from Smith 1968 and Gurnell *et al*. 2001. The amount of seeds available to 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.

In 2009, the study was repeated. On this occasion, ten transects were conducted, one for every four hectares (Gurnell, Lurz & Pepper 2001), covering approximately the trapping area. These transects covered an area of 500m^2 (0.05 ha) and were not conducted in areas that did not contain squirrels.

Donor Site Monitoring

Assessments of red squirrels in the donor sites was conducted using the indirect method of hair tube analysis (see above).

In 2009, Emily Goldstein, a Masters student in NUI Galway conducted two hair tube surveys in Lough Key Forest Park in June (set A) and July (set B) 2009. In each survey 39 hair tubes were set out corresponding to the locations of the traps during the translocation phase. The results were analysed in relation to habitat type and location.

The main post-translocation investigation of the red squirrel population at Portumna Forest Park was carried out in 2005 (Quinn 2005) in conjunction with Poole's study. In the current study, hair tubes were set out in August 2010 (30 hair tubes), and again in October 2010 (18 hair tubes).

Union Wood was only used as a source of one red squirrel (during the first phase of the Belleek translocation). The forest manager was approached for information regarding the red squirrels in Union Wood after that removal.

RESULTS

Belleek Forest Park

Translocation

Table 1 displays the 15 red squirrels translocated to Belleek Forest Park, 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.

The soft release technique did not succeed as it became apparent that squirrels were able to escape the enclosure through the roof of the enclosure. Attempts to fix the enclosure by the BFPEC did not rectify the problem. Due to the failure of the enclosure it is not possible to estimate initial survival, however, 67% of red squirrels translocated were captured in subsequent trapping sessions. Despite the squirrels escaping from the enclosure, individuals continued to use the enclosure, breaking back in again to access the food there. Squirrels were caught in a live trap inside the enclosure on various occasions.

During the first live trapping session (August 2008) 9 translocated individuals were captured (60%), 5 of which were in a breeding condition. One other translocated individual was caught in a later month. Table 2 displays the 9 individuals captured in August 2008 and their breeding condition at that time. During that trapping session 10 juveniles were tagged as offspring of the translocated stock.

Table 1: 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.

Phase	Sex	Weight (g)	Shin bone length (mm)	Donor site	Freq ID: 173...
Phase one	Male	315	64.1	Lough Key	165
Phase one	Female	260	62.8	Lough Key	339
Phase one	Female	320	63.7	Lough Key	265
Phase one	Male	295	68	Union Wood	306
Phase one	Female	280	64	Lough Key	
Phase two	Female	315	69.6	Lough Key	256
Phase two	Male	230	67.5	Lough Key	216
Phase two	Male	230	66.6	Lough Key	
Phase two	Female	260	64.3	Lough Key	
Phase three	Female	265	67.2	Lough Key	
Phase three	Female	270	67.8	Lough Key	
Phase three	Female	275	62	Lough Key	
Phase three	Female	275	66.4	Lough Key	
Phase three	Male	295	66.1	Lough Key	
Phase three	Female	315	69.9	Lough Key	

Table 2: Nine translocated red squirrels recaptured in the first trapping session after completion of translocation.

Phase translocated	Sex	Breeding status
One	Male	Actively reproductive
One	Male	Actively reproductive
One	Female	In oestrus
One	Female	Negative
Two	Male	Actively reproductive
Two	Female	Lactating
Three	Female	Negative
Three	Female	Negative
Three	Female	Negative

Figure 10 shows the core areas of the three females (A) and three males (B) tracked in April 2008. Four of the six squirrels established their core areas to include the release enclosure, which was being supplemented with food at this time. This caused an overlap in both male-male as well as female-male core areas. Two squirrels (216 and 339) established initial home ranges away from the enclosure. However, their core areas did include a supplementary feeder. As well as including the enclosure in its home range, squirrel 165 also extended its range to include a supplementary feeder. Table 3 shows the size of each core area, together with the time spent utilising the core area.

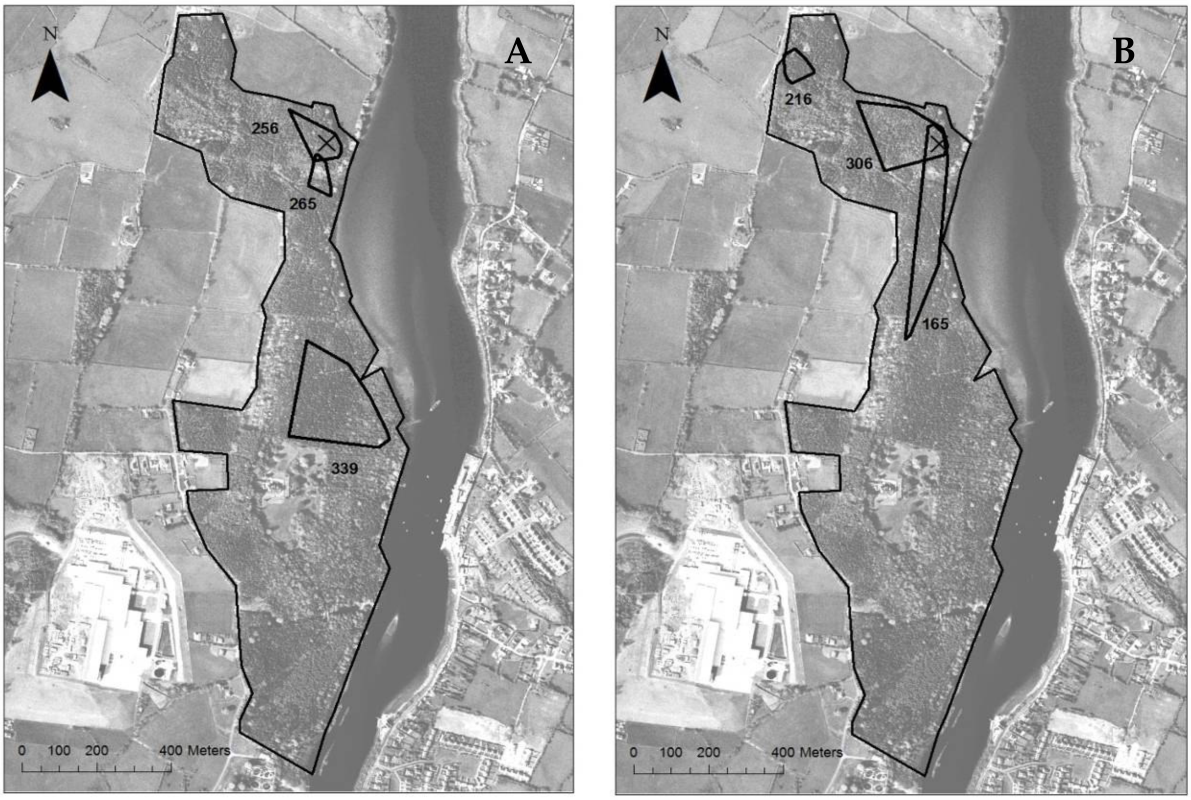

Figure 10: Core areas of six radio-tracked squirrels (A - three females and B - three males) in April 2008 in Belleek Forest Park. The enclosure is marked with an X.

Table 3: Core area size and percentage time spent utilising the core area for radio tracked squirrels in Belleek Forest Park in April 2008

Freq ID 173 ...	Sex	Core area usage (%)	Core area size (ha)
165	Male	65	3.14
216	Male	90	0.49
306	Male	85	2.9
256	Female	60	0.96
265	Female	80	0.97
339	Female	85	4.9

In September 2009, 18 months after the initial radio-tracking was conducted, another tracking session was undertaken. Eight squirrels were fitted with collars, four male and four female. The squirrels were fitted with the collars at random from live-trapping. However, two of the eight collars failed shortly after tracking began, although they had been tested before being fitted. Therefore, six squirrels were tracked, four females and two males. Figure 11 shows the core areas of the four females (A) and the four males (B) from this period. Overlap of core areas is minimal 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 tracked on both occasions (339/429). Analyses of home range showed that this individual maintained its core area in the same general location from session to session. The only change being a slight contraction in the size of its area. Table 4 shows the size of each core area, together with the time spent utilising the core area.

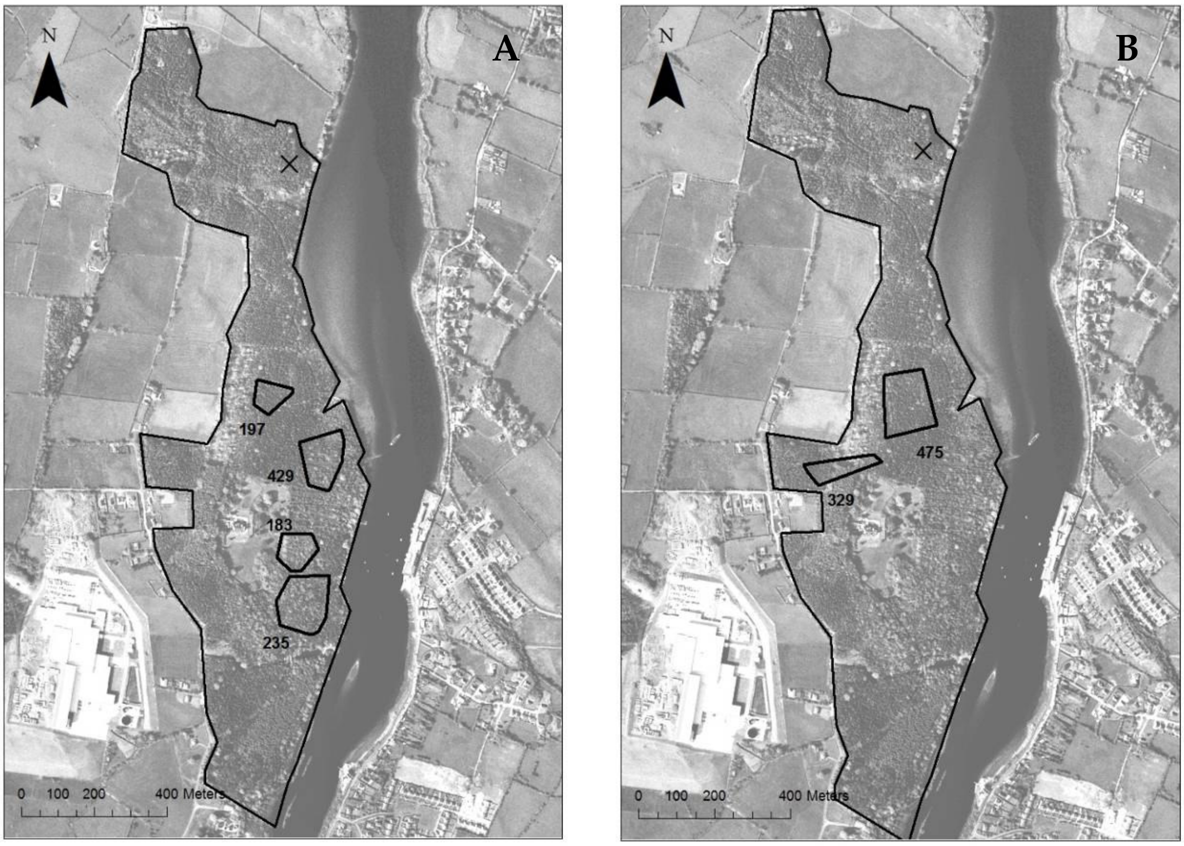

Figure 11: Core areas of six radiotracked squirrels (A - four females and B - two males) in September 2009 in Belleek Forest Park. The enclosure is marked with an X.

Table 4: Core area size and percentage time spent utilising the core area for radio tracked squirrels in Belleek Forest Park in September 2009

Freq ID 173 ...	Sex	Core area usage (%)	Core area size (ha)
235	Female	80	1.33
183	Female	55	0.85
429	Female	60	1.39
197	Female	50	0.61
329	Male	70	0.77
475	Male	60	1.87

There were no significant differences in core area size between sessions or between genders (Tables 3 and 4). Table 5 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 and male-female pairings. There is more male to 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 5: Overlap of core areas of radio tracked squirrels in April 2008 and September 2009 (pair 475 and 197)

Squirrel 1	Squirrel 2	Sex	Area of overlap (ha)	% overlap for squirrel 1	% overlap for squirrel 2
165	306	Male/ Male	0.46	14.6	49.5
165	265	Male/ Female	0.47	14.9	100
165	256	Male/ Female	0.92	29.3	25.4
306	256	Male/ Female	0.98	100	25.7
475	197	Male/ Female	1.01	37.8	100

Post-Release Monitoring

Table 6 and Figure 12 display the population estimates calculated for each trapping session. The Minimum Number Present remains constant reflecting animals known to be alive in each session. The Fisher Ford estimate uses a constant survival rate of individuals; the survival rate between trapping sessions is high (Ø = 0.97). From this value, the annual survival rate is 0.89 (i.e. 89% of squirrels survive from one year to the next). The highest population estimate was in February 2010: 55.62. The

Lincoln Index is given together with 95% confidence intervals, the most erratic of the techniques used, actually drops below the MNP in two months. The upper limits of the confidence interval would be more reliable in this case. Population estimates were converted into population densities by incorporating the size of the trapping grid and boundary strip (Table 6).

Table 5: Population estimates at Belleek Forest Park for each trapping session

Trapping months	MNP	Lincoln Index	Fisher-Ford
August 2008	21	24 ± 6.64	22.1
November 2008	14	13.2 ± 3.59	12.2
January 2009	13	12.5 ± 1.65	13.96
May 2009	15	36 ± 19.7	23.5
September 2009	19	26.67 ± 12.15	35.78
November 2009	16	10 (±N/A)	31.8
February 2010	23	18.6 ± 4.8	55.62
April 2010	21	37.3 ± 20.58	42.8
July 2010	20	40 ± 22.05	45.34

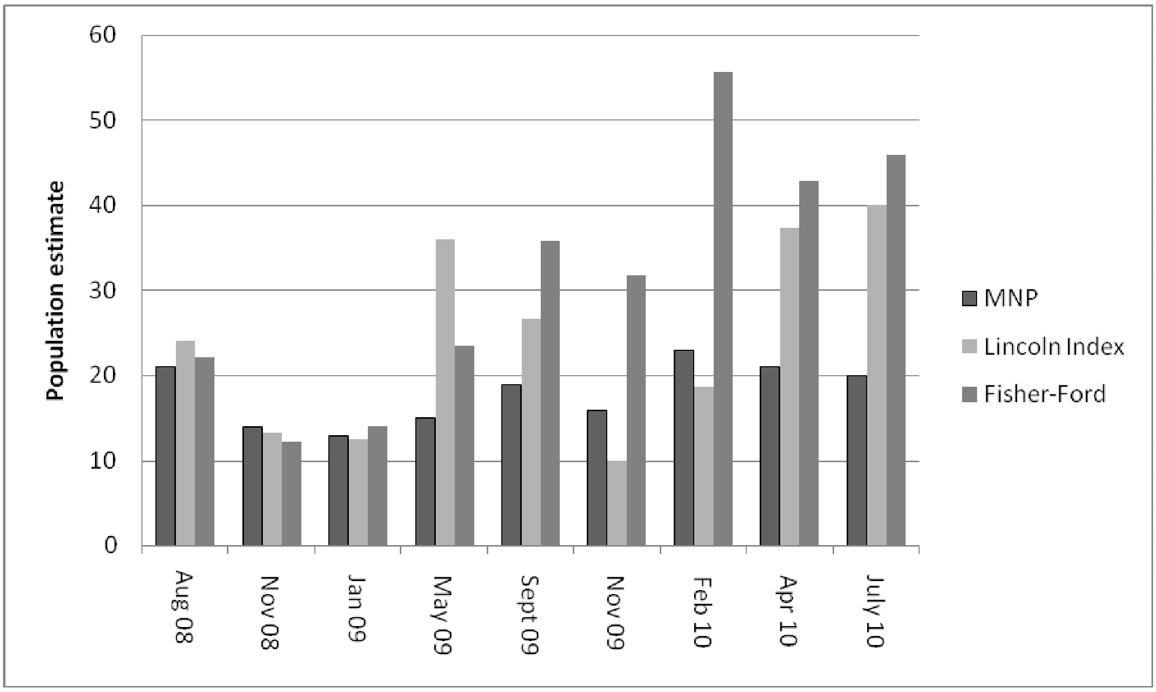

Figure 12: Population estimates at Belleek Forest Park based on live trapping

Table 6: Population density for each trapping session at Belleek Forest Park based on the three population estimates

Trapping months	MNP	Lincoln Index	Fisher-Ford
August 2008	0.39	0.44 ± 0.12	0.41
November 2008	0.26	0.24 ± 0.07	0.23
January 2009	0.24	0.23 ± 0.03	0.26
May 2009	0.28	0.67 ± 0.36	0.44
September 2009	0.35	0.49 ± 0.22	0.66
November 2009	0.3	0.18 (±N/A)	0.59
February 2010	0.37	0.30 ± 0.78	0.9
April 2010	0.34	0.61 ± 0.33	0.7
July 2010	0.33	0.65 ± 0.37	0.74

Trapping success is displayed in Figure 13. In August 2008 during the first trapping session trap success was at its highest (31.5%). Trapping success was at its lowest during November 2009 (7.29%). The average trapping success was calculated for all trapping sessions as 20.7%.

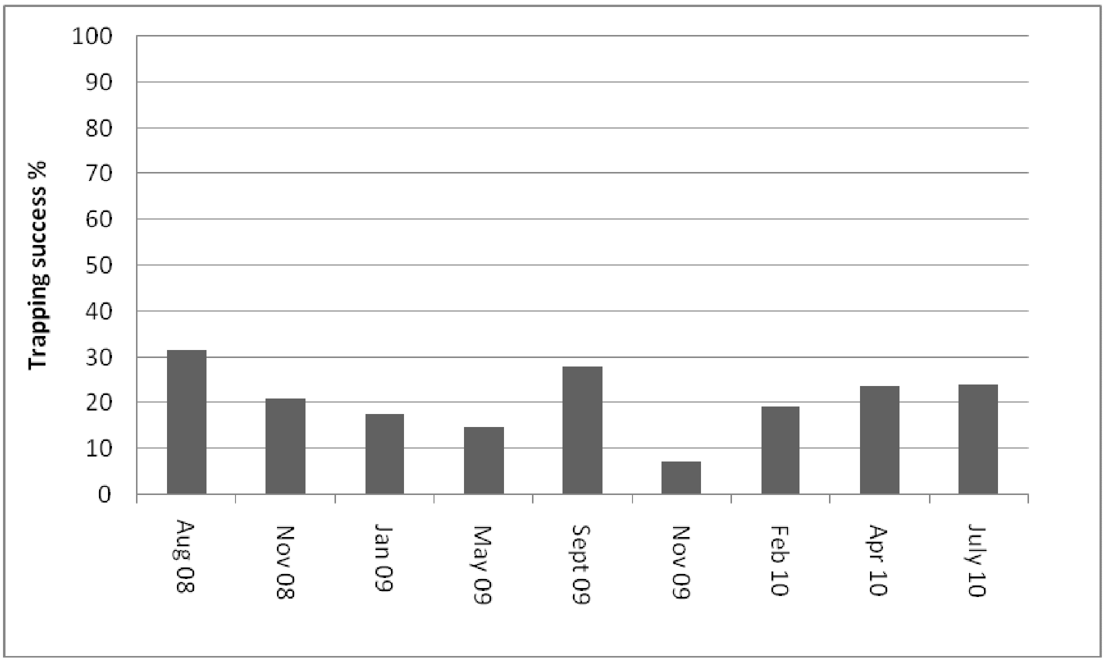

Figure 13: Trapping success rate for each trapping session at Belleek Forest Park

After the second phase of translocation, red squirrels were trapped (March 2008) in order to fit them with radio collars for radio-tracking and to assess their general health. During this trapping period two new offspring were captured. These juveniles were the progeny of the nine individuals translocated from phases one and two and the first of the new recruits to be caught. After translocation had been completed, the first session of post-release monitoring began with live-trapping (August 2008). Of the 15 squirrels translocated nine were recaptured (60% of translocated stock), the weights of these nine were compared with their original weight at translocation and were found to have significantly increased (paired t test, $t = 2.749$, $df = 9$, $p = 0.023$). Ten new recruits were also caught and marked.

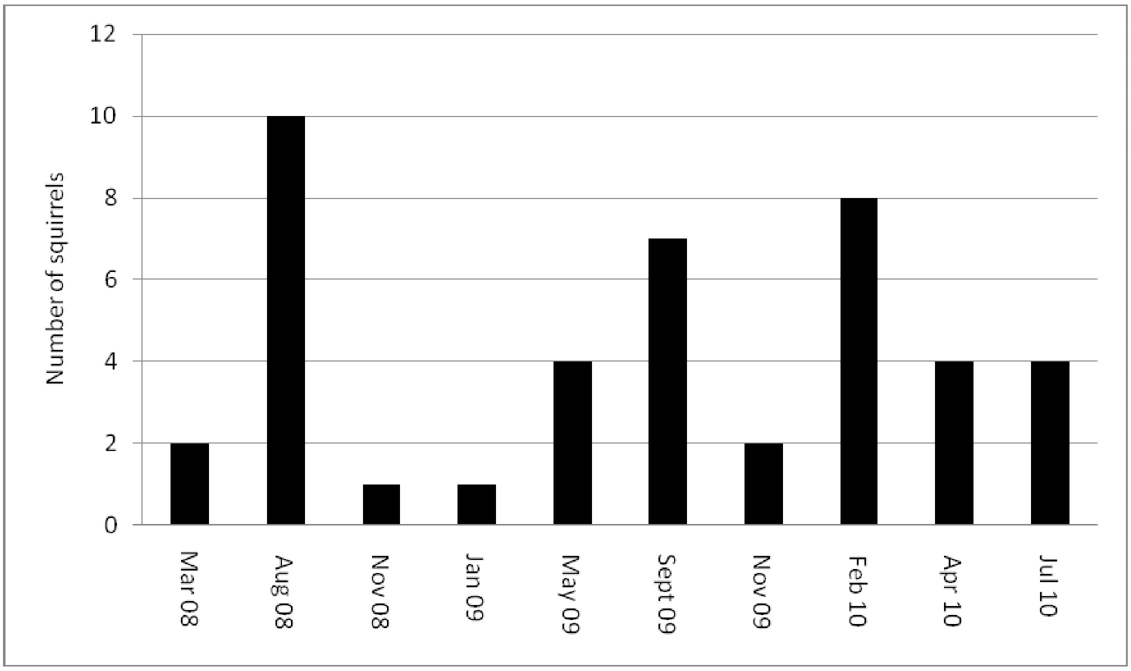

Figure 14: New recruits captured and tagged each trapping session at Belleek Forest Park

Figure 14 displays the number of new recruits in each trapping month. As Belleek Forest Park is isolated from other woodlands, the new recruits tagged in these sessions are offspring born in the park to the new population. The maximum number of new recruits caught was in the initial trapping month of August 2008 (March 2008 being a short session for the sole purpose of attaching radiocollars to squirrels). 50% of all squirrels caught in that month were new individuals. New recruits were tagged in each trapping session irrespective of the time of year; a total of 43 new squirrels were recorded at Belleek Forest Park since the translocation.

Throughout the study changes in mean weight were being monitored (Figure 15); overall mean weight was calculated as 286.2 ± 7.66g. No significant differences were found in the mean weight of all squirrels with respect to season or year. Figure 16 displays male and female mean weights for each trapping session. Male and female Mean weight was tested for significance for both trapping month and animal sex using a two-way ANOVA; no significant difference was found.

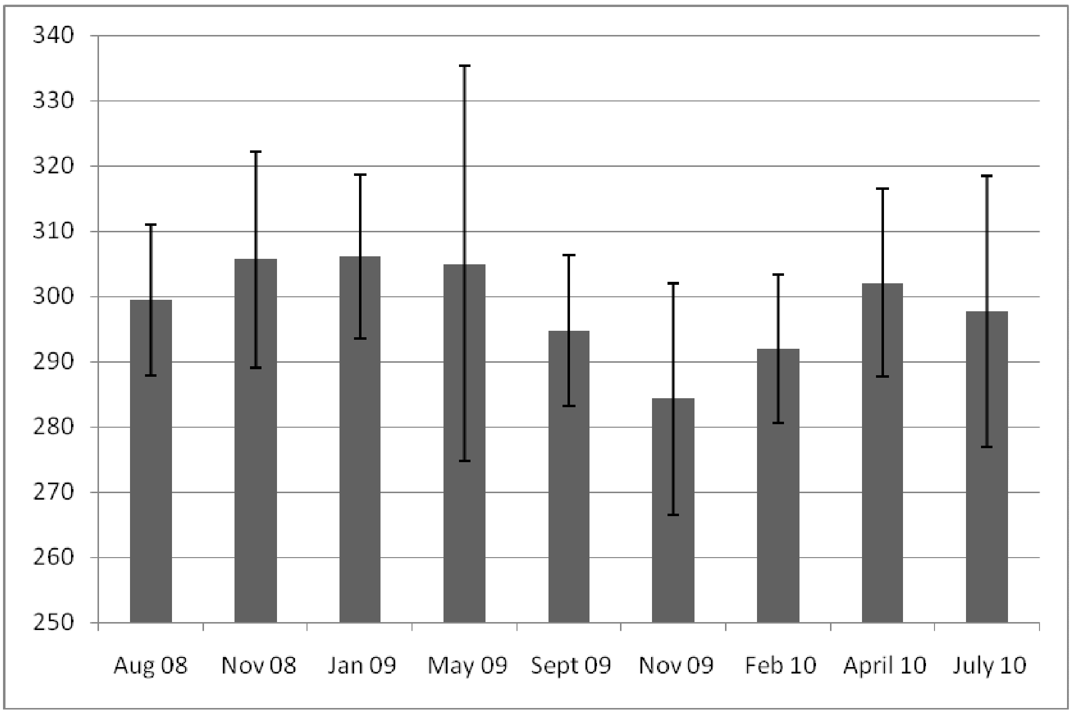

Figure 15: Mean weights for both sexes during trapping sessions at Belleek Forest Park

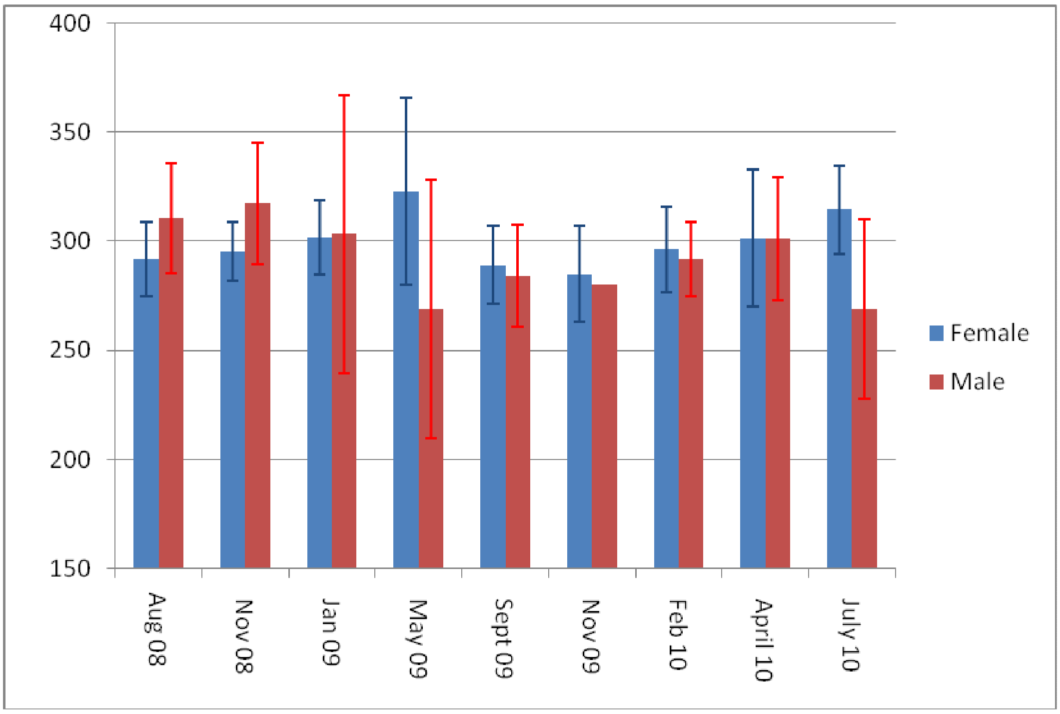

Figure 16: Mean weights of male and female squirrels during trapping sessions at Belleek Forest Park

Body size was investigated, as indicated by shin bone length (Table 7). No significant differences in shin bone length were found between the sexes.

Table 7: Mean shin bone lengths across all trapping sessions at Belleek Forest Park with 95% confidence intervals.

Mean shin bone length (mm)	Mean male shin length (mm)	Mean female shin length (mm)
66.9 ± 0.9	66.6 ± 1.54	67.0 ± 1.08
n = 58	n = 28	n = 30

The regression of shin bone length on body weight for all adult squirrels in each trapping month was calculated, five months were found to have a significant regression (January, May and September 2009, February and July 2010). The regression of all adult squirrels caught during the study was calculated and was found to be significant (weight = 4.164 + 10.07(shin bone length), r^2= 0.243 p = 0.0002) (Figure 17).

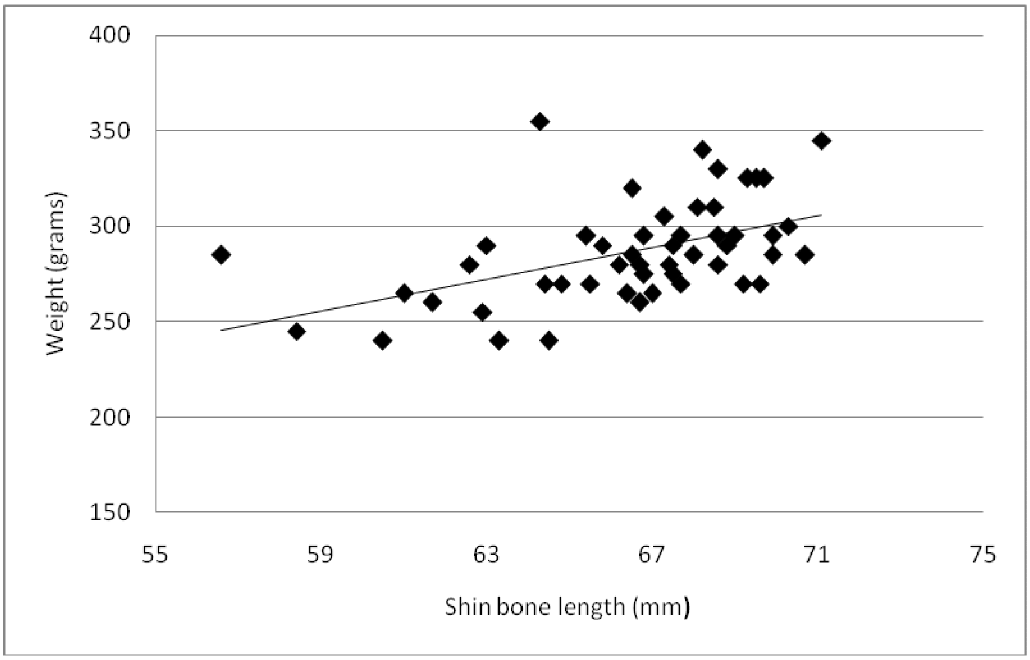

Figure 17: Significant linear regression of adult squirrel body weight and shin bone length at Belleek Forest Park

Of the 15 red squirrels translocated the female to male ratio was 2:1. 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 18).

The breeding condition of female and male red squirrels is displayed in Figures 19 and 20 respectively. This shows the change in status of the population as the seasons progressed. Females found to be in a breeding condition were found in August 2008 (16.7% of total females), May 2009 (85.7%), September 2009 (63.6%), April 2010 (60%) and July 2010 (80%). In each of these months females were found to be in oestrus, rearing young or have recently weaned young. In one case in April 2010 a pregnant squirrel was captured.

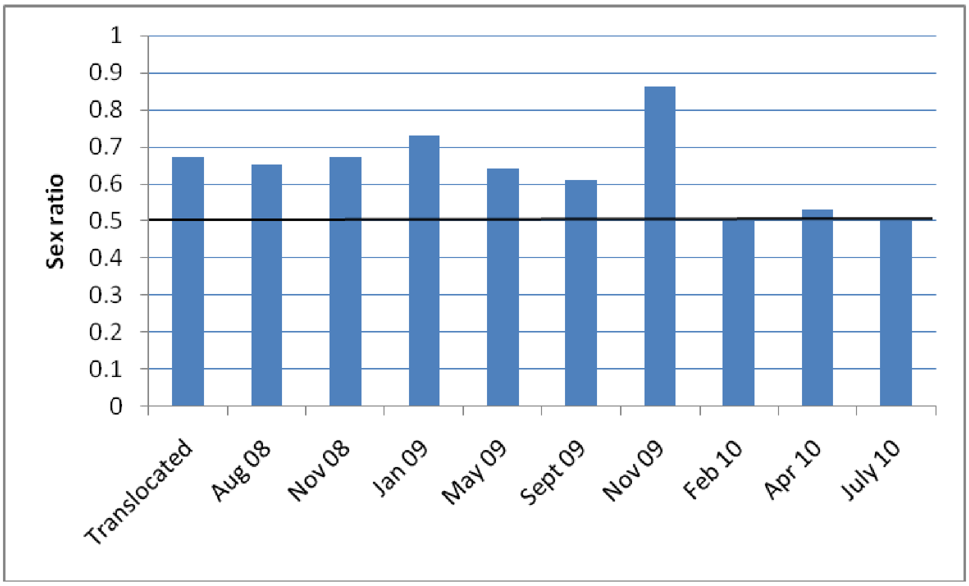

Figure 18: The sex ratio (expressed as proportion of females in the population) caught during the study in Belleek Forest Park

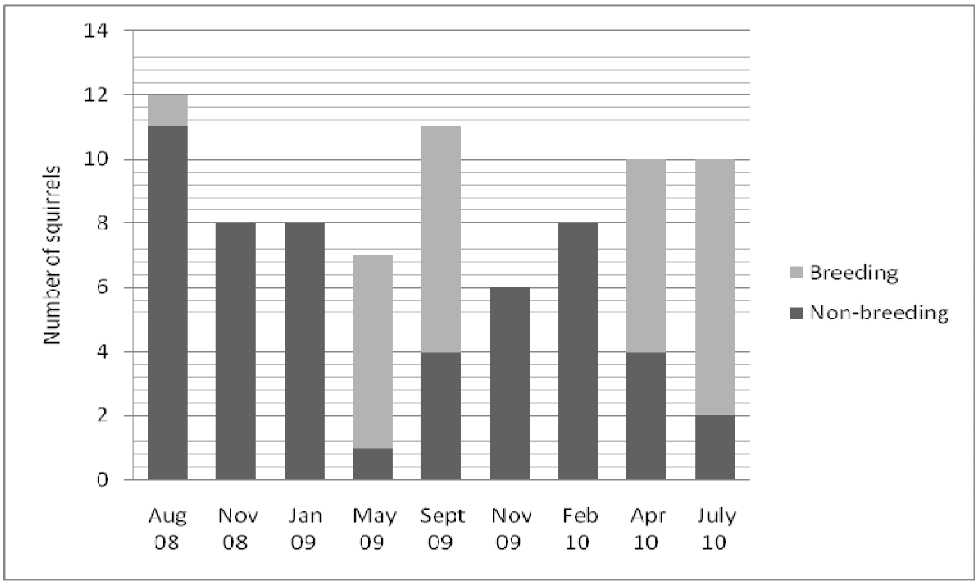

Figure 19: The breeding status of female squirrels caught in Belleek Forest Park

A high number of males were found to be in an actively breeding condition in April and July 2010. In two trapping months (November 2008 and 2009) males were found to be not actively breeding.

Of all trapping months, three had either sub-adults or juveniles captured. In May 2009 20% of squirrels caught were sub-adults, in September 2009 11.7% of squirrels were also sub-adults and in July 2010, 5.3% were juvenile. More sub-adults were captured than juveniles.

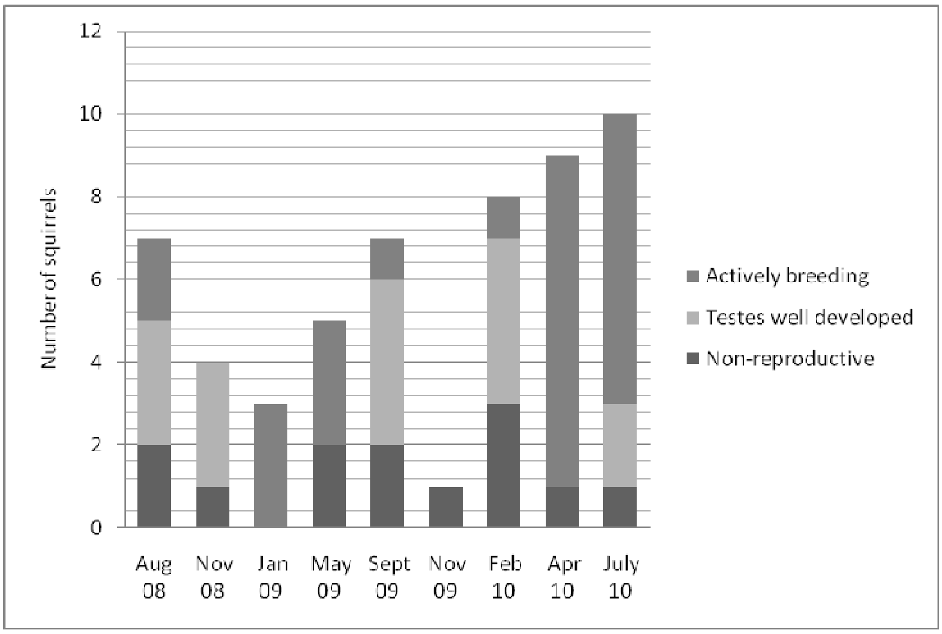

Figure 20: Breeding status of male squirrels caught in Belleek Forest Park

Table 8 displays the number of breeding females counted in each breeding season, the potential number of young born was calculated using an average of three kittens per litter. This was then compared with the number of new recruits marked during the trapping sessions. New recruits found in February 2010 were included with the 2009 cohort, given their weight and the fact that breeding had not yet begun in the woods at that time.

Table 8: The number of new recruits marked at Belleek Forest Park compared to the potential young born as detected through breeding females

Breeding season	Number of breeding females	Potential young born	New recruits counted
2008	1	3	14
2009	7	21	23
2010	9	27	8

In 2008, members of the public reported sightings of the red squirrel in areas surrounding Ballina. It was assumed that these individuals were dispersing into these areas from the translocated population at Belleek Forest Park. These reports were investigated and verified (Table 9, Figure 21). Residents adjacent to Belleek Forest Park found red squirrels became frequent visitors to bird feeders on their property and a report was also received of a red squirrel crossing traffic.

Table 9: Verified sightings of red squirrels in Ballina, Co Mayo, since the translocation to Belleek Forest Park

Year	Location of sighting	Habitat type
2008	Ballina Beverages	Small woodlot of conifers
2008	Dernan Grove estate	Small woodlot of conifers
2009	The Moorings estate	Beech trees
2009	Ballina Golf course	Hazel trees
2009	Shanaghy woods	50 ha of conifer wood
2010	Mount Falcon Hotel	Mixed trees

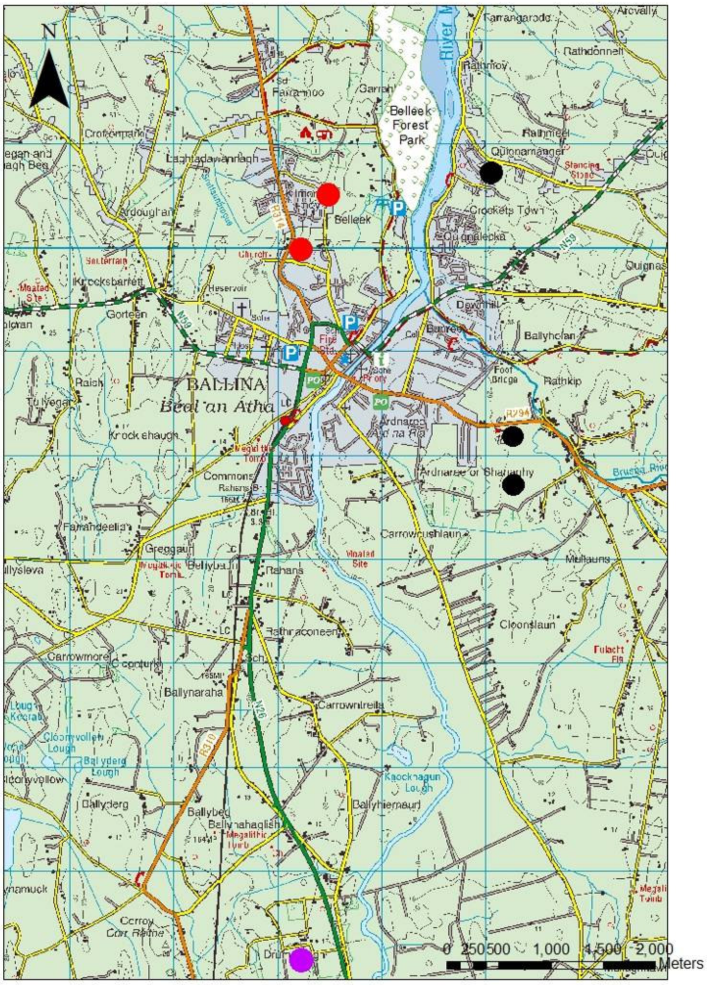

Figure 21: OS Discovery map of Ballina town, Co Mayo showing red sightings since the translocation of red squirrels to Belleek Forest Park (2008 reports in red; 2009 reports in black; 2010 reports in purple)

In 2009 and 2010, the quality of habitat at Belleek Forest Park was assessed by analysing the amount of seed crop available to the squirrels. The main tree seeds available for squirrel consumption were Scots pine, sitka spruce and larch, beech and oak. Norway spruce trees were not producing any cones in Belleek Forest Park. The total seed fall for each year was calculated by extrapolating the amount of seeds for each m² over the known area (ha) for each tree species.

Figure 22 displays the density of available seed crop in m² during 2009 and 2010. It shows that during the two year study, beech was abundant (beech nuts eaten by red squirrels could not be quantified), Scots pine was being consumed by the squirrels and sitka spruce was also being fed on in a smaller quantity.

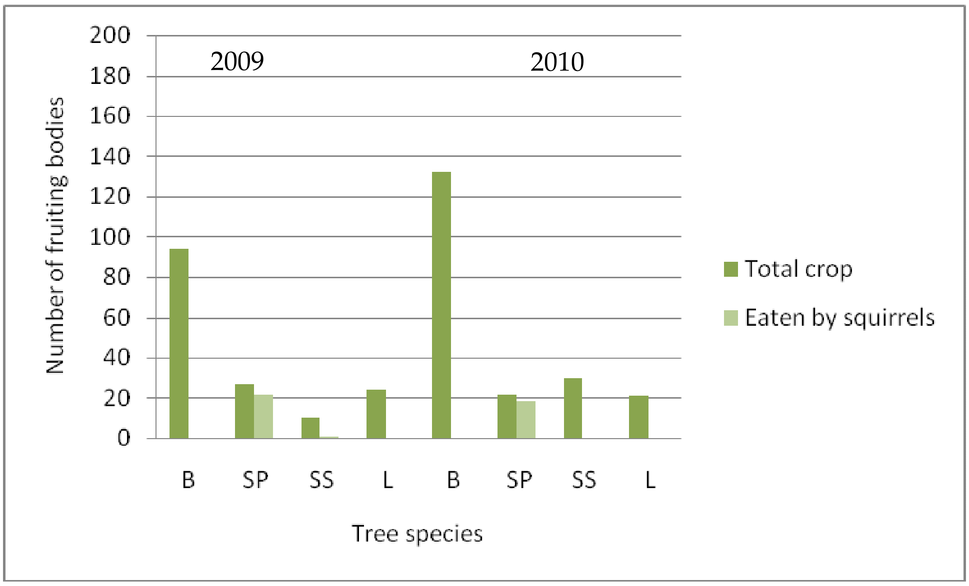

Figure 22: Average cone densities (cones/m²) in quadrats beneath beech (B), Scots pine (SP), sitka spruce (SS) and larch (L) at Belleek Forest Park in 2009 and 2010

Tables 10 and 11 display how many cones or beech casts were available in 2009 and 2010 in Belleek Forest Park. These figures were calculated by extrapolating the amount of seed count into the known area that the tree species occupies. 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.

Table 10: Seed crop available in Belleek Forest Park in 2009, extrapolated from 33 quadrats examined during each trapping session

Tree species	Cones/casts available	Seeds available	Energy kJoules
Beech	714,400	1,428,800	4,000,640
Scots pine	133,000	2,660,000	478,800
Sitka spruce	30,000	6,450,000	2,58,000
Larch - Japanese	97,600	1,366,400*	122,976

*Estimated from the average number of scales on a larch cone compared to those found on a lodgepole pine cone

Table 11: Seed crop available in Belleek Forest Park in 2010, extrapolated from 33 quadrats examined during each trapping session

Tree species	Cones/casts available	Seeds available	Energy KJoules
Beech	1,003200	2,006,400	5,617,920
Scots pine	85,000	1,700,000	306,000
Sitka Spruce	90,300	19,414,500	776,580
Larch - Japanese	85,200	1,192,800*	107,352

*Estimated from the average number of scales on a larch cone compared to those found on a lodgepole pine cone

Derryclare

Of the 18 sections of woodland investigated in May 2008, only four areas were found to be positive for feeding signs of squirrels; sections 13, 16 and 17 plus the Nature Reserve, 18. All other areas examined were found to be negative for the signs of squirrels (Figure 23). During the initial stages of post-release monitoring (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 are still found in the woods in 2010. Assuming they were a minimum of one year of age when translocated, they were at least six years of age in 2010. The dispersal of squirrels through the woods is shown through the annual distribution maps (as detected by live trapping, radio tracking, hair tube surveys and feeding surveys) shown in Figure 23.

Population estimates, based on mark recapture data for each trapping session, were made and are displayed in Table 12. Estimates were calculated using the one of three methods; Minimum Number Present, Lincoln Index and the Fisher-Ford model as described for Belleek Forest Park.

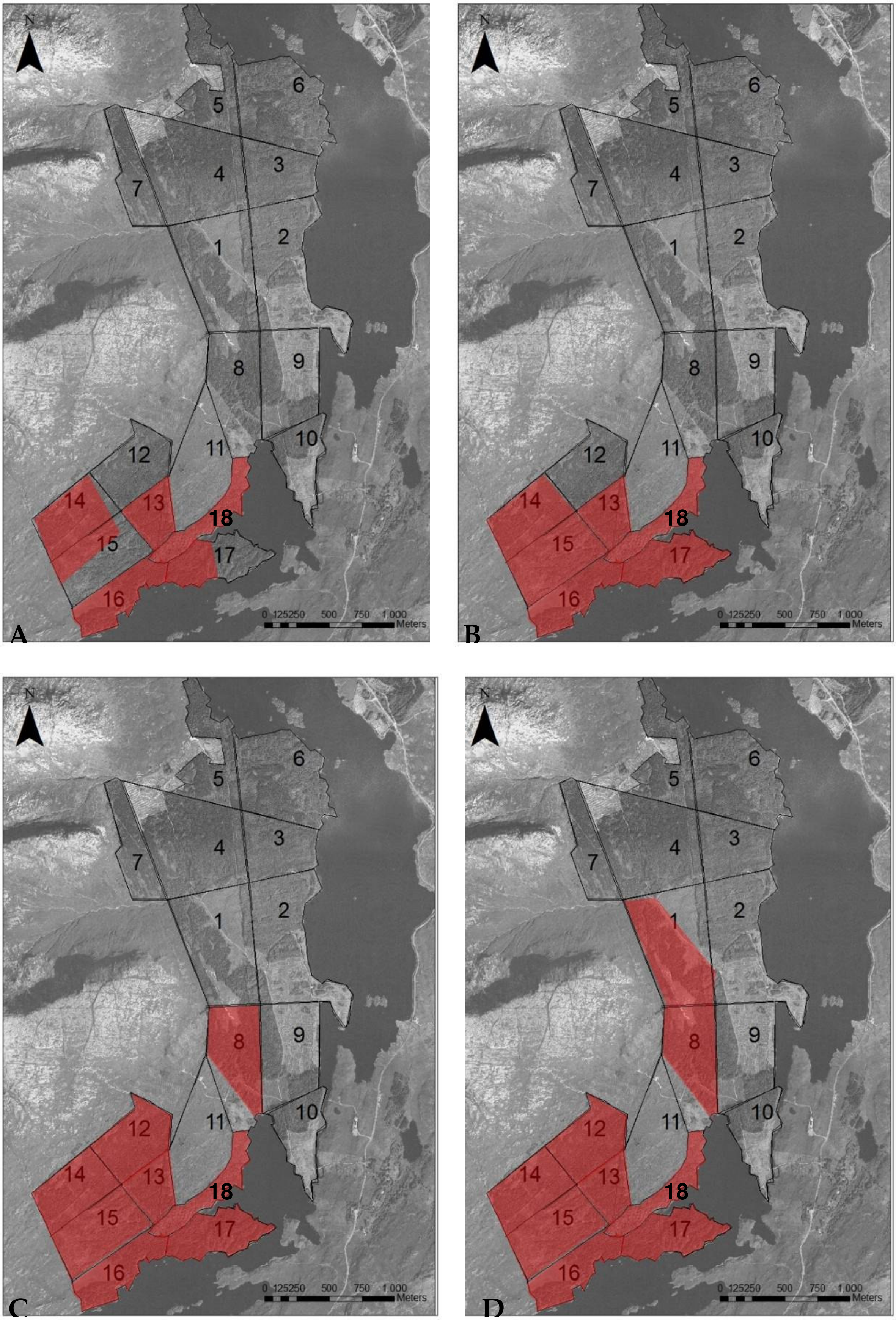

Figure 23: The dispersal of red squirrels through Derryclare woods, as seen through positive records derived from live trapping, hair tubes and feeding signs (A - 2007 (status as of Poole (2007)), B - 2008, C - 2009, D - 2010)

Table 12: Population estimates for each trapping session at Derryclare using three techniques

Trapping months	MNP	Lincoln Index	Fisher-Ford
June 2008	17	17 (±N/A)	25.46
August 2008	12	11.2 ± 2.29	8.91
October 2008	10	10 (±N/A)	9.81
December 2008	10	10 (±N/A)	8.03
February 2009	14	15.16 ± 1.86	14.77
June 2009	11	8 (±N/A)	11.98
August 2009	11	8 (±N/A)	7.85
October 2009	12	17.5 ± 12.12	12.75
December 2009	12	10 (±N/A)	11.32
April 2010	13	7 (±N/A)	10.16
June 2010	17	17.5 ± 2.3	18.89

The Fisher-Ford estimate gives the highest population of 25.46 in the first months trapping (June 2008) but is the lowest 8.91 in the second months trapping (August 2008) (Figure 24). The Lincoln Index and MNP follow a very similar trend for the first five sessions (June 2008 – February 2009). However, in June and August 2009 both the Lincoln Index and the Fisher-Ford estimate give lower values than the MNP. In general all values remain low throughout the study, and little variation was seen as the study progressed.

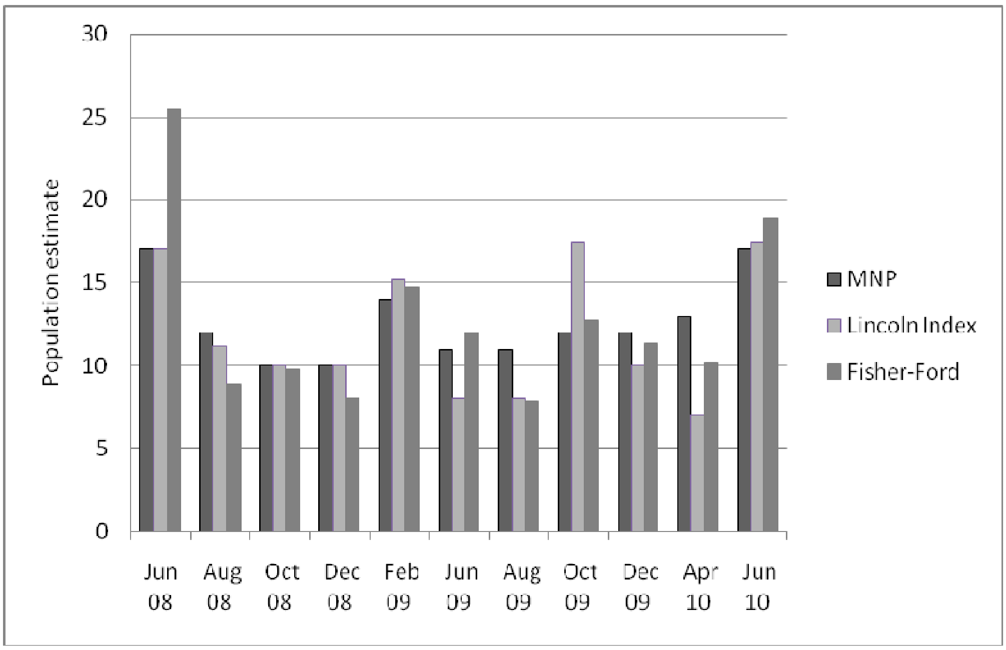

Figure 24: Population estimates at Derryclare based on live trapping

The Fisher-Ford method produces a single-survival rate from trapping session to trapping session, for Derryclare this rate (Ø) was 0.9. From this an annual survival rate of 0.59 can be derived.

The population estimates were converted to population density by incorporating the size of the respective trapping grid, and including a boundary strip. In 2010, the trapping grid changed to incorporate other areas of the woodland known to contain squirrels. 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 this area.

In June 2010, one adult male (255g) was captured on this area of the grid. However, this was an indication of squirrels beginning to spread into the woodland block, rather than a sign of an established population.

Table 13: Population density (squirrels per ha) for each trapping session at Derryclare based on the three population estimates

Trapping months	MNP	Lincoln Index	Fisher-Ford
June 2008	0.29	0.29 (± N/A)	0.39
August 2008	0.21	0.19 ± 0.03	0.15
October 2008	0.17	0.17 (± N/A)	0.17
December 2008	0.17	0.17 (± N/A)	0.14
February 2009	0.24	0.26 ± 0.03	0.25
June 2009	0.19	0.14 (± N/A)	0.21
August 2009	0.19	0.14 (± N/A)	0.14
October 2009	0.21	0.3 ± 0.21	0.22
December 2009	0.21	0.17 (± N/A)	0.21
April 2010	0.22	0.12 (± N/A)	0.17
June 2010	0.28	0.29 ± 0.04	0.31

The range covered by the red squirrels in Derryclare were as follows: 2007, 82.9ha; 2008, 112.5ha; 2009, 146.25ha; 2010, 259.5ha. Extrapolating from the average MNP over the course of the study (0.22 squirrels per ha), the minimum number of squirrels (rounded to the nearest whole number) estimated in Derryclare are as follows: 2007, 18 squirrels; 2008, 25 squirrels; 2009, 32 squirrels; 2010, 57 squirrels.

The highest trapping success rate was the first trapping session in June 2008 (34.6%) (Figure 25). The lowest percentage was in April 2010 (10%) when adjustments had been made to the trapping grid.

In February and July 2009, hair tubes were used to assess any further dispersal of squirrels into surrounding woodland. Of the twenty-four hair tubes put out in block 12 (Figure 23) 37.5% of them were found to contain hairs. Of the hair tubes found to contain hairs all were positive for red squirrel hairs, which were identified using cuticular analysis. Another set of hair tubes was deployed in July 2009 in the next nearest area of mature trees (block 8, Figure 23). Of the twenty-four hair tubes put out in section 8, 83.3% of them contained red squirrel hair. However, hair tubes were placed at a density of two per hectare in this section. Therefore, the total area known to contain squirrels at this time was calculated as 146.25 ha. The density of red squirrels was calculated. Section 12 showed a density of 0.33 squirrels per hectare and Section 8 a density of 0.37 squirrels per hectare.

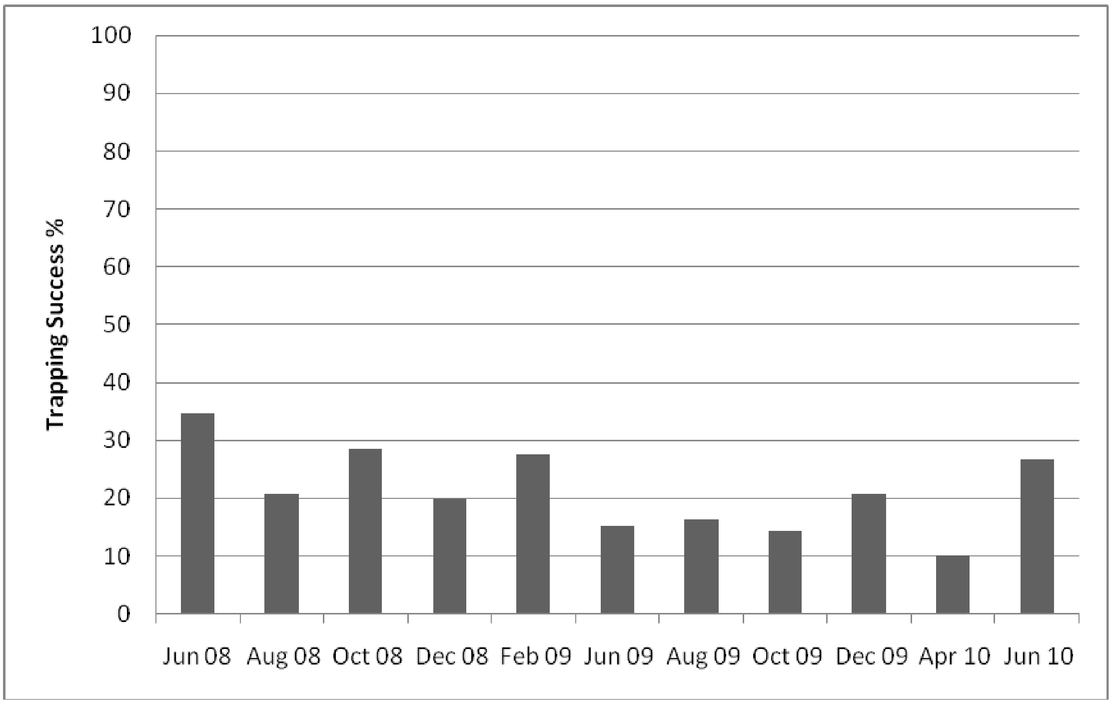

Figure 25: Trapping success rate for each trapping session at Derryclare

In 2010, line transects were used in order to further examine the dispersal of red squirrels. The first transect was conducted in block 1, 425 metres away from the closest hair tube (block 8). Nine transects (three in block 1, three in block 4 and three on the border between blocks 1 and 2) were completed over a two day period. Details of the cones available and eaten are given in Table 14, and helped to inform the 2010 distribution shown in Figure 23.

In order to examine the density of squirrels in these 'frontier areas', the amount of cones available to the squirrels and the amount fed upon by the squirrels was calculated and from that the amount of energy available (KJ) and eaten derived. Two transects were removed from the calculation as they were situated in sitka spruce regions and no eaten cones were found. A total of 1,243,200 lodgepole pine cones were estimated to be available in the 28ha study area covered by the seven transects (one transect for every 4ha). Gurnell (1987) estimated that a single lodgepole pine cone contains 20 - 40 seeds. With an energy content of 0.098 KJ per seed (Smith 1968, Gurnell *et al*. 2001), an average energy value of 2.94KJ was calculated per pine cone. Using the estimated value of 1,243,200 lodgepole pine cones in the area, total energy of 36,550,008KJ was available. The same principal was applied to the amount of lodgepole pine cones eaten by squirrels. The energy value per ha for the study area was 26.46KJ in 0.035ha for the year, or 2.07KJ.day $^{-1}$.ha $^{-1}$. This resulted in an estimate of squirrel density of 0.003 to 0.005 per hectare based on the requirements that the amount of energy consumed by an adult red squirrel per day ranges from 400 to 700KJ. This indicates a very low number of squirrels, or even just exploratory moves into the area at this time.

Table 14: Feeding sign transects at the frontier of squirrel spread in Derryclare (with eaten or uneaten lodgepole pine (LP) and sitka spruce (SS) cones).

Transect no	LP uneaten	LP eaten by squirrel	LP eaten by other	SS uneaten	SS eaten by squirrel
1	219	4	6	12	0
2	407	4	9	0	0
3	258	0	14	0	0
4	189	1	2	5	0
5	114	0	0	5	0
6	193	0	4	0	0
7	116	0	14	27	0
8	0	0	0	108	0
9	0	0	0	142	0
Total	1496	9	49	299	0

The first live trapping session took place in June 2008, this was the first time the squirrels had been trapped since 2007. Any squirrel without a tag was tagged as a new recruit to the known population. Of the 17 squirrels captured in June 2008, six were from the originally translocated stock and 11 were new progeny. Of the 11, two were juveniles, three were sub-adults and six were adults, classified to an age class by their weight.

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 26 shows the new recruits caught in each trapping session. In three months of the study no new recruits were caught, August 2008, December 2008 and August 2009. Of the total number of new recruits caught from October 2008 onwards two were sub-adults and 12 were classified as adults with the lightest weighing 255 grams and the heaviest weighing 310 grams. In total for all trapping months, 7.7% of new recruits have been classified as juveniles, 19.3% as sub-adults and 73% as adults.

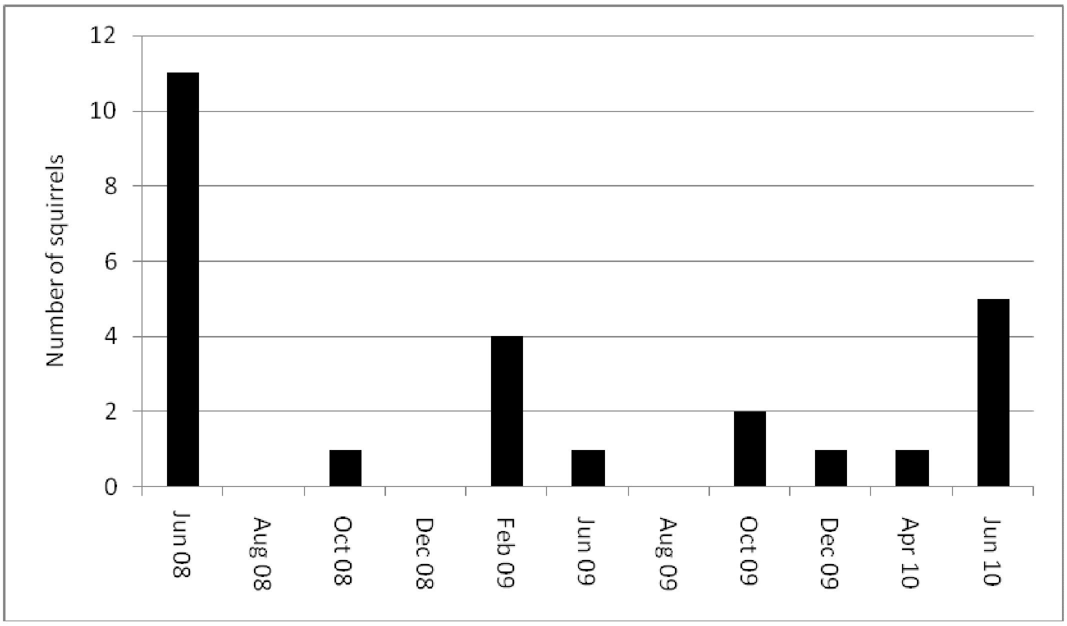

Figure 26: New recruits captured and tagged each trapping session at Derryclare

Mean weight was calculated for all squirrels for each trapping session (Figure 27). The mean weights range from 257.81g to 292.85g, with an overall mean weight for all squirrels of 275.45 ± 5.43g. There is no significance difference between session or years for overall mean weight.

Mean weight for male and females was also calculated (Figure 28). There were no significant differences detected between seasonal weight change or from year to year or between males and females using a two way ANOVA.

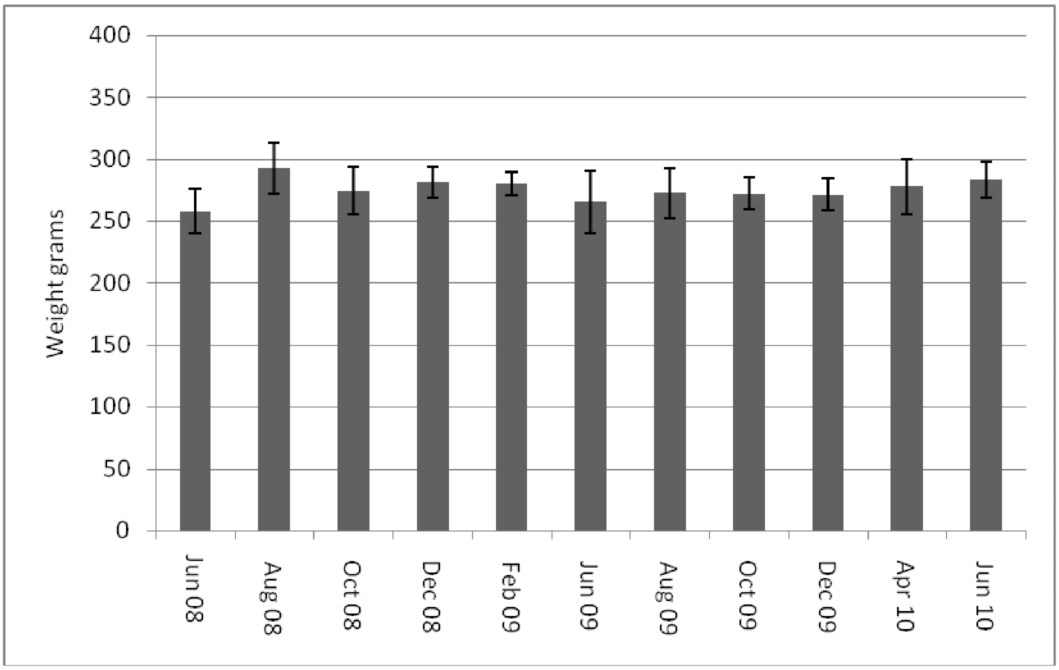

Figure 27: Mean weights with 95% confidence intervals for all squirrels caught in Derryclare in each trapping session

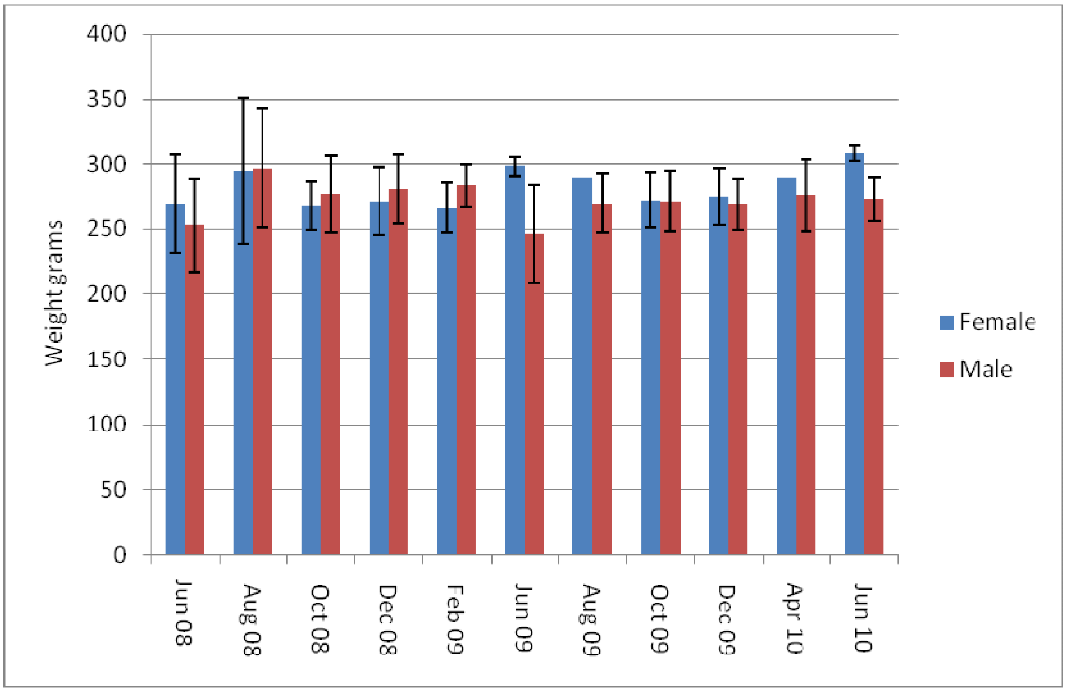

Figure 28: Mean weights with 95% confidence intervals for male and female squirrels caught in Derryclare in each trapping session

Body size was investigated, as indicated by mean shin bone length (Table 15). There was no significant difference between the sexes.

Table 15: Mean shin bone length with 95% confidence intervals for all trapping sessions in Derryclare

Mean shin length (mm)	**Mean male shin length (mm)**	**Mean female shin length (mm)**
66.6 ± 1.12	66.5 ± 1.26	66.6 ± 1.71
n = 32	n = 11	n = 21

The linear regression of shin bone length on body weight is presented for all squirrels in Derryclare in Figure 29. Regression analysis showed that there was a significant relationship between shin bone length and weight for all squirrels (weight = 7.184 – 213.2(shin length); $r^2 = 0.318$ $p < 0.001$).

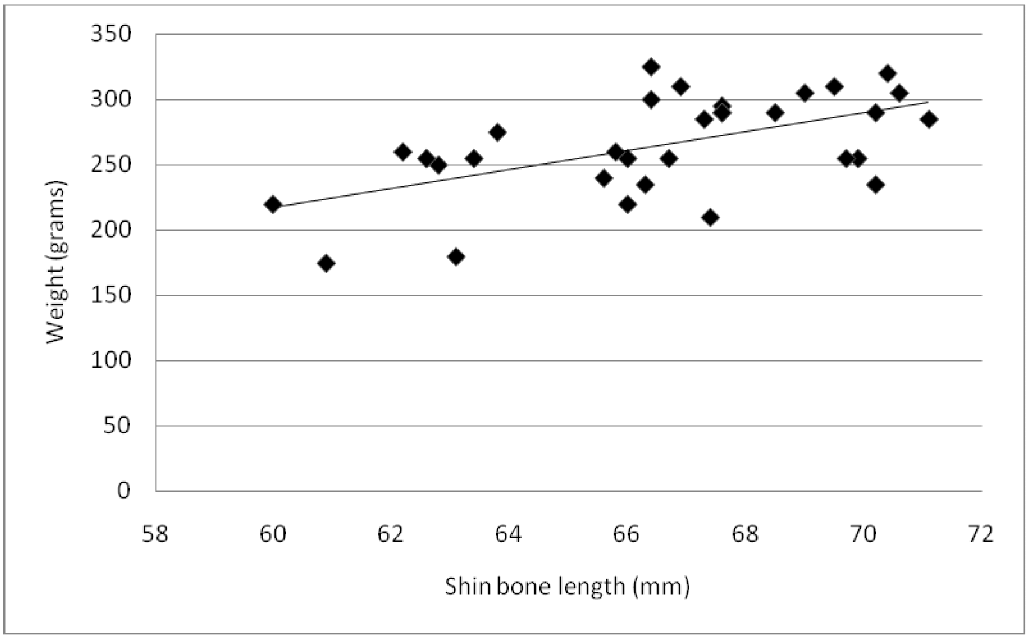

Figure 29: Linear regression of shin bone length against weight for all squirrels at Derryclare

The sex ratio between the sexes was calculated for each trapping session at Derryclare (Figure 30). It was found that males were dominant to females in all but one trapping month (August 2008) in which the ratio is 1:1.

The average male to female ratio over the trapping period was 2.1:1. Since the beginning of the study the ratio between the sexes within the trapping area has diverged so that more males are captured than females.

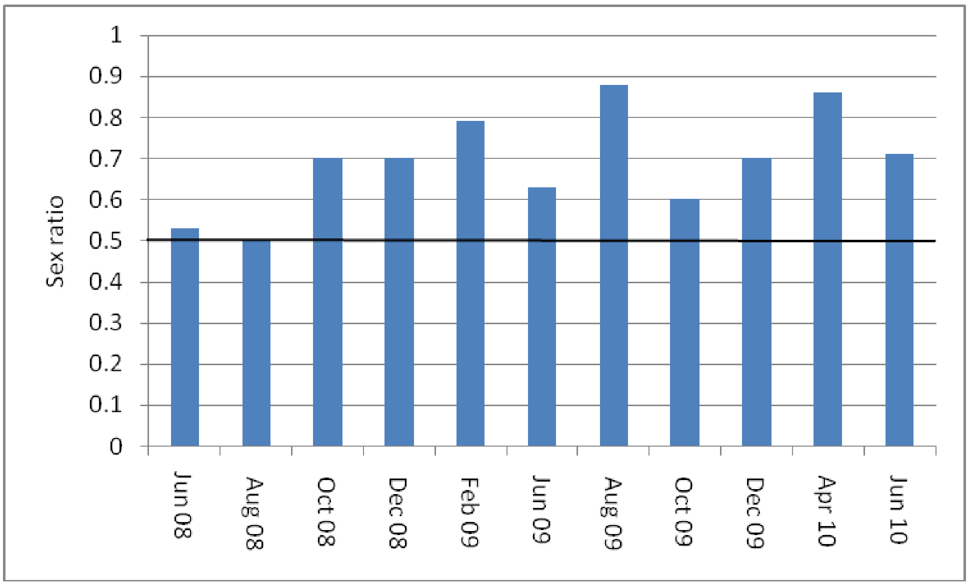

Figure 30: The sex ratio (proportion of animals captured that were males) for each trapping session at Derryclare

The breeding condition of female (Figure 31) and male squirrels (Figure 32) was calculated for each trapping session. Breeding females were found in June 2008 (87.5% of total females), August 2008 (60%), February 2009 (33.3%), June 2009, August 2009 and June 2010 (100% respectively). None were found to be in breeding condition in October 2008, December 2008, October 2009, December 2009 and April 2010 (only one female captured). In June 2008 the female captured in a non-breeding condition was a juvenile. In August 2008, a pregnant squirrel was captured. At least some of the males were found to be in an actively breeding condition in all trapping months apart from one, October 2008.

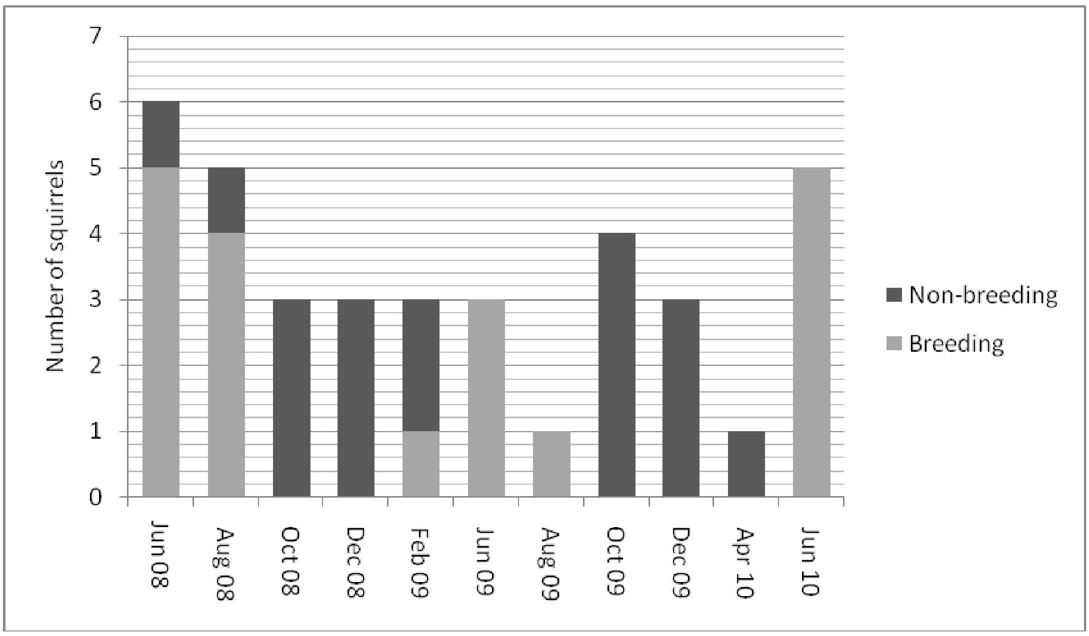

Figure 31: Breeding status of females captured in each trapping session in Derryclare

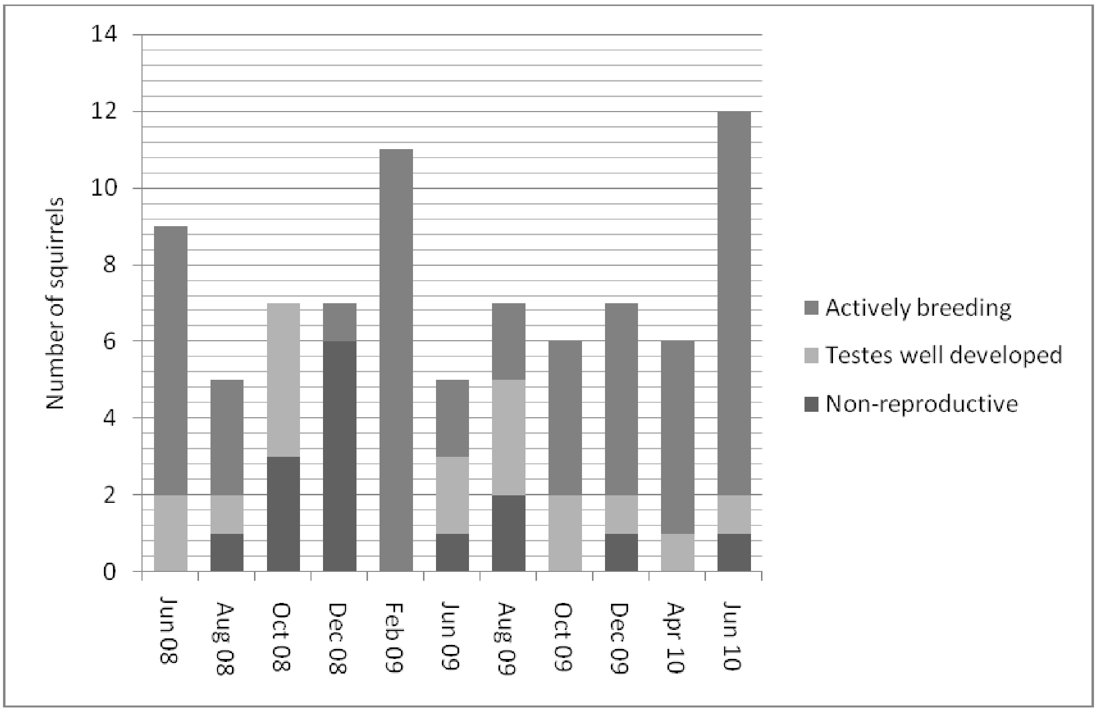

Figure 32: Breeding status of males captured in each trapping session in Derryclare

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 kittens born per litter (Table 16). 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 16: The number of potential young born in each breeding season in Derryclare and the number of new recruits marked.

Season	Number of breeding females	Possible number of young born	New recruits counted
2008	7	24	16
2009	3	9	5
2010	5	15	5

In March and April 2009, radio-tracking was undertaken and used to examine habitat use in Derryclare. Seven squirrels were collared, four male and three female (Table 17). The signals for two of the radio-collars could not be picked up by the receiver subsequently.

Table 17: Habitat use by radiocollared squirrels in Derryclare in 2009

Freq ID ...	Sex	Fixes gained	Nature Reserve	Lodgepole Pine	Sitka Spruce
328	Female	25	0	100	0
236	Female	14	71.4	28.6	0
197	Female	7	28.6	71.4	0
276	Male	18	5.6	55.5	38.9
175	Male	3	100	0	0
317	Male	0	-	-	-
285	Male	0	-	-	-

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. 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.

Data was collected in the autumn of 2008 and 2009 on the amount of seed crop available to the 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 line transects (Table 18). There were no eaten sitka spruce cones recorded on any of the transects. 5681 lodgepole pine cones were recorded, of which 828 were eaten by squirrels. The area covered by the transects was 1550m^2 (0.155ha), which can be extrapolated to represent the available lodgepole pine in Derryclare (276ha). The average eaten pine cone contains approximately 20 - 40 seeds (Gurnell 1987, Smith 1981) with 30 taken as the overall average. Each seed has an energy value of 0.098kJ (Smith 1968; Gurnell *et al*. 2001), which gives an estimated energy value of 2.94kJ per average pine cone. This gave a total amount of energy available from Lodgepole pine cones for 2008 in Derryclare of 30,023,280 kJ.

Table 18: Total number of eaten and uneaten lodgepole pine (LP) and sitka spruce (SS) cones counted along 31 line transects in Derryclare in 2008

Transect	Uneaten LP cones	Squirrel eaten LP cones	Total LP cones	Uneaten SS cones	Squirrel eaten SS cones	Total SS cones
1	241	17	258	8	0	8
2	422	91	513	9	0	9
3	82	0	82	48	0	48
4	442	64	506	0	0	0
5	55	1	56	0	0	0
6	68	0	68	72	0	72
7	34	0	34	43	0	43
8	18	0	18	42	0	42
9	120	0	120	1	0	1
10	111	0	111	59	0	59
11	79	0	79	20	0	20
12	29	0	29	32	0	32
13	330	90	420	17	0	17
14	175	71	246	9	0	9
15	388	113	501	0	0	0
16	396	56	452	6	0	6
17	53	2	55	40	0	40
18	67	6	73	6	0	6
19	92	0	92	0	0	0
20	19	1	20	15	0	15
21	451	76	527	2	0	2
22	4	0	4	59	0	59
23	108	21	129	0	0	0
24	167	80	247	0	0	0
25	267	126	393	0	0	0
26	85	0	85	1	0	1
27	18	1	19	4	0	4
28	130	0	130	75	0	75
29	156	3	159	49	0	49
30	5	0	5	109	0	109
31	241	9	250	18	0	18
Total	4853	828	5681	744	0	744

Table 19: Available energy and consumed energy in Derryclare wood for 2008 (taken from line transects and extrapolated to the survey area and larger woodland area)

	Cones Available	Energy Available (kJ)	Cones Consumed	Energy Consumed (kJ)
Line transects (1550m^2)	5681	16702.14	828	2434.32
Per m^2	3.7	10.88	0.53	1.57
Total lodgepole (276ha)	10,212,000	30,023,280	N/A	N/A

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 (Gurnell *et al*. 2001). Therefore it was calculated that in the larger woodland area covered by Lodgepole pine (276 ha), the potential number of red squirrels that could have been supported in 2008 was estimated to be between 117 and 205 individuals.

The number of eaten cones along each transect were 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 (Figure 33).

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 34).

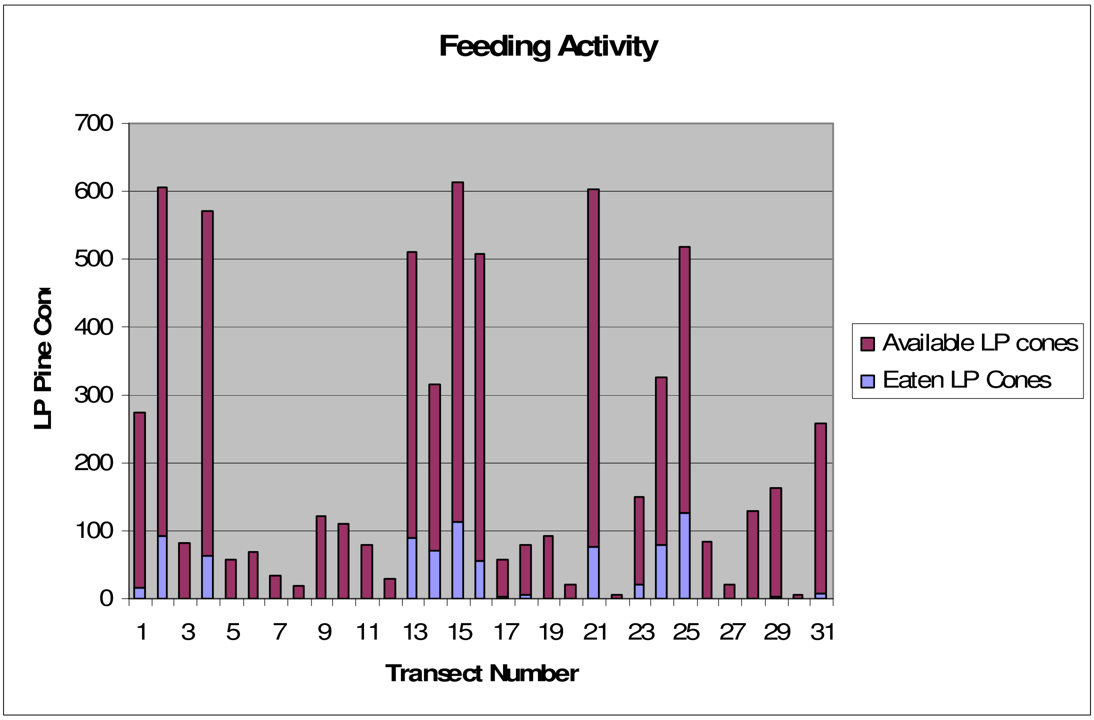

Figure 33: Proportion of lodgepole pine cones available to red squirrels that they had eaten in Derryclare in 2008

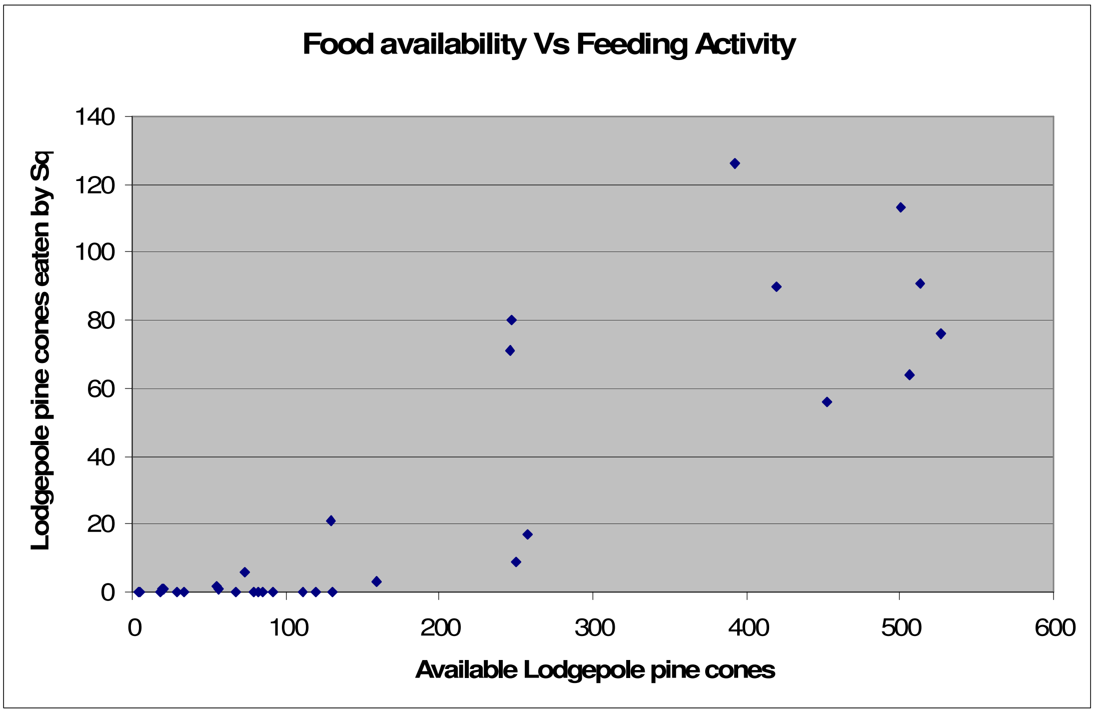

Figure 34: The correlation between Lodgepole pine cone availability and feeding activity of red squirrels at Derryclare wood ($r = 0.872$, $p < 0.01$**, $n = 31$)

In 2009, another survey was conducted, this time based on the trapping grid (Table 20). 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 27,345,528kJ (Table 21).

Given that the study area (40 ha) at Derryclare wood 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 40ha study area, an actual squirrel density of between 0.1 to 0.14 per ha can be calculated.

Once again, feeding activity was highest in the most productive areas (Figure 35).

Table 20: Total number of eaten and uneaten lodgepole pine (LP) and sitka spruce (SS) cones in Derryclare

Transect	Uneaten LP cones	Squirrel eaten LP cones	Other eaten LP cones	Uneaten SS cones	Squirrel eaten SS cones
1	10	0	0	0	0
2	18	0	0	0	0
3	6	0	0	0	0
4	145	51	0	0	0
5	185	103	2	10	0
6	119	44	0	0	0
7	67	1	0	0	0
8	365	19	0	0	0
9	241	71	3	0	0
10	165	66	4	0	0
Total	1321	355	9	10	0

Table 21: Available energy and consumed energy detected from feeding transects in Derryclare in 2009

	Cones available	Energy available (kJ)	Cones consumed	Energy consumed (kJ)
Line transects ($500m^2$)	1685	4953.9	355	1043.7
Per m^2	3.37	9.9	0.71	2.1
Total lodgepole (276ha)	9,301,200	27,345,528	N/A	N/A

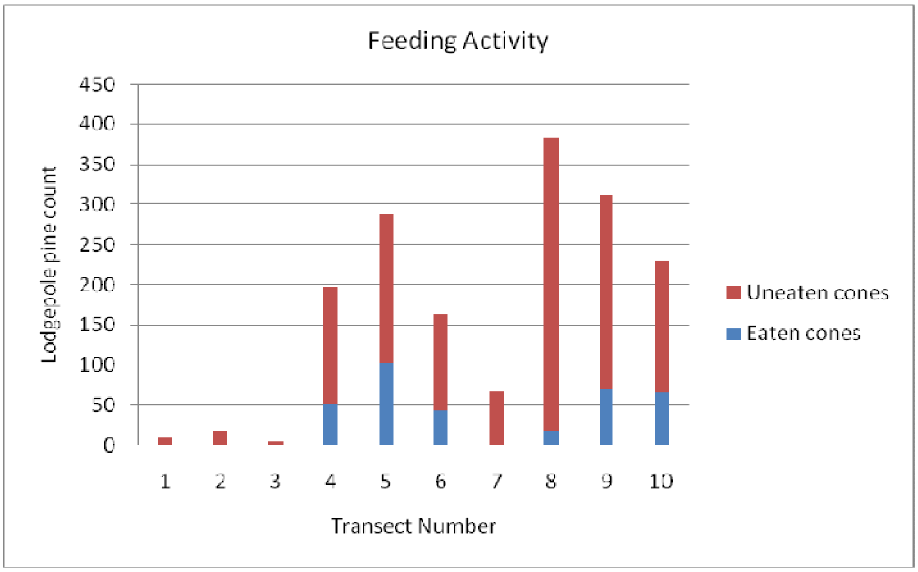

Figure 35: Proportion of lodgepole pine cones available to red squirrels that they had eaten in Derryclare in 2008

Donor Site Monitoring

Lough Key

There were three habitat types in the areas where the hair tubes were deployed: WD1, WD2, and WD3. 23% of the hair tubes were placed within WD1, 59% were within WD2 and 18% were within WD3.

When set A of the glue blocks was collected (June 2009) two of the hair tubes were found on the ground having fallen from the tree; 5 tubes were found this way when set B was collected (July 2009). Microscopic analysis of the cuticula of the mammal hair collected on the glue blocks of the hair tubes revealed that hairs were collected from red squirrel, brown rat (*Rattus norvegicus*), wood mouse (*Apodemus sylvaticus*) and pine marten (*Martes martes*) individuals. Figure 36 shows the location where each species' hair was found for set A and Figure 37 shows the same for set B.

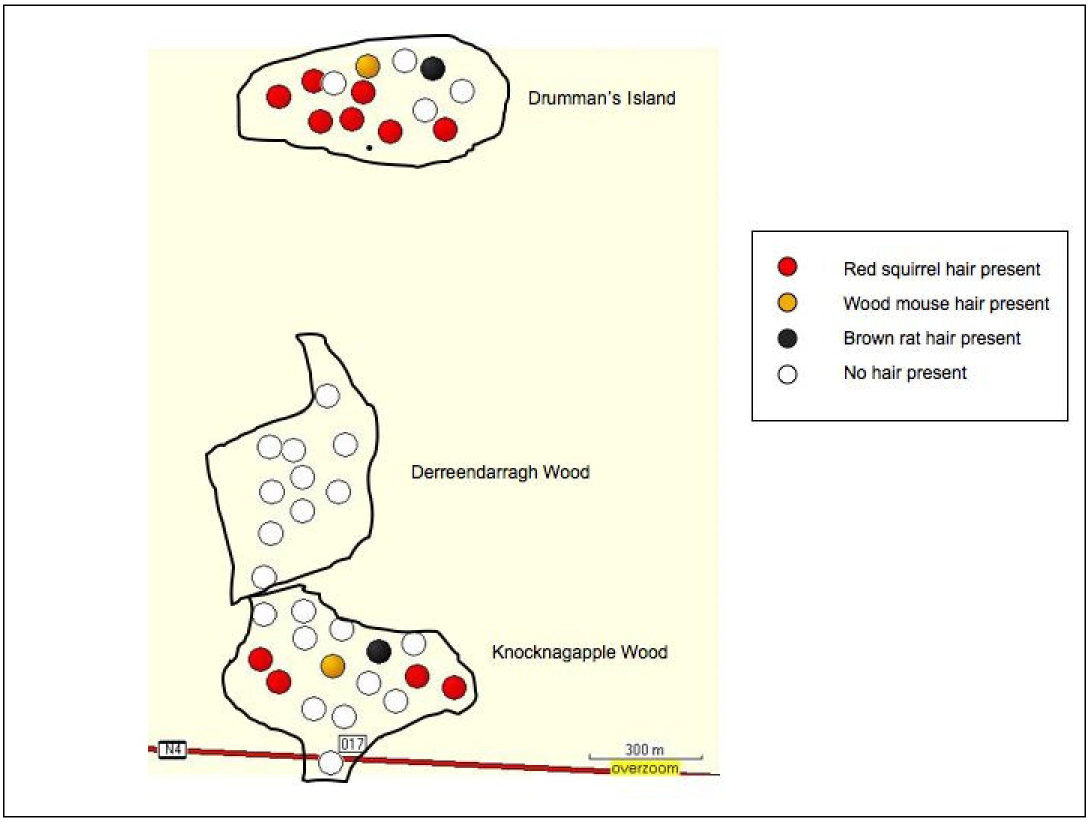

Figure 36: Location and type of hair found in July 2009 in Lough Key. Each circle represents one hair tube

In set A, 38% of the hair tubes contained glue blocks that had collected hair, 23% had collected feathers and 44% were empty of animal signs. Both mammal hair and feathers were collected by 5% of the glue blocks. Tubes that contained hair always only displayed hair from one mammal species.

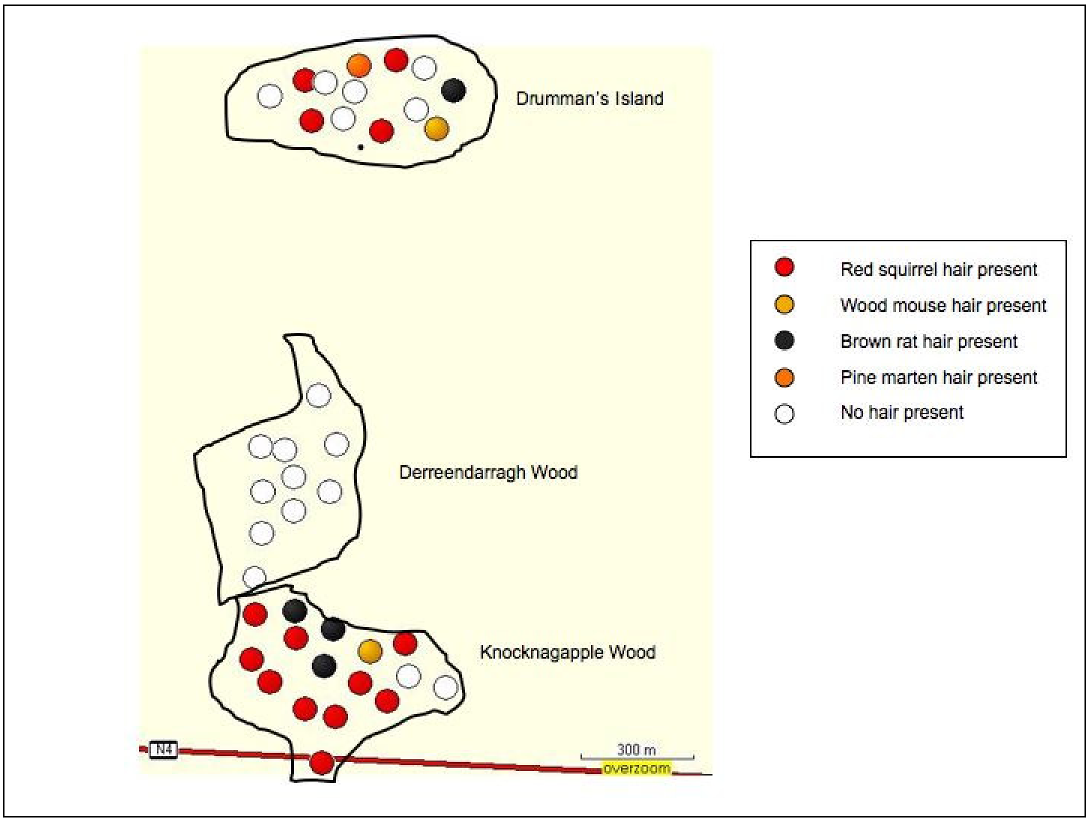

Figure 37: Location and type of hair found in August 2009 in Lough Key. Each circle represents one hair tube

In set B, 53% of the hair tubes contained glue blocks that had collected hair, 31% had collected feathers and 21% were empty of animal signs. Again, 5% of the blocks collected both mammal hair and birds feathers. Similarly to set A, the tubes that contained hair always only displayed hair from one mammal species.

Of the 39 tubes placed out in set A, 11 of them, or 28.2%, gathered red squirrel hair. In set B, 14 of the 39 tubes, or 35.9%, contained red squirrel hair, giving an average over the two sets of 32.1%.

The type of tree on which the hair tubes were place and the habitat type in which they were placed were not found to have a significant effect on hair tube use by squirrels (using a χ^2 test). The third variable tested was the woodland area within which the tubes were located. On Drumman's Island 11 of the 26 hair tubes were positive, 0 of the hair tubes in Derreendarragh Wood were positive and 14 of the 34 tubes in Knocknagapple Wood contained red squirrel hair. The χ^2 test performed on this data showed the woodland in which the hair tube was located had a significant effect on whether or not hair tubes were found to be positive ($p < 0.01$).

The density of the red squirrel population was determined in Lough Key Forest and Activity Park as a whole and within each sampled woodland using Garson and Lurz's (1998) equation. Each hair tube is assumed to draw animals from the one hectare surrounding its location. Table 22 shows the results of the calculations.

Table 22: Density of red squirrels within areas of Lough Key Forest and Activity Park from hair tube usage (after Garson and Lurz, 1998)

Wood Area	**Density: Squirrels/hectare**
Overall sample area	0.316
Drumman's Island	0.414
Derreendarragh Wood	0.000
Knocknagapple Wood	0.406

Portumna Forest Park

Two hair tube surveys were also conducted in Portumna Forest Park, the source wood for the Derryclare translocation. In August 2010, 29 tubes were placed out, with six proving positive for red squirrels, and four for other species. In October 2010, nine hair tubes out of a possible 17 were used by red squirrels (with no other species being identified on this occasion). This gives a squirrel density over the two sessions of 0.33 squirrels per ha using Garson and Lurz's 1998 formula.

Union wood

As Union wood was only used for the translocation of one individual red squirrel the assessment of the population was deemed not to be necessary. However, the local forest manager was contacted. It was reported that red squirrels are still a common sight at Union wood (Paul Murray, forest manager pers. comm.).

Discussion and Recommendations

Belleek Forest Park Translocation

These translocations were carried out strictly in compliance with the IUCN Guidelines (1998). The Belleek translocation consisted of a number of stages, some of which were carried out before the current study began.

A feasibility survey of Belleek Forest Park was undertaken by Lawton (2006) to ensure that the wood was suitable for a red squirrel translocation. The carrying capacity, based on published squirrel densities for given habitats, the size and relative isolation of the wood were all considered, together with possible reasons for red squirrels not to be present at the time and logistical implications. It was found that the woodland was potentially capable of having a carrying capacity of 65 squirrels, which is quite a low population size and the isolation of Belleek from other woodlands may limit the conservation benefit of the translocation. However, the translocation did hold merit with regards to the education benefits and the involvement of the general public, the carrying capacity was sufficient to support a squirrel population and the isolation ensured that grey squirrels would not arrive at the Forest Park readily, and so it was determined feasible. Belleek wood is a mixed-species woodland with a variety of coniferous and deciduous trees, providing the squirrels with pine cones and hardwood masts. 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). As Belleek Forest is maintained as an amenity woodland by Coillte, the silviculture of the woodland is monitored and managed, a thirty year forestry plan has been devised for the management of Belleek Forest and the red squirrels have become a key factor in the future plans (Tiernan *et al*. 2009).

The source populations were investigated prior to translocation to ensure that the individuals were fit and healthy and that the suitability of the woodland was studied. Transportation distance and hence time from the target site were kept to a minimum to ensure as little stress as possible to the animals (Poole 2007). Other guidelines followed when investigating the source stock was that the 'source population should ideally be closely related genetically to the original native stock and show similar ecological characteristics' (IUCN 1998). 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 50km and a travel time of one hour. A further advantage was that these animals were not from areas where grey squirrels had invaded, meaning they had not been exposed to SQPV.

The feasibility study recommended a minimum of 12 individuals would be needed to be translocated into the woodland. However, a target of 15-20 individuals was chosen for translocation to allow for some mortality before breeding (Finnegan 2007). Pregnant and lactating females were not chosen for translocation and individuals with a weight lower than 210g were also considered unsuitable.

The translocation was undertaken in three phases with no mortalities or injuries occurring between capture and release into the enclosure, showing that the transportation and handling techniques were effective. The enclosure was designed and constructed prior to the current study beginning, and did not prove suitable. Squirrels escaped very quickly from the enclosure during phases two and three. They 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 BFPEC between phases proved unsuccessful. The problems with the enclosure led to the Belleek translocation effectively being a hard-release translocation, albeit with supplementary food and nest boxes provided. This may have contributed to some squirrels dispersing from Belleek to neighbouring parks and gardens. It did not affect the overall translocation success, but five of those ten squirrels translocated in phases two and three were not captured again during the study. The timing of translocation is an important consideration for any study. The squirrels need to be released from the enclosure prior to the winter, to enable them to begin to forage and cache foods and construct dreys while there is enough natural resources in the woodland (Poole & Lawton 2009). Squirrels are notoriously difficult to catch however during the autumn months, when natural food levels are high. Translocating them in early spring may mean that that year's breeding season is lost, and mortality high to the next breeding season. The staggered translocation in this case was very successful, but does add to the expense and duration of the project.

The release of red squirrels received a high amount of publicity in the local area and this should help ensure the continued appreciation of red squirrels in the Ballina region. This reinforces the benefit of translocating the squirrels for educational purposes. This project also shows that local involvement, as was provided in this case through the BFPEC, can help in educating the public as well as reducing overall project costs.

Post-release monitoring

Settlement Behaviour and Home Ranges

Six of the nine translocated individuals were radio tracked in April 2008 to study settlement patterns of the red squirrels. During this period supplementary food was being regularly put in the eight feeders around the woodland and also in the enclosure. Settlement patterns show that four of the six squirrels set up core areas around the release enclosure and one male extended its core area to also include a supplementary feeder. 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 escapes from the enclosure, the squirrels still returned on a regular basis unlike previous studies in which squirrels utilised the surrounding feeders and were never found to re-enter the enclosure (Poole & Lawton 2009, Jackson 1998). Two of the six red squirrels established their home ranges away from the enclosure, however, in both cases their range included a feeder. 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 settled nearby. Poole & Lawton (2009) also reported individuals moving away from the release site immediately on release, and used only the natural resources of the woodland. In this study, however, it was found that those individuals that moved away were utilising the feeders as well as the natural resources. Kenward & 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 (Scots pine, sitka spruce, beech, hazel, oak and horse chestnut). Therefore red squirrels were familiar with the tree seed crop present at Belleek.

In general, dominant 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 patterns of radio tracked squirrels at Belleek Forest displayed a high percentage of overlap, with four of the six squirrels (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 abandoning the spacing patterns of reduced core area overlap among males and nearly exclusive core areas among females. Although at Belleek Forest 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, another radio-tracking session was conducted in order to investigate how the population had changed within the 18 months since the previous session. Eight squirrels were fitted with radio collars, however, two could not be traced once tracking began. The remaining squirrels were tracked successfully.

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 other males and females (Wauters & Dhondt 1990). The only core area overlap recorded between these individuals was between a male and female.

Individuals tracked at this time did not rely on the release enclosure for resources as their home ranges (and the trapping points where they were collared) were situated away from the release site. The population was utilising other areas of the woodland. However, supplementary feeding was still on-going and feeders were located within individual home ranges, suggesting squirrels were still taking advantage of supplementary food supplies.

Of the red squirrels tracked in the second session of radio telemetry one female squirrel had been tracked previously. Squirrels were radio collared at random and not targeted. In the second session it was found that this female had remained in a similar location with a slight shift of core area and contraction in its size but not significantly. 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 occuring in grey squirrel populations, with the overall home range remaining the same (Lawton & Rochford 2007). This indicates a shift in home range use, rather than a shift in position.

The core area sizes detected within the current study are similar to those found in similar habitats elsewhere in the red squirrel's range (Table 23).

Table 23: Male (M) and female (F) red squirrel core area size reported in various studies

Habitat	**Country**	**Core area (ha)**	**Method**	**Study**
Mixed	Belgium	M: 1.01 – 1.12 F: 0.8 – 1.24	MCP and cluster analysis	Wauters *et al.* 1994
Deciduous	Belgium	M: 2.68 F: 1.94	MCP	Wauters & Dhondt 1992
Coniferous	England	M: 1.39 F: 2.17	Cluster analysis	Lurz *et al*. 2000
Coniferous	Ireland	M: 1.02 F: 1.5	MCP	Reilly 1997
Mixed	Ireland	M: 1.83 F: 1.57	MCP	Current study, 2010

Population and density estimates

Population and density estimates were based on live-trapping data and mark-recapture technique. Some studies have found the capture of red squirrels to be difficult (e.g. Moller 1986); Gurnell &

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 the 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 to be conducted on a bi-monthly period in both woods, however, due to other field experiments, it was not always possible to adhere to a rigid schedule. The gaps between trapping months, however, did not affect population estimation.

In order to counter-act some of the under-estimation or over-estimation in density estimations, three methods of calculating estimates were used. The first method was the Minimum Number Present, an estimation of the known minimum population from captured individuals. It is affected by trapping success, which is variable from month to month. Variation in the MNP throughout the study also represents real population changes (Lurz & Garson 1997). It accounts for the recapture of individuals that may not have been recaptured for some time, whether due to trap-shyness, potential emigration away from the population or poor trapping success.

The second estimator used in this study was the Lincoln Index, The Lincoln Index assumes there are no gains of losses to the population between the two samples. With a very short space (one day) between samples, this problem is mostly eradicated. Confidence limits allow us to see the accuracy of each estimate. On occasion, the Lincoln Index estimations are lower than the MNP in certain months; this is an unreliable estimation as the minimum amount of squirrels in the population is known.

The third method used was the Fisher-Ford model. Previous studies have found it to be unreliable in the first sessions of the study period (Lawton 1999, Poole 2007). These artificial highs were attributed to the high rate of survival of marks over the first few months. However, in this study the Fisher-Ford estimate shows a similar trend to the other methods in the first few months.

Overall, the three methods need to be examined together to see trends in population size and density. From the initial introduction of 15 red squirrels the population in Belleek Forest Park increased from year to year. Initially the red squirrel population spread quite quickly through the woodland, maintaining low densities at first, but densities increased at a constant rate in all areas of the forest park towards the carrying capacity.

Densities at Belleek Forest by mid-2010 had reached values of 0.61-0.74ha. This is similar to densities calculated in other studies. Moller (1986) calculated red squirrel density in a coniferous site in

Scotland, dominated by Scots and Corsican pine, at 0.33 ha^{-1}. Lurz & Garson (1995) estimated a red squirrel density of 0.21 ha^{-1} in a predominantly sitka and Norway spruce forest in England. Typical red squirrel densities for mixed woodland are 0.21 - 1.27 squirrels per ha (Finnegan *et al.* 2007, Poole 2007) and for a broadleaved woodland are 0.5 - 1.3 squirrels per ha (Tonkin 1983, Wauters & Dhondt 1990). Fluctuations in squirrel density can be attributed to abundance of tree seeds (Wauters *et al.* 2004), however, during this study supplementary feeding was on-going as the population became established. With a predicted maximum carrying capacity of 65 squirrels at Belleek Forest (Lawton 2006), it is possible that the red squirrel population in Belleek Forest Park has yet to peak.

In Derryclare, population estimates were made based on live trapping and mark-recapture data collected on a 40ha trapping grid. Initially a baseline survey was conducted at the beginning of 2008. Derryclare wood had not been monitored since the initial post-translocation monitoring had come to an end in 2006 (Poole 2007). At that time the population had begun to breed and a minimum of nine offspring were produced in the breeding season of 2006 (Poole & Lawton 2009). The trapping grid was altered from 40ha to 33ha (June and August 2008) as certain traps had to be omitted from the process, mainly due to the inaccessibility of these traps and time constraints due to day-length during winter months. In April 2010, the trapping grid was altered again, in this case the experimental design changed to incorporate areas in which squirrels had dispersed to in order to include individuals in less established areas. Twelve 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 the spread.

It was found that the population of red squirrels at Derryclare had increased in number since the introduction, with the amount of seed crop available being an important factor, as supplementary feeding had stopped a year after translocation (Poole 2007). Squirrels continued to be recruited to the population, and given the distance to other squirrel populations, these were progeny of the resident squirrels. The establishment of red squirrels at Derryclare differed to that at Belleek Forest as the habitat and woodland size was different. At Derryclare the red squirrels began as a clumped population remaining close to the site of introduction. 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 but poorer habitat at Derryclare promotes clumping of the population, rather than a uniform dispersion as seen in Belleek. Spreading the supplementary feeders throughout Belleek Forest Park may have encouraged the squirrels to spread throughout the woodland on release. Densities on the original trapping grid (33ha) were 0.17 – 0.29 squirrels per hectare and 0.22- 0.28 squirrels per hectare on the second grid which incorporated 20ha of the original site and 6ha of the new grid.

Fluctuations in trapping success did not correspond to the time of the year, with peaks occurring in winter months as well as summer months. The lowest trapping success occurred in the first month in which the trapping grid had changed, possibly due to the squirrels' inability to locate traps. In the following month the trapping success returned to typical levels.

New recruits

As breeding and the recruitment of juveniles into the population was a sign of the success of the translocation, initial breeding status and new recruits were monitored. During the post-release monitoring phases, new recruits were classed as any individuals being tagged for the first time. In Belleek Forest Park, the first juvenile caught after translocation was in March 2008, a month after the second phase of translocation. As pregnant females were not translocated these offspring were the progeny of the five red squirrels translocated in August 2007. This showed that the red squirrels already translocated had settled into the environment and were in a healthy condition to breed. In the following trapping month (August 2008) the highest number of new recruits was captured and clearly showed that a number of the translocated stock was now breeding. A mooted fourth phase of translocation was not deemed necessary due to the new animals recruited from within. The recruitment of these young animals can be attributed to the availability of home ranges due to the space in the wood not taken up by adult squirrels and the availability of food. The recruitment of both sexes into the population by juveniles (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 would have been minimal, with access available to unoccupied, high-quality food patches.

The lowest number of recruits being caught was in winter months. This is to be expected as red squirrel litters are usually born in the spring (February – April) and summer (May – August) (Harris & Yalden 2008). Wauters *et al*. (1993) found that there was no difference in recruitment rate between juveniles from spring and summer litters.

There are a number of other factors that can also affect the recruitment of a population. Size of individual litters can affect the total recruitment of young (Gurnell 1987). Red squirrels are capable of having 1 – 5 young (Gurnell 1983), however, the probability of recruitment of locally born juveniles is higher when they are in good condition, that is they have a high body mass at weaning (Wauters *et al*. 2004). Hence, the condition of the mother of the offspring is important as heavier mothers produce heavier offspring than mothers of lower body mass (Wauters, Bijnens & Dhondt 1993). This in turn relates to the quality of the habitat that the female occupies and how much competition she encounters for that range (Wauters & Lens 1995). The fact that the red squirrels at Belleek Forest Park were at a low density and in receipt of supplementary food boosted the amount of recruitment that occurred in the woodland. With an average of three young per litter, females that were found to be in a breeding condition during each breeding season were used in calculating a potential number of offspring. 51 potential offspring were estimated, which when related to the number of new recruits tagged (43) indicates that most of the potential number of young were tagged during trapping sessions, and the ratio of young born to juveniles recruited was very high.

In comparison to the recruitment at Belleek Forest, new recruits in Derryclare were not captured in every trapping month. There were three months in which no new squirrels were tagged, twice during the summer months and once in the winter. 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). Eleven recruits were caught in the first session of trapping (June 2008) as the population at Derryclare was being visited for the first time since Poole's 2007 study was completed. During this initial trapping session six of the original translocated stock were 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 2010, reaching the upper limits of a wild squirrel's life expectancy. This longevity can be credited to the population being below the carrying capacity of the woodland, reducing intrasexual competition for food. The survival of these individuals was a positive sign of the condition of squirrels, as body condition is significantly correlated with survival (Wauters & Dhondt 1989a).

Weight and body size

After release, body weight was examined to assess the impact of translocation on squirrels to Belleek. During the first trapping session (August 2008) it was found the original squirrels recaptured had significantly increased their body weight. In general, red squirrels tend to have lower weights in the late spring to summer period and are at their maximum weight in autumn – winter (Kenward & Tonkin 1986). Red squirrels are able to attain a 12% increase in over-winter weight (Kenward & Holm 1989) as abdominal fat reserves increase during periods of high food availability. Lurz & Lloyd (2000) suggest that fat accumulation is less likely to be pronounced in conifer habitats where autumn and winter food supplies are more predictable. At Belleek Forest no significant difference was found in relation to season or year in body weight; this can be related to the availability of supplementary food throughout the year, rather than habitat quality. However, Magris & Gurnell (2002) found that there was no difference in the body mass of supplementary fed and non-fed animals. Klenner & Krebs

(1991) found that although supplementary feed increases the population density in the American red squirrel it did not affect juvenile and adult body mass. Thus, supplementary feeding can affect density but does not affect individual body mass and condition (Magris & Gurnell 2002). Squirrels in Belleek Forest Park were significantly heavier than those in Derryclare wood. This may be due to supplementary feeding, which had ended at Derryclare, but it may also just indicate a superior squirrel habitat in Belleek.

Body weight is intrinsically linked to body size (Wauters & Dhondt 1989b); squirrels with a larger body size weigh more, irrespective of age (Reilly 1997). In Belleek Forest it was found that body size did have an effect on body weight, with adult squirrels with a higher weight being larger in size. This increase in size may also be attributed to supplementary feed as well as predating on seed crops. Body weight, body length and habitat quality can all be correlated to survival, as heavier squirrels survive better than squirrels with a lower body weight (Wauters & Dhondt 1989a).

No seasonal body weight differences were found to be significant for red squirrels at Derryclare. This can be related to the persistent availability of food in the wood and the red squirrel's ability to cache food (Rice-Oxley 1993).

Sex ratios

The translocated red squirrels to Belleek Forest Park were in a sex ratio of 2:1 female to male. Models carried out by Poole (2007) recommended a minimum number of seven females and three males for translocation (at time of first breeding season). The number of females available to breed is important, however, parity is advisable as males induce oestrus in females, plus their home ranges may not encompass all the females at such low densities (Poole 2007). At Belleek a ratio of 1:1 (7 of each) was aimed for, however, the numbers of each were dictated to some degree by the squirrels caught. Two years after their introduction the red squirrels 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) suggests that this can be explained in terms of a self-correcting system based on natural selection acting on surpluses of males or females.

In contrast to Belleek Forest the sex ratio from live trapping data at Derryclare wood is male biased with all but one month showing roughly twice as many males to females. As the population at Derryclare has been established for longer this contradicts the concept that surpluses of males or females are evened out to produce a sex ratio of 1:1. However, the trapping grid occupies approximately 40 hectares of a much larger red squirrel range in which not all squirrels are being captured and hence may have skewed the results. As male squirrels have larger home ranges, they are more likely to come into contact with traps, and be examined.

Reproduction and breeding status

Throughout the live trapping study at Belleek, a high percentage of females were found to be in a breeding condition during the breeding season (December – October). The lowest percentage of females found to be breeding was in August 2008, however, a lot of juveniles were caught during this month. Red squirrels are seasonal breeders and mating may occur at any time between December and July, with the gestation period lasting approximately 38 days. In certain circumstances females can come into a second oestrus and become pregnant a second time in a year, once their first litter has weaned (Gurnell 1987). A female's body weight and condition determine the number of young weaned and whether a second litter is possible (Wauters & Dhondt 1989a, 1990). The fact that red squirrels at Belleek were able to utilise supplementary feed as well as natural resources may have had an influence on the number of females entering oestrus and successfully producing young. Shuttleworth (1997) found that supplementary feed did not enable females to enter oestrus any earlier or to produce more young at Formby, England. However, this may have been due to the high density of females occupying the coniferous woodland. At Belleek Forest the carrying capacity of the woodland had not been reached and hence intraspecific competition was not of high importance. Klenner and Krebs (1991) found that there was little difference in the proportion of males entering breeding condition but that adult females reached breeding condition one month earlier when supplementary food was available.

Male breeding condition was broken into three categories, non-reproductive, testes well developed and actively breeding (Reilly 1997). Those males that did not have a pigmented scrotum but were still well developed were placed in the second category. The hair on the scrotum becomes stained in actively breeding males (Gurnell 1987) explaining the use of three categories. The only month in which males were found not to be in a breeding condition was in November 2009, in all other months males were found to be in a breeding condition. This indicates potentially long breeding seasons in Belleek.

Males were found to be in a reproductive condition in every trapping month apart from October 2008 in Derryclare. There was no discernable difference in the duration of breeding seasons at the two woodlands. 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). In June 2008, February 2009 and June 2010, a high number of males caught were in breeding condition in Derryclare. It is possible that males were moving into the trapping area during this period in order to breed with local females. Overall, the breeding condition of both males and females was found to be high in the majority of the trapping sessions, proving that the population was still successfully producing offspring each year, and that conditions offered squirrels in Derryclare the opportunity of an extended breeding season.

Dispersal from woodland – Belleek Forest

In the initial feasibility study of Belleek Forest Park (Lawton 2006) it was clear that the isolation of the woodland would prevent the red squirrels from dispersing to other suitable habitat. During the post-release monitoring red squirrels were seen in areas around Belleek Forest Park and Ballina town by members of the public. It is the natural behaviour of young squirrels to seek to disperse to new habitats (Wauters, Somers & Dhondt 1997). Studies on Italian red squirrels have shown that exploring behaviour has caused squirrels to make excursions more than a kilometre in distance (Wauters, Casale & Foranasari 1997). Reports were verified that red squirrels had moved across to the eastern side of the river Moy. It is difficult to judge how red squirrels from the wood may have managed the crossing; the bridge is continually crossed by traffic but they may have moved across the river at low tide. Pauli (2005) reported sightings of the American red squirrel (*Tamiascuirus 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 being used. The third possibility is that red squirrels from other woodlands could have made excursions into the area. However, red squirrels have only been seen since the introduction of red squirrels to Belleek Forest Park. The farthest report of red squirrel dispersal is approx 6 km away from the woodland at Mount Falcon Hotel, which is surrounded by an area of trees. In each case it was verified the red squirrels have found suitable habitat, although invariably it was a small size and therefore would not support more than a minor number of individuals. The losses of red squirrels from Belleek may have been influenced by the 'hard' style of release caused by poor enclosure design. This did not impact on the overall success of the translocation, but certainly led to some animals being lost to the target wood, and this led to some concern amongst members of the public regarding the well-being of the squirrels. A perception that the red squirrels are fleeing the target area, particularly if some individuals are road casualties, could have an impact on public support for this type of conservation work

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 seeds (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).

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 recognised as Norway spruce, Scots pine, sitka spruce, larch, beech and oak.

Over the course of the study only one Norway spruce cone was counted. Norway spruce covers 25.9ha of woodland at Belleek, it was planted in the 1950s making the trees approximately 60 years old. At this age the production of cone crop has typically ended (Table 24). Another species with no seed production was oak; Belleek has approximately 4ha of pedunculate oak trees (*Quercus robur*) the majority of which were only planted in the last few years. Therefore, the four main species counted as target species for squirrel consumption were beech, Scots pine, sitka spruce and larch.

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, so an accurate estimation is not possible. The data can be used, however, to examine potential food available over time, and its implications for the red squirrel population.

Table 24: Seed producing capabilities for major tree species at Belleek Forest Park based on age (adapted from Tiernan *et al.* 2009)

Tree species	**Age of first good seed crop (years)**	**Age of maximum production (years)**	**Average yield in grams of clean seed/litre of cones**
Norway spruce	30-35	50-60	13
Larch - Japanese	15-20	40-60	14
Scots pine	15-20	60-100	6

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/m^2 and poor when fewer tree seeds were available; these assumptions were based on energy content per seed species and a squirrels daily requirement. Gurnell *et al.* (2001) suggest that a squirrel's daily requirement is between 400 to 700KJ per day. Beechnuts were found to be in good condition, as are many of the broadleaved species in the woodland. Plans to promote squirrel-friendly species and management of the wood to replace non-seed producing trees are important, and included in Coillte's management plan for the Forest Park (Tiernan *et al.* 2009).

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 autumn of each year as the vast majority of cones reach the ground by late autumn-winter (Lurz *et al*. 2000). There were two main species of coniferous trees available in Derryclare wood; lodgepole pine and sitka spruce. In 2008, 45% of transects examined were predominantly in sitka spruce stands, however, no eaten cones were found. In 2009, line transects were not conducted in these stands as the known squirrel distribution was found to be in lodgepole pine areas. 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. Throughout the two years only lodgepole pine cores were fed upon and as such the source of energy was only considered from this tree species. Radio-tracking confirmed the lodgepole pine stands and the Nature Reserve to be the key habitats for red squirrels in Derryclare.

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 of (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 as accurate measurements of cone predation by squirrels can be made as cone cores fall to the forest floor.

To determine the energy value of a lodgepole pine seed, values from calorific studies in the literature were used. Gurnell (1987) and Smith (1981) give a value of 20 – 40 tree seeds per lodgepole pine cone, given an energy value of 0.098 KJ per seed (Smith 1968), an average value of 2.94 KJ was derived for a lodgepole pine cone.

In 2008, a potential squirrel density of 0.42 to 0.74 squirrels per hectare was estimated (in lodgepole only). Studies in similar habitat 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 – 0.11 squirrels per hectare was below estimations made by live trapping data of 0.17 – 0.29 squirrels per hectare (MNP and Lincoln Index). In 2009, density estimations were similar to those the previous year (0.14 - 0.3 squirrels per hectare). 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 the 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.

Comparing the years 2008 and 2009 it was found that per m^2 there were 0.33 more cones available in 2008 and hence 0.98kJ per m^2 more energy available. However, it was found that there was 0.18 more cones counted that had been consumed by red squirrels in 2009 and hence 0.54 more energy (kJ per m^2) consumed.

As Derryclare has a 9ha Nature Reserve of broadleaved species adjoining the coniferous areas, this can provide a rich source of tree seeds for the population during the summer. The Nature Reserve was not studied for seed analysis in 2008 or 2009, however, it is considered a valuable source of food for the red squirrels and would offer optimum habitat at densities of up to one squirrel per hectare.

Indirect monitoring at Derryclare wood

In this study the dispersal of squirrels away from the trapping grid and into surrounding areas was investigated using two techniques; hair tube surveys and feeding transects. Initially hair tubes were used to assess the immediate areas surrounding the trapping grid and the presence or absence of squirrels. Detecting presence is simpler than proving absence; one squirrel hair or squirrel eaten cone core validates the presence of a squirrel, but the lack of these signs does not definitively validate the absence of the animal. Therefore, these methods were used for the detection of the presence of squirrels and how far they had spread into the woodland. In conifer forests, an assessment of the remains of complete cones and cone cores eaten by squirrels can provide information on spatial distribution and habitat use by squirrels (Gurnell, Lurz & Pepper 2001). Due to the arduous terrain feeding transects were used rather than hair tubes in areas adjacent to known squirrel dispersal. The presence of cone cores confirmed that squirrels had moved into the area.

Finnegan (2002) found that there was a positive correlation between the two indirect methods of hair tube surveys and cone core sampling. From three different sites Finnegan (2002) estimated a density of 0.11 – 0.7 from cone core sampling. In the more remote areas investigated in this study a density of 0.003 to 0.005 squirrels per hectare was found, indicating that although red squirrels had visited the area they had not yet established themselves in the area and the presence may have represented no more than 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) (Figure 23). It showed a relatively uniform spread through suitable habitat, delayed at times by large areas of unsuitable habitat (e.g. block 11, which is mainly clear fell and very young stands of trees). It is important for the well-being of the population at Derryclare and other similar large wooded areas, that fragmentation of stands within the wood is avoided, to allow free dispersal of squirrels from one area to another. Corridors linking stands and successional planning must be considered when producing the felling plan for the wood.

Donor woodlands

Between the translocation of red squirrels to Derryclare woodland and Belleek Forest Park, three donor sites were chosen (Finnegan 2007, Poole 2007). These sites were chosen based on assessments carried out via live trapping, which determined whether it was feasible to remove a large number of individuals from the source populations and whether any removal would not cause detrimental effects to the population. Once it was discovered that the source population was fit and healthy and of a suitable density, the removal of squirrels could begin.

The donor site for Derryclare was Portumna Forest Park, Co Galway. In Poole's (2007) initial study of the woodland an overall population estimate of 244 squirrels was obtained at a density of 0.93 squirrels per hectare. Difficulty was encountered in the selection process as suitable females were difficult to catch as many of the females were showing signs of lactation or were below the minimum weight threshold (210g). In total 19 red squirrels were taken from the woodland. Post removal studies were conducted in January – July 2006 using live trapping and line transects; it was found that even though the population had suffered an initial decrease it recovered quickly. In 2010, further investigation of the status of the red squirrel population at Portumna was undertaken, the main aim of this was to ensure that the population was still in a good condition five years after the removal of red squirrels. In this study hair tube surveys were to be used as a means to test for the presence of red squirrels as well as the density. The density calculated using Garson and Lurz's 1998 equation was quite low when compared to the previous density calculated in Poole's study, but there are question marks over using this formula for estimating squirrel density from hair tubes. All of the tubes would need to be positive for squirrel hair to achieve a density similar to Poole's original estimation for the wood. Finnegan (2002) found that estimating density from positive hair tubes using Garson and Lurz's equation disagreed with density determined by live trapping in an Irish woodland. To definitely compare the red squirrel population in Portumna in 2010 with that of 2005, a live trapping and line transect study would be required. The scope of this current project did not allow for such an investigation. As the population had recovered by the following year (2006) it would be difficult to link any actual drop in red squirrel numbers to the translocation, given the number of other variable which can influence squirrel populations. The red squirrel population in Portumna Forest Park has continued to thrive. Red squirrels used the hair tubes frequently and were easily seen or detected through searches for feeding signs during the survey. No ill effects to the population caused by the translocation were detected in this study.

Two donor sites were chosen for Belleek Forest Park and assessment was made before the first phase of translocation by Finnegan (2007). Potential donor sites were chosen from the north-west region of Ireland and were within a distance of 50km and a travel time of one hour. The donor sites were Lough Key Forest Park, Co Roscommon and Union wood, Co Sligo. Assessments were made using live trapping; results estimated a density of 0.22 squirrels/ha and 0.16 squirrels/ha respectively, giving a population estimate of 44 squirrels in Lough Key and 50 in Union wood. Finnegan found that compared with Portumna Forest Park these estimations were quite low, however, assessment was hindered by a low trapping success and it was assumed that actual population size was much higher. The low trapping success also influenced the amount of red squirrels translocated in 2007 (five individuals).

As 14 red squirrels were removed from Lough Key Forest Park, hair tube surveys were carried out to assess the post translocation status of the source site. The densities of red squirrels were again calculated using Garson & Lurz (1998) equation which was based on investigations made in 5 study sites in England. The results indicated a density of 0.319 squirrels per hectare for the complete sampling area, when compared to the original density of 0.22 squirrels per hectare (Finnegan 2007) which suggests that the population at Lough Key had not been impacted by the removal of squirrels for translocation. Although these densities taken from hair tubes are unreliable (see above), it does indicate a substantial number of squirrels were active in Lough Key after the translocation was completed.

In total only one squirrel was removed from Union wood, Co Sligo, this was due to a poor capture rate and lower density of squirrels at the site. As such the investigation into this site to evaluate density was deemed not to be necessary. However, the local Forest Manager (Coillte) was contacted to confirm that red squirrels were still a common sight at the woodland.

Conclusions and recommendations

The translocation of red squirrels to Belleek Forest Park can be 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.

Finnegan (2007) provided an assessment of donor sites that were also used in the two translocation phases of the current study. The re-evaluation of the donor sites shows that Finnegan's initial assessment was accurate in that they proved suitable source populations, which recovered well after the extraction of individual squirrels. These findings agree with Poole's (2007) model, that removal of individuals for a translocation has little impact on source populations, however, care must be taken not to overburden source populations. It is recommended that proper monitoring of source populations before and after translocation should be conducted as good practice. If a series of translocations are to take place they should be sourced from several areas, with no one area used in consecutive years or even within the same three year period (Poole 2007). A high number of individuals taken in a series of removals would cause a possible population crash over time. Several donor sites will also improve genetic integrity of translocated populations, but greatly increase the cost of the translocations.

The main problem with the translocation of red squirrels to Belleek Forest Park was the construction and reliability of the release enclosure. Initially a soft release programme was planned as it proved to be a success in other studies (Poole & Lawton 2009, Venning *et al*. 1997). However, the roof of the release enclosure at Belleek was not designed correctly and thus several of the squirrels escaped shortly after translocation. These individuals were found to come and go from the enclosure and take advantage of supplementary food placed inside, and the nest boxes provided. In retrospect this translocation was a hard release and therefore the first test of a successful translocation, that >75% of individuals survive to release from the enclosure, is not applicable here. That five squirrels were not captured subsequently and reports were received of squirrels beyond the boundaries of Belleek Forest Park before Belleek was at capacity, validates the use of soft release over hard release for the survival of the individuals, if not the success of the translocation overall.

As the grey squirrel has not established itself in the west of Ireland it puts the red squirrel stock there in a favourable position as it has not come into contact with the SQPV. Although no outbreaks of the virus have been reported in Ireland, it seems that the antibodies of the disease are present (M. McGoldrick *pers. comm*). The use of an enclosure allows for the continued assessment of individual health and presence of disease before release and as such is the preferred technique. By sourcing squirrels from grey squirrel free areas, the chance of disease impacting upon the translocation is greatly reduced.

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 core areas in the vicinity of a feeder. This also provides evidence that feeders can encourage squirrels to remain in the area of the woodland without distant excursive movements occurring. This is important if the woodland is particularly isolated, and dispersal is unlikely to be successful. However, the population must not become reliant on the supplementary feeders, or maintained at population densities that are otherwise untenable in the habitat. The supplementary feeding should be ended before the population grows beyond the densities predicted for the habitat during the feasibility study. In that way the supplementary feeding can help to ensure the early success of the translocation, but in the long term, the natural resources will dictate the density of the population.

During the fitting of radio collars in March 2008, two juveniles were caught. This provided evidence that the population had begun to breed, which was confirmed during the first session of live trapping in August 2008 when ten new recruits were captured. Overall, the capture of 67% of translocated stock subsequent to release and the capture of new recruits marked the translocation as a success overall as the objective that at least 50% of translocated stock survive to the breeding season and that the population should breed successfully was accomplished. This can be compared with a 68% survival rate to the following years breeding season (Poole & Lawton 2009) at Derryclare woodland.

The involvement of the Belleek Forest Park Enhancement Committee was important for the success of the translocation. Their continued support in promoting the project and help in supplementary feeding was a valuable asset in the development of the squirrel population. Costs were kept down thanks to the voluntary work they provided, and also in supplying materials and effort to build the enclosure, before the current project started. Stocking the supplementary feeders also facilitated the research team, allowing them to concentrate on other areas of the project. However, there were problems with the enclosure design and there was less control for project managers regarding the timing, quality and quantities of supplementary food being used. The use of voluntary groups is to be encouraged in conservation work, and can be very useful. However, the amount of time required to sufficiently educate, train and manage the volunteers, and to ensure that their input is focussed and effective, should not be underestimated..

As Belleek Forest is isolated from other woodlands it is considered to be part of a fragmented landscape. Carey *et al*. (2007) reported that the west of Ireland provides poor suitability for squirrel dispersal due to the lack of suitable corridors, the presence of lakes, peat land and mountainous regions; this can be highlighted by the lack of red squirrels in county Mayo and west county Galway. Landscape can have a positive or negative role on dispersal (Verboom & Apeldoorn 1990), including negative effects such as red squirrel casualties due to roadkill (Shuttleworth 2001), or squirrels not encountering suitable habitat after dispersal. It prevents red squirrels from naturally dispersing to other woods and hence decreases gene flow, local density and genetic diversity in the 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 a population was modelled. It was found that the mean probability of extinction (P(E)) in 10 years is less than 0.05 for the 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 (which is seen in the post-release monitoring in Derryclare where three originals were captured in 2010). It is only after four years that inbreeding starts to increase the threat of extinction to 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 at Derryclare required an addition of a further four pairs of squirrels. It was recommended that after the initial translocation, intervention is required once every 8 years on 4 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, show the need for long term management and commitment to the translocation projects.

It is important to note that these models are hypothetical rather than rigid predictions. However, these findings can be used when considering the fate of the population at Belleek Forest Park, as the two woodlands experience being isolated from other populations of red squirrels and thus the probability of extinction is relevant to both translocated populations. Therefore, long term management of the two translocated populations at Derryclare and Belleek is important to ensure the survival of red squirrels in these regions.

Through the experience gained after translocation of red squirrels to Belleek Forest Park and the recommendations made following Poole's (2007) translocation of red squirrels to Derryclare woodland, the practicalities of a successful translocation can be outlined.

It is recommended that a minimum initial breeding population of 13 individuals (with at least 7 females) is introduced in any future translocations. As the population will be over-wintering before they reach their first active breeding season, a minimum number of 19 to 20 individuals should be translocated, allowing for a survival rate of 67% through the winter. An additional one pair of squirrels should be added every eight years for the next 32 years, to negate the effects of inbreeding.

The feasibility studies correctly predicted the success of the two translocations and the short to medium term prospects for the new populations. These exercises are worthwhile and the knowledge available from these and previous translocations can be used to inform future translocation decisions.

A translocation project requires an experienced squirrel biologist to be involved in order to carry out the feasibility study on the target wood, and design the project if suitable. Prior experience in trapping and handling squirrels is preferable as red squirrels are difficult animals to work with (Gurnell & Pepper 1994) and training is necessary for any inexperienced fieldworker. The undertaking of a translocation project is labour intensive during the initial phases of the study as construction of the release enclosure, transport and placement of traps takes a lot of time and effort.

Materials required to perform a translocation must be sourced. These include: traps and handling equipment, bait, radio-tracking equipment (if deemed necessary), transport requirements for squirrels and fieldworkers, supplementary feeders and materials required to construct the release enclosure. Other practicalities include the selection of the donor woodlands, which require a separate survey assessing the status of the source populations. It is important also to consider distance between woodlands, the ability to construct enclosures and the amount of disturbance that the public may induce while squirrels are being held in the enclosure.

It is vital that the cooperation of the owner of the target woodland is gained, and the long-term management implications clearly set out. This includes ensuring a sustainable felling plan is adhered to, continuous connectivity between woodland patches are maintained and that the squirrels are considered in any future planting decisions.

When determining the suitability of a woodland to host a translocation, an estimation must be made on the red squirrel carrying capacity of that site. Many factors influence the viability of a population, but as a minimum, a relatively isolated woodland must be able to provide sufficient resources for 60 to 80 red squirrels. The carrying capacity is determined by the habitat type; red squirrels tend to range in density from 0.32 squirrels per hectare (Lurz & Garson 1997) for sitka spruce/lodgepole pine plantation to 1.0 squirrels per hectare (Holm 1991) in broadleaved woodland. This means a minimum woodland size of 60 to 80 hectares for mature broadleaved forests and 187.5 to 250 hectares for mixed conifer plantations. Monoculture sitka spruce woodland is unlikely to offer sufficient resources to retain newly introduced red squirrels in a site and should be avoided.

The final practicality to consider when planning a translocation is the financial costs. In general, two main costs should be calculated, the labour costs and the material elements. Labour costs will be high as translocation is very time consuming both in the capture and movement phase and the post-release monitoring. Mileage is also a cost not to be under-estimated. Due to the fact that a translocation is a long-term study with many phases to consider, a time frame of 24 months is an absolute minimum required to complete the study, which would include a short period of initial post-release monitoring, but not the longer term monitoring of populations stipulated by the IUCN (1998).

The reasons for protecting the red squirrel are important to note and are two-fold, the conservation of a native species and the economic impact of a publicly charismatic species.

Conserving the red squirrel is important in promoting biodiversity in Ireland and as such comes into the National Biodiversity Plan outlined by the Irish government in their commitment to maintain and enhance biodiversity. Red squirrels also have an important ecological role to perform in forests; foraging activities and caching behaviour can aid seed dispersal and promote sapling growth (Jensen

1985). The red squirrel can also be used as an educational tool in order to demonstrate the impact that an introduced species can have on a native species and the implications in preserving that species.

The second aspect is the red squirrel's role in eco-tourism attraction. In England the North West Development Agency (NWDA 2005) estimated that red squirrels at Formby Nature Reserve attract a tourist spend of £1 million every year. In Wales, eco-tourism was listed as one of the reasons for commencing a red squirrel conservation project on Anglesey (Shuttleworth 2003). In Scotland, red squirrel sightings are a highlight of eco-tourism websites (www.ecotourismblog.com, 2010).

The red squirrel has been targeted as a species for concern and is protected under the Irish Wildlife Act (1976) and Amendment Act (2000). The All Ireland Species Action Plan (2008) set out several means by which the species may be conserved. The advantages of using translocation, which was listed in the Action 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 any detrimental effects. The main disadvantage associated with translocation is the financial cost, although this may not be prohibitive compared to immunocontraceptives or vaccines if and when they become available. The cost of translocation can be offset if an income attached to eco-tourism can be raised.

Two primary requirements for translocation to be feasible were outlined by Poole (2007). The first is the existence of potential target woodlands to which red squirrels can be moved. In Ireland these may not be found in the eastern half of the country where the grey squirrel is widespread and well established and where few natural barriers can be found to prevent the further spread of the introduced species. Grey squirrel eradication is absolutely essential before any translocation takes place in these regions. Recolonisation of greys must not be possible, and in the long term it is difficult to see how this can be prevented, given the rapidity and ease by which grey squirrel recolonisation can occur (Lawton & Rochford 2007). Until a permanent means of removing grey squirrels from a woodland is developed, translocation is only suitable in areas removed from the current grey squirrel distribution.

It is along western counties such as Donegal, Galway, Mayo, Clare and Kerry, where the landscape is unfavourable for squirrel dispersal that there is a better chance of finding suitable target sites, without the threat from grey squirrels. Suitable woods in these counties should be assessed in order to design a programme of translocations.

REFERENCES

Andren, H. and Lemnell, P. A. (1992). Population fluctuations and habitat selection in the Eurasian red squirrel, *Sciurus vulgaris*. *Ecography* **15**: 303-307.

Barrington, R. (1880). On the introduction of the squirrel into Ireland. *Scientific Proceedings, Royal Dublin Society.* 615 - 631.

Bath, S. K., Hayter., A. J., Cairns, D. A. and Anderson, C. (2006). Characterisation of home range using point peeling algorithms. *The Journal of Wildlife Management* **70**(2): 422 - 434.

Begon, M. (1979). *Investigating animal abundance; capture-recapture for biologists.* Edward Arnold Ltd. University of Liverpool.

Bertolino, S., Lurz, P. W. W. and Rushton, S. P. (2006). *Prediction of the grey squirrel spread from Italy into adjacent countries, For the European Squirrel Initiative (ESI)* University of Newcastle.

Bertram, B. C. R. and Moltu, D. P. (1986). Reintroducing red squirrels into Regent's Park. *Mammal Review* **16**(2): 81-88.

Brandl, R., Bezzel, E., Reichholf, J. and Volkl, W. (1991). Population dynamics of the red squirrel in Bavaria. *Zeitschrift für Saugetierkunde* **56**: 10-18.

Bright, P. W. and. Morris, P. A. (1994). Animal translocation for conservation: performance of dormice in relation to release methods, origin and season. *Journal of Applied Ecology* **31**: 699 - 708.

Bruemmer, C. M., Rushton, S. P., Gurnell, J., Lurz, P. W. W., Nettleton, P., Sainsbury, A. W. and Duff, J. P. (2010). Epidemiology of squirrelpox virus in grey squirrels in the UK. *Epidemiology and Infection* **138**: 941 - 950.

Bryce, J., Cartmel, S. and Quine, C. P. (2005). *Habitat use by red and grey squirrels: Results of two recent studies and implications for management*. Forestry Commission Information Note FCIN076, Edinburgh.

Carey, M., Hamilton, G., Poole, A. and Lawton, C. (2007). *The Irish squirrel survey 2007.* COFORD, Dublin.

Cartmel, S. (1997). A study of red and grey squirrels in Clocaenog Forest, North Wales: A preliminary study**.** In: *The conservation of red squirrels* Sciurus vulgaris *L.* PTES, London, 89 - 96.

Coillte (2004). *Derryclare Forest Inventory*. Coillte, Newtownmountkennedy, Co. Wicklow.

de Buitlear, E. (1993). *Ireland's Wild Countryside*. Boxtree Ltd., London.

Ecotourism Scotland (2010). http:// www.ecotourismblog.com

Fahy, O. J., Muller, M., Gabbet, M., Gormally, M. and Sheehy Skeffington, M. (1999). *Derryclare Wood: a multidisciplinary study of its structure and age.* National University of Ireland, Galway.

Fairley, J. (1984). *An Irish Beast Book,* The Blackstaff Press, Belfast.

Fairley, J., Tangney, D., Hassett, S., Kirby, N., O'Donnell, G. and McAney, K. (1995). *The Mammals of the Park - Connemara National Park.* Office of Public Work, Galway.

Finnegan, L. (2002). *A study of the potential use of hair tubes as an indirect method for estimating squirrel densities.* B. Sc. (Mod) thesis, Department of Zoology, Trinity College, Dublin.

Finnegan, L. (2007). *The translocation of red squirrel (Sciurus vulgaris) to Belleek Forest Park, Mayo - Phase one*. Unpublished report to the National Parks and Wildlife Service, Dublin.

Finnegan, L., Edwards, C. and Rochford, J. (2008). Origin of, and conservation units in, the Irish red squirrel (*Sciurus vulgaris*) popultion. *Conservation Genetics* **9**: 1099-1109.

Finnegan, L., Hamilton, G., Perol, J.and Rochford, J. (2007). The use of hair tubes as an indirect method for monitoring red and grey squirrel populations. *Biology and Environment-Proceedings of the Royal Irish Academy* **107B**: 55-60.

Fornasari, L., Casale, P. and Wauters, L. (1997). Red squirrel conservation: the assessment of a reintroduction experiment. *Italian Journal of Zoology* **64**: 163-167.

Fossit, J. A. (2000). *A Guide to Habitats in Ireland*, The Heritage Council, Kilkenny.

Fowler, J., Cohen, L. and Jarvis, P. (1998). *Practical statistics for field biology*. Wiley, New York.

Garson, P. J. and Lurz, P. W. W. (1998). *Red Squirrel monitoring: the potential of hair-tubes for estimating squirrel abundance*. Draft Report, Department of Agriculture and Environmental Science, University of Newcastle.

Goldstein, E. A. (2009). *Post-translocation monitoring of a red squirrel (Sciurus vulgaris L.) source population in Lough Key Forest Park, Co. Roscommon*. Master's Thesis, National University of Ireland, Galway.

Griffith, B., Scott, J. M., Carpenter, J. W. and Reed, C. (1989). Translocation as a species conservation tool: status and strategy. *Science* **245**: 477 - 480.

Gurnell, J. (1983). Squirrel numbers and the abundance of tree seeds. *Mammal Review* **13**(2/3/4): 133-148.

Gurnell, J. (1987). *The Natural History of Squirrels*. Christopher Helm Ltd., Oxford.

Gurnell, J., Lurz, P. W. W. and Pepper, H. (2001). Practical techniques for surveying and monitoring squirrels. Forestry Commission. Edinburgh.

Gurnell, J. and Pepper, H. (1993). A critical look at conserving the British red squirrel *Sciurus vulgaris*. *Mammal Review* **23**(3/4): 127-137.

Gurnell, J. and Pepper, H. (1994). *Red squirrel conservation: Field study methods*. Forestry Commission, Edinburgh.

Gurnell, J., Rushton, S. P., Lurz, P. W. W., Sainsbury, A. W., Nettleton, P., Shirley, M. D. F., Bruemmer, C. and Geddes, N. (2006). Squirrel poxvirus: Landscape scale strategies for managing disease threat. *Biological Conservation* **131**: 287-295.

Harris, S. and Yalden, D. W. (2008). *Mammals of the British Isles: Handbook*. The Mammal Society.

Hayden, T. and Harrington, R. (2000). *Exploring Irish Mammals,* Town House, Dublin.

Hochkirch, A., Witzenberger, K. A., Teerling, A. and Niemeyer, F. (2008). Translocation of an endangered insect species, the field cricket (*Gryllus campetris* Linnaeus 1758) in northern Germany. *Biodiversity Conservation* **7**: 355 - 365.

Hodder, K. H. and Kenward, R. E. (1998). Estimating core ranges: a comparison of techniques using the common buzzard (*Buteo buteo*). *Journal of Raptor Research* **32**(2): 82-89.

Hodder, K. H. and Bullock, J.M. (1997). Translocations of native species in the UK: Implications for biodiversity. *Journal of Applied Ecology* **34**(3): 547-565.

Holm, J. (1991). *The ecology of red squirrels* (Sciurus vulgaris) *in deciduous woodland*. PhD thesis, University of London.

IUCN (1987). *The IUCN Position Statement on Translocation of Living Organisms.* Prepared by the IUCN/SSC Re-introduction Specialist. IUCN, Gland, Switzerland and Cambridge UK.

IUCN (1998). *Guidelines for Re-introductions*. Prepared by the IUCN/SSC Re-introduction Specialist Group, IUCN, Gland, Switzerland and Cambridge, UK.

Jackson, N., Shuttleworth, C. and Kenward, R. E.. (2002). *Red squirrel* Sciurus vulgaris *reintroduction into Newborough forest: a pilot study.* Forestry Commission, UK.

Jackson, N. (1998). Two trial releases of captive-bred red squirrels to a woodland site in Colwyn bay, North Wales. In: *3rd NPI Red Alert UK Forum for Red Squirrel Conservation.* Collins, L., Cooper, M. (eds.) Scottish Natural Heritage, pp. 67 - 78.

Jensen, T. S. (1985). Seed-seed predator interactions of European beech, *Fagus silvatica* and forest rodents, *Clethrionomys glareolus* and *Apodemus flavicollis*. *Oikos* **44**: 149 - 156.

Kenward, R. E. and Hodder, K. H. (1998). Red squirrels (*Sciurus vulgaris*) released in conifer woodland: the effects of source habitat, predation and interactions with grey squirrels (*Sciurus carolinensis*). *Journal of Zoology* **244**(1): 23-32.

Kenward, R. E. and Holm, J. L. (1989). What future for British red squirrels? *Biological Journal of the Linnean Society* **38**: 83 - 89.

Kenward, R. E. and Tonkin, J. M. (1986). Red and grey squirrels; some behavioural and biometric differences. *Journal of Zoology* **209**: 279 - 304.

Klenner, W. and Krebs, C. J. (1991). Red squirrel population dynamics I. The effect of supplemental Food on demography. *The Journal of Animal Ecology* **60**(3): 961-97.

Lawton, C. (1999). *Grey squirrel* (Sciurus carolinensis) *ecology in managed broadleaved woodland.* Ph.D. Thesis, Department of Zoology, Trinity College Dublin.

Lawton, C. (2006). *Belleek wood as a potential translocation site for red squirrels (*Sciurus vulgaris*) - An assessment*. Unpubished report to the National Parks and Wildlife Service, Dublin.

Lawton, C. and Rochford, J. (2007). The recovery of grey squirrel (*Sciurus carolinensis*) populations after intensive control programmes. *Biology and Environment* **107** (1), 19-29.

Lurz, P. W. W. and Garson, P. J. (1997). Forest management for red squirrels in conifer woodlands: a northern perspective**.** In**:** *The Conservation of Red Squirrels,* Sciurus vulgaris *L.* PTES, London, 145-151.

Lurz, P. W. W., Garson, P. J. and Ogilvie, J. F. (1998). Conifer species mixtures, cone crops and red squirrel conservation. *Forestry* **71**(1): 67-71.

Lurz, P. W. W., Garson, P. J. and Rushton, S. P. (1995). The ecology of squirrels in spruce dominated plantations: implications for forest management. *Forest Ecology and Management* **79**(1-2): 79-90.

Lurz, P. W. W., Garson, P. J. and Wauters, L. (2000). Effects of temporal and spatial variations in food supply on the space and habitat use of red squirrels (*Sciurus vulgaris* L.). *Journal of Zoology* **251**: 167-178.

Lurz, P. W. W., Gurnell, J. and Magris, L. (2005). *Sciurus vulgaris.* Mammalian Species No. 769. *American Society of Mammalogists*: 1-10.

Lurz, P. W. W. and Lloyd, A. J. (2000). Body weights in grey and red squirrels: do seasonal weight increases occur in conifer woodland? *Journal of Zoolgy* **252**: 539-543.

Lynch, A. B., Brown, M. J. F. and Rochford, J. M. (2006). Fur snagging as a method of evaluating the presence and abundance of a small carnivore, the pine marten (*Martes martes*) *Journal of Zoology* **270**: 330 - 339.

MacKinnon, K. (1978). Competition between Red and Grey Squirrels. *Mammal Review* **8**(4): 185-190.

Magris, L. and Gurnell, J. (2002). Population ecology of the red squirrel (*Sciurus vulgaris*) in a fragmented woodland ecosystem on the Island of Jersey, Channel Islands. *Journal of Zoology* **256**: 99 - 112.

Marnell, F. Kingston, N. and Looney, D. (2009). *Ireland Red List No. 3: Terrestrial Mammals*, National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin, Ireland.

McInnes, C. J., Coulter, L., Dagleish, M. P., Fiegna, C., Gilray, J., Willoughby, K., Cole, M., Milne, E., Everest, D. J. and MacMaster, A. M. (2009). First cases of squirrelpox in red squirrels (*Sciurus vulgaris*) in Scotland. *Veterinary Record* **164**: 528 - 531.

McKay, F.D., Sainsbury, A.W., Nettleton, P. and Graham, D. (2004). *The seroprevalence of squirrel poxvirus in grey squirrels (*Sciurus carolinensis*) in Northern Ireland in relation to red and grey squirrel distribution and habitat.* Unpublished MSC thesis, University of London.

Moffat, C. B. (1923). Is the squirrel a native of Ireland? *The Irish Naturalist Journal* **32**(4): 33-35.

Moller, H. (1983). Foods and foraging behaviour of red (*Sciurus vulgaris*) and grey (*Sciurus carolinensis*) squirrels. *Mammal Review* **13**: 81 - 98.

Moller, H. (1986). Red squirrels (*Sciurus vulgaris*) feeding in a Scots pine plantation in Scotland UK. *Journal of Zoology* **209**: 61-83.

Nelson, N. J., Keall, S. N., Brown, D. and Daugherty, C. H. (2002). Establishing a new wild population of Tuatara (*Sphenodon guntheri*). *Conservation Biology* **16**(4): 887 - 894.

NPWS (1968). *The distribution of red and grey squirrels in Ireland*. Unpublished internal report, Office of Public Works, Dublin

NPWS & EHS (2008). *All Ireland Species Action Plan, Red Squirrel*. Environment & Heritage Service, Belfast and National Parks & Wildlife Service, Dublin.

NWDA (2005). *Nature's Edge - Investing in sustainable development and a natural advantage for England's Northwest*. The Northwest Regional Development Agency.

O'Toole, L., Fielding, A. H. and Haworth, P. F. (2002). Re-introduction of the golden eagle into the Republic of Ireland. *Biological Conservation* **103**: 303 - 312.

O' Teangana, D., Russ, J. M., Mathers, R. G. and Montgomery, W. I. (2000). Habitat associations of the red squirrel *Sciurus vulgaris* and the grey squirrel *Sciurus carolinensis* in Northern Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy* **100B**(1): 27-33.

Pauli, J. N. (2005). Evidence of long-distance swimming capabilities in red squirrels *Tamiasciurus hudsonicus*. *Northeastern Naturalist* **12**(2): 245 - 248.

Poole, A. (2007). *An investigation of translocation as a technique to conserve the red squirrel (*Sciurus vulgaris*) in Ireland.* Ph.D. Thesis, Department of Zoology, NUI Galway

Poole, A. and Lawton, C. (2009). The translocation and post release settlement of red squirrels *Sciurus vulgaris* to a previously uninhabited woodland. *Biodiversity Conservation* **18**: 3205 - 3218.

Quinn, N. (2005). *The hair tube analysis and supplementary feeding of red squirrels (*Sciurus vulgaris*, L.) in Portumna Forest Park, Co Galway*. Unpublished B.Sc. Thesis, Department of Zoology, National University of Ireland, Galway, Galway.

Reilly, S. (1997). *Aspects of the ecology of the red squirrel,* Sciurus vulgaris*, in commercial conifer forests*. Department of Zoology, Trinity College, University of Dublin.

Reynolds, J. C. (1985). Autumn-winter energetics of Holarctic tree squirrels: a review. *Mammal Review* **15**(3): 137-150.

Reynolds, J. C. and Bentley, S. (2001). *Selecting forest reserves for red squirrel conservation.* Unpublished Paper for England Squirrel Group.

Rice-Oxley, S. B. (1993). Caching behaviour of Red Squirrels *Sciurus vulgaris* under conditions of high food availabilty. *Mammal Review* **23**(2): 93-100.

Rushton, S. P., Lurz, P. W. W., South, A. B. and Mitchell-Jones, A. (1999). Modelling the distribution of red squirrels (*Sciurus vulgaris*) on the Isle of Wight. *Animal Conservation* **2**(02): 111-120.

Sainsbury, A. and Gurnell, J. (1995). An investigation into the health and welfare of red squirrels, *Sciurus vulgaris*, involved in reintroduction studies. *Veterinary Record* **137**: 367 - 370.

Scharff, R. F. (1923). The squirrel in Ireland. *The Irish Naturalist Journal* **32**(6): 63.

Sheehy, E. (2009). *Feeding Ecology of a Translocated Population of Red Squirrels,* Sciurus vulgaris*, in Derryclare Wood, Connemara.* B.Sc. Thesis, Department of Zoology, National University of Ireland Galway.

Shuttleworth, C. M. (1997). The effect of supplemental feeding on the diet, population density and reproduction of red squirrels (*Sciurus vulgaris*). In: *The Conservation of the Red Squirrel* Sciurus vulgaris, *L.* PTES, London, 13 - 24.

Shuttleworth, C. M. (2001). Traffic related mortality in a red squirrel (*Sciurus vulgaris*) population receiving supplemental feeding. *Urban Ecosystems* **5**(2): 109-118.

Shuttleworth, C. M. (2003). A tough nut to crack: red squirrel conservation in Wales. *Biologist* **50**: 231 - 235.

Skelcher, G. (1997). The ecological replacement of red by grey squirrels**.** In: The Conservation of Red Squirrel Sciurus vulgaris *L.* PTES, London. 67-78.

Smith, C. (1968). The adaptive nature of social organisation in the genus of tree squirrels *Tamiasciurus*. *Ecological Monographs* **38**: 31 - 64.

Smith, C. (1981). The indivisible niche of *Tamiasciurus*: An example of nonpartitioning of resources. *Ecological Monographs* **51**(3): 343 - 363.

Teerink, B. J. (1991). *Hair of West-European Mammals*, Cambridge University Press.

Tiernan, D., McEvey, J. and Collins, C. (2009). *Belleek long term forest management plan*, Coillte Teoranta, Davitt House, Castlebar, Co Mayo.

Tompkins, D. M., White, A. R. and Boots, M. (2003). Ecological replacement of native red squirrels by invasive greys driven by disease. *Ecology Letters* **6**(3): 189-196.

Tonkin, J. M. (1983). Activity patterns of the red squirrel (*Sciurus vulgaris*). *Mammal Review* **13**(2-4): 99-111.

Venning, T., Sainsbury, T. and Gurnell, J. (1997). Red squirrel translocation and population reinforcement as a conservation tactic. In: *The Conservation of the Red Squirrel* Sciurus vulgaris, *L.* PTES, London, 133-143.

Verboom, B. and Apeldoorn, R. V. (1990). Effects of habitat fragmentation on the red squirrel, *Sciurus vulgaris* L. *Landscape Ecology* **4**(2/3): 171-176.

Watt, H.B. (1923). The American grey squirrel in Ireland. *Irish Naturalists Journal* **32**(9): 95.

Wauters, L. (1997). The ecology of red squirrels in fragmented habitats: a review. In: *The Conservation of the Red Squirrel* Sciurus vulgaris, *L.* PTES, London, 5 - 12.

Wauters, L., Bijnens, L. and Dhondt, A. A. (1993). Body mass at weaning and juvenile recruitment in the red squirrel. *Ecology* **62**: 280-286.

Wauters, L., Casale, P. and Fornasari, L. (1997). Post-release behaviour, home range establishment and settlement success of reintroduced red squirrels. *Italian Journal of Zoology* **64**: 169 - 175.

Wauters, L., Currado, I., Mazzoglio, P.J. and Gurnell, J. (1997). Replacement of red squirrels by introduced grey squirrels in Italy: Evidence from a distribution survey. In: *The Conservation of the Red Squirrel* Sciurus vulgaris, *L.* PTES, London, 79 - 88.

Wauters, L. and Dhondt, A. A. (1989a). Body weight, longevity and reproductive success in red squirrels (*Sciurus vulgaris*). *The Journal of Animal Ecology* **58**(2): 637-651.

Wauters, L. and Dhondt, A. A. (1989b). Variation in length and body weight of the red squirrel (*Sciurus vulgaris*) in two different habitats. *Journal of Zoology* **217**: 93 - 106.

Wauters, L. and Dhondt, A. A. (1990). Red Squirrel (*Sciurus vulgaris* Linnaeus 1758) population dynamics in different habitats. *Z. Saugetierkunde* **55**: 161-175.

Wauters, L. and Dhondt, A. A. (1992). Spacing behaviour of red squirrels, *Sciurus vulgaris*: variation between habitats and the sexes. *Animal Behaviour* **43**: 297-311.

Wauters, L. and Dhondt, A. A. (1993). Immigration pattern and success in red squirrels. *Behavioural Ecology and Sociobiololgy* **33**(3): 159-167.

Wauters, L., Gurnell, J., Martinoli, A. and Tosi, G. (2002). Interspecific competition between native Eurasian red squirrels and alien grey squirrels: does resource partitioning occur? *Behavioral Ecology and Sociobiology* **52**(4): 332-341.

Wauters, L., Hutchinson, Y., Parkin, D. T. and Dhondt, A. A. (1994). The effects of habitat fragmentation on demography and on the loss of genetic variation. *Proceedings: Biological Sciences* **255**(1343): 107 - 111.

Wauters, L., Bertolino, S., Adamo, M., Van Dongen, S. and Tosi, G. (2005). Food shortage disrupts social organization: The case of red squirrels in conifer forests. *Evolutionary Ecology* **19**(4): 375-404.

Wauters, L. A. and Dhondt, A. A. (1987). Activity budget and foraging behaviour of the red squirrel (*Sciurus vulgaris* Linnaeus, 1758) in a coniferous habitat. *Zeitschrift fur Saugetierkunde* **52**: 341-353.

Wauters, L. A. and Dhondt, A. A. (1995). Lifetime reproductive success and its correlates in female Eurasian red squirrels. *Oikos* **72**: 402-410.

Wauters, L. A., Githiru, M., Bertolino, S., Molinari, A., Tosi, G. and Lens, L. (2008). Demography of alpine red squirrel populations in relation to fluctuations in seed crop size. *Ecography* **31**(1): 104-114.

Wauters, L. A. and Lens, L. (1995). Effects of food availablity and density on red squirrel (*Sciurus vulgaris*) reproduction. *Ecology* **76**(8): 2460-2469.

Wauters, L. A., Lens, L. and Dhondt, A. A. (1995). Variation in territory fidelity and territory shifts among red squirrel, *Sciurus vulgaris*, females. *Animal Behaviour* **49**: 187-193.

Wauters, L. A., Lurz, P. W. W. and Gurnell, J. (2000). Interspecific effects of grey squirrels (*Sciurus carolinensis*) on the space use and population demography of red squirrels (*Sciurus vulgaris*) in conifer plantations. *Ecological Research* **15**(3): 271-284.

Wauters, L. A., Somers, L. and Dhondt, A. A. (1997). Settlement behaviour and population dynamics of reintroduced red squirrels *Sciurus vulgaris* in a park in Antwerp, Belgium. *Biological Conservation* **82**: 101-107.

Wauters, L. and Dhondt, A. A. (1986). Activity budget and foraging behaviour of the red squirrel (*Sciurus vulgaris* Linnaeus, 1758) in a coniferous habitat. *Zeitschrift fur Saugetierkunde* **55**: 341 - 353.

Wauters, L., Matthysen, E., Adriaensen, F. and Tosi, G. (2004). Within-sex density dependence and population dynamics of red squirrels *Sciurus vulgaris*. *Journal of Animal Ecology* **73**: 11-25.

Wilson, D. E. and Reeder, D. M. (2005). *Mammal Species of the World: A Taxonomic and Geographic Reference*. Third Edition, Volume 2. The John Hopkins University Press, Baltimore.