Red Squirrels of Raven Point: A priority for protection.

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Executive summary:

Two species of squirrel are found in Ireland, the European red squirrel (*Sciurus vulgaris*) and the Eastern grey squirrel (*Sciurus carolinensis*). The introduced grey squirrel is now found in 26 of the 32 counties and their continued expansion has coincided with a decline in red squirrel numbers and a contraction of their range within Ireland. The Irish Squirrel Survey 2007 showed that although red squirrels are abundant in Ireland they have largely disappeared from a four counties in the Leinster region - Meath, Westmeath, Carlow, Kilkenny. Given these findings, there is a clear threat to the continued existence of red squirrels in the Leinster region and any remaining strongholds should be identified and protected from invasion by grey squirrels. Five Red Squirrel Preferred Areas (RSPAs) have been identified in Northern Ireland which are intended to provide a focus for conservation measures. Identifying potential RSPAs in the Republic of Ireland is a proposed action under the All-Ireland Species Action Plan for the Red Squirrel 2008. The aim of this report is to assess the red squirrel population and examine the potential of Raven Point Nature Reserve in Wexford as a RSPA using the criteria of Reynolds and Bentley (2001).

Although it is not known when red squirrels first became established within the Raven, the results of this study indicate that the Raven is currently home to a substantial healthy population of ~319 red squirrels with an overall estimated density of 1.39 squirrels per hectare. Evidence of habitat-related density is observed in the Raven. Density varied significantly throughout the woodland ranging from 3.47 squirrels per hectare in the northern section to 1.07 squirrels per hectare in the southern section. This variation in density coincided with variation in tree diversity which was also associated with variation in the diet of the squirrels. Squirrels were observed feeding on five tree species: Corsican pine (*Pinus nigra maritima*), Lodgepole pine (*Pinus contorta*), Scot's pine (*Pinus sylvestris*), Maritime pine (*Pinus pinaster*) and Shore pine (*Pinus contorta contorta*). Corsican pine constituted the majority of feeding records (68%) with Lodgepole pine being the next most frequently observed (23%). In the area with the highest density and where the diversity of trees was also highest, the diet was more evenly spread between Corsican pine and Lodgepole pine with Scot's pine also representing a significant proportion of observations. The mean adult body weight of the Raven squirrels of 330g indicates a healthy population with no evidence of food shortages. This is further substantiated by both the estimated breeding rate of 0.73 and the degree of overlap in home ranges of radio-collared squirrels.

Reynolds and Bentley (2001) suggest the use of 4 main criteria in the assessment of a potential red squirrel reserve. These include: (1) the magnitude of the threat from grey squirrels, (2) the extent and suitability of habitat, (3) site defendability and (4) site management. Overall, the Raven is rated in the highest category for 3 of the 4 criteria and in the next best category for the remaining criterion. It is also home to an extensive healthy red squirrel population. It is unlikely that any of the remaining red squirrel populations in the Leinster region will be as highly rated given that most are found within large commercial plantations in Wicklow and the Laois-Offaly region which would prove impossible to defend from grey squirrel invasion. It is therefore recommended that the Raven be considered of the highest priority for protected and designation as an RSPA.

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1. Introduction:

Two species of squirrel are found in Ireland, the European red squirrel (*Sciurus vulgaris*) and the Eastern grey squirrel (*Sciurus carolinensis*). The red squirrel is considered to be an indigenous Irish species with recent genetic work indicating that the current population may be a mixture of both native and translocated stock from Britain (Finnegan, Edwards and Rochford 2008). The grey squirrel was introduced at Castleforbes, Co. Longford in 1911 (Watt 1923). Since then it has spread rapidly and is now found in 26 of the 32 counties (Carey *et al.* 2007). The rapid expansion of grey squirrels has been accompanied by a decline in red squirrel numbers and a contraction of their range within Ireland. This is generally considered to be due to the ability of grey squirrels to out-compete red squirrels.

The exact nature of any competitive advantage of grey squirrels is still not clearly understood and may vary depending on habitat. Studies of coniferous woodland where both species coexist have shown no evidence that either the proportion of red females breeding or red adult survival rates are reduced in the presence of greys (Wauters and Gurnell 1999; Wauters, Lurz and Gurnell 2000). There was also little direct interspecific competition between reds and greys (Wauters *et al.* 2000). However, female red squirrel fecundity and juvenile recruitment were reduced in the presence of greys (Wauters and Gurnell 1999; Gurnell *et al.* 2004). In deciduous woodland, grey squirrels are better able to exploit acorns before they are ripe and available to reds. This is predicted to result in the slow replacement of reds by greys (Kenward and Holm 1993). The difference in feeding abilities between the two species in this habitat is likely to make reds more susceptible to food shortages (Gurnell and Pepper 1993), which could lead to a reduction in the number of breeding females and subsequent recruitment into the population. Juvenile male red squirrels also find it difficult to establish a territory in the presence of greys. Thus any competitive advantage is likely to be greatest in deciduous woodland and populations can coexist for longer in coniferous habitats (Bryce, Johnson and MacDonald 2002).

Red squirrel populations seem particularly susceptible to disease and have historically suffered numerous declines as a result (Edwards 1962; Vizoso 1968; Scott, Keymer and Labram 1981; Keymer 1983). Of particular concern in Britain currently is infection with squirrel poxvirus (SQPV). This disease has been shown to be a significant factor in red squirrel population declines (Tompkins *et al.* 2002; Tompkins, White and Boots 2003). Grey squirrels act as hosts without developing the disease (Sainsbury *et al.* 2000) and as they colonise a new area they spread the disease into previously unexposed red populations. Although no clinical cases of SQPV have thus far been observed in Ireland, grey squirrels have been found to have antibodies to the disease both in Northern Ireland (McKay *et al.* 2004) and also in the Republic (Colin Lawton, personal communication).

The Irish Squirrel Survey 2007 showed that although red squirrels are still abundant in Ireland they have largely disappeared from a number of counties in the Leinster region - Meath, Westmeath, Carlow, Kilkenny and are under threat elsewhere because of the presence of the grey squirrel (see figure 1). The speed of this replacement is of grave concern. Reds have been almost completely replaced by greys in Carlow and Kilkenny in the space of only

10 years (Carey *et al.* 2007). Since the previous survey (1997), grey squirrels had increased significantly along the eastern seaboard, from where they had been predominantly absent. With the estimated rate of range expansion of 5 km/yr, it is predicted that in Wexford a convergence of two grey squirrel populations, spreading south from Wicklow and east from Kilkenny, will soon occur. Given these findings, there is a clear threat to the continued existence of red squirrels in the Leinster region and any remaining strongholds should be identified and protected from invasion by grey squirrels.

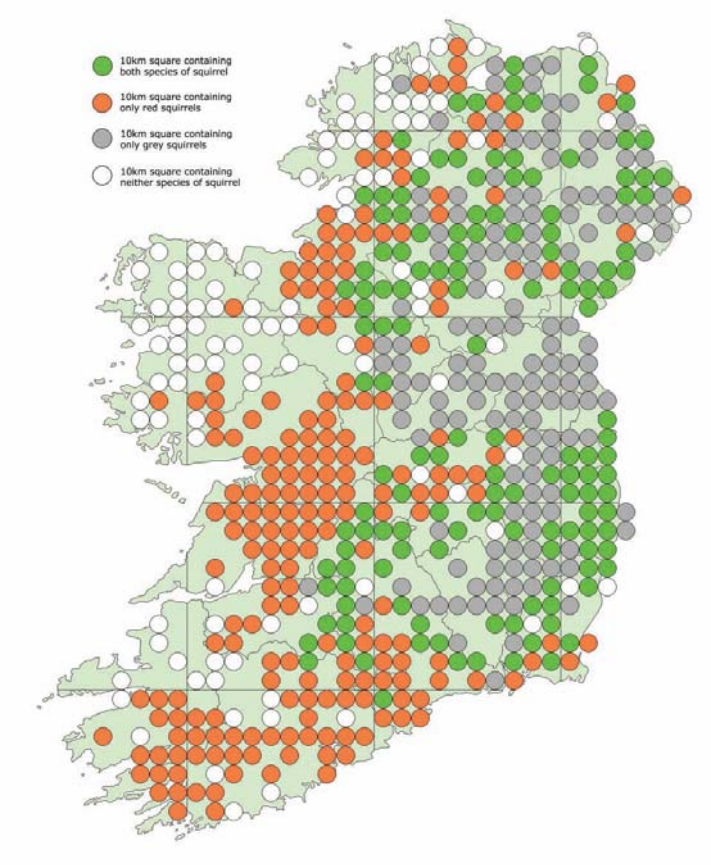

Figure 1: Summary map of survey results showing distribution of both squirrel species and their overlap zones (Carey *et al.* 2007).

The Red Squirrel Action Plan for Northern Ireland (McGhie and Milburne 2000) identified five Red Squirrel Preferred Areas (RSPAs) intended to provide a focus for conservation measures and include targeted control of grey squirrels to prevent their colonisation. Each preferred area comprises of a core conifer-dominated woodland with a mixture of age classes and species together with some berry-bearing shrubs to ensure a continuous food supply. The surrounding buffer zone is either coniferous woodland or non-squirrel habitat such as agricultural land or open moor, with limited opportunities for grey squirrel incursions. Identifying potential RSPAs in the Republic of Ireland is a proposed action under the All-Ireland Species Action Plan for the Red Squirrel 2008. By 2010, it is proposed to identify woodlands that currently support a red squirrel population and meet criteria along the lines of Reynolds and Bentley (2001) for distinction as Red Squirrel Preferred Areas (RSPAs) in terms of extent, structure and potential for grey squirrel control. The aim of this report is to

assess the red squirrel population and examine the potential of Raven Point Nature Reserve in Wexford as a RSPA.

The Raven is situated on the north side of Wexford Harbour (see figure 2), incorporating the dynamic sand system of Raven Point and the coast running north to Curracloe House. The site was designated as a National Nature Reserve in 1983 and incorporates a large sand dune system comprising a suite of coastal habitats listed on Annex I of the EU Habitats Directive. It has also been designated both a Special Area of Conservation (SAC, site code 000710) and a Special Protected Area (SPA, site code 004019).

Figure 2: Location of the Raven Point Nature Reserve.

The Raven was planted with ~240ha of commercial conifer forest in the 1930s and 1950s, partly as a coastal defence measure to stabilise the dunes and protect the slob behind. The main species planted included Corsican Pine (*Pinus nigra maritima*), Lodgepole Pine (*P. contorta*), Shore Pine (*P. contorta contorta*), Maritime Pine (*P. pinaster*), Monterey Pine (*P. radiata*), Scot's Pine (*P. sylvestris*), Sitka Spruce (*Picea sitchensis*) and Monkey Puzzle (*Araucaria araucana*). The understory comprises of either a Bracken (*Pteridium aquilinum*) / Bramble (*Rubus fruticosus*) /Ivy (*Hedera helix*) community with Bluebell (*Hyacinthoides non-scripta*) or a mixed grass and sedge community with Common Bent (*Agrostis capillaris*), Sweet Vernal grass (*Anthoxanthum odoratum*) and Sand Sedge (*Carex arenaria*). In some wetter parts, the under-storey vegetation is dominated by Creeping Willow (*Salix repens*).

It is not known how or when red squirrels became established in the Raven. The first mention of red squirrels is contained in the 2007 squirrel survey (Carey *et al.* 2007). There was no mention in the earlier 1997 survey (O Teangana *et al.* 2000). However one of the authors (W. Carr) remembers sighting red squirrels in the woodland in 1999. Grey squirrels have not reached the area yet. The successful implementation of wildlife management and conservation plans relies on accurate information regarding abundance, distribution, habitat use, and population trends (e.g. Broome 2001; Ripple *et al*. 2001; Ferrand and Gossman 2001). In selecting RSPAs, it is also preferable that the site contain a viable population of red squirrels. There is no previous information available on the population of red squirrels in the Raven and as such, it is vital to establish the extent and distribution of the population.

2. Methodology

2.1 Population distribution, density and abundance:

Distribution:

The distribution of squirrels within the reserve was determined by walking along pathways on 25th August 2008 and plotting the location of fresh feeding signs. Freshly eaten cones were distinguished by their bright colour, green remaining scales and lack of desiccation (see figure 3).

Figure 3: Example of a freshly eaten Maritime pine cone (*Pinus pinaster*). An older cone is on the left of the picture.

Density and abundance:

There are a number of methods available to determine the presence and abundance of squirrels. The most direct method involves live-trapping and marking individuals but this method can be complicated by variations in the probability of catching individuals within and between trapping periods (e.g. Gurnell 1983, 1996; Lurz, Garson & Rushton 1995). There are five main indirect methods for assessing squirrel populations; these are visual surveys, hair tube surveys, drey counts, feeding transects and whole maize bait (Gurnell, Lurz and Pepper 2001). Visual surveys allow for density and abundance estimates to be obtained. The remaining four methods require calibration and are generally used to give a population index rather than a direct estimate of density. The Raven reserve contains ~240ha of continuous woodland. Initial surveys indicated that the distribution of tree species varied within the reserve which could result in varying squirrel densities. The understory also varied throughout. In order to gain accurate information on squirrel distribution and density and take into consideration potential differing habitats within the reserve, line transects were selected as the method to determine density and abundance.

Due to the extensive and impenetrable undergrowth of bracken found throughout much of the reserve, the selection of areas for line transects was limited to paths. Eight approximately

parallel paths crossing the reserve in an east-west direction were selected (see figure 4). Each transect was marked out at 25m intervals using coloured cable ties placed both on the surrounding vegetation and on the ground. Transects varied in length from 200m up to 800m and totalled 3.1km.

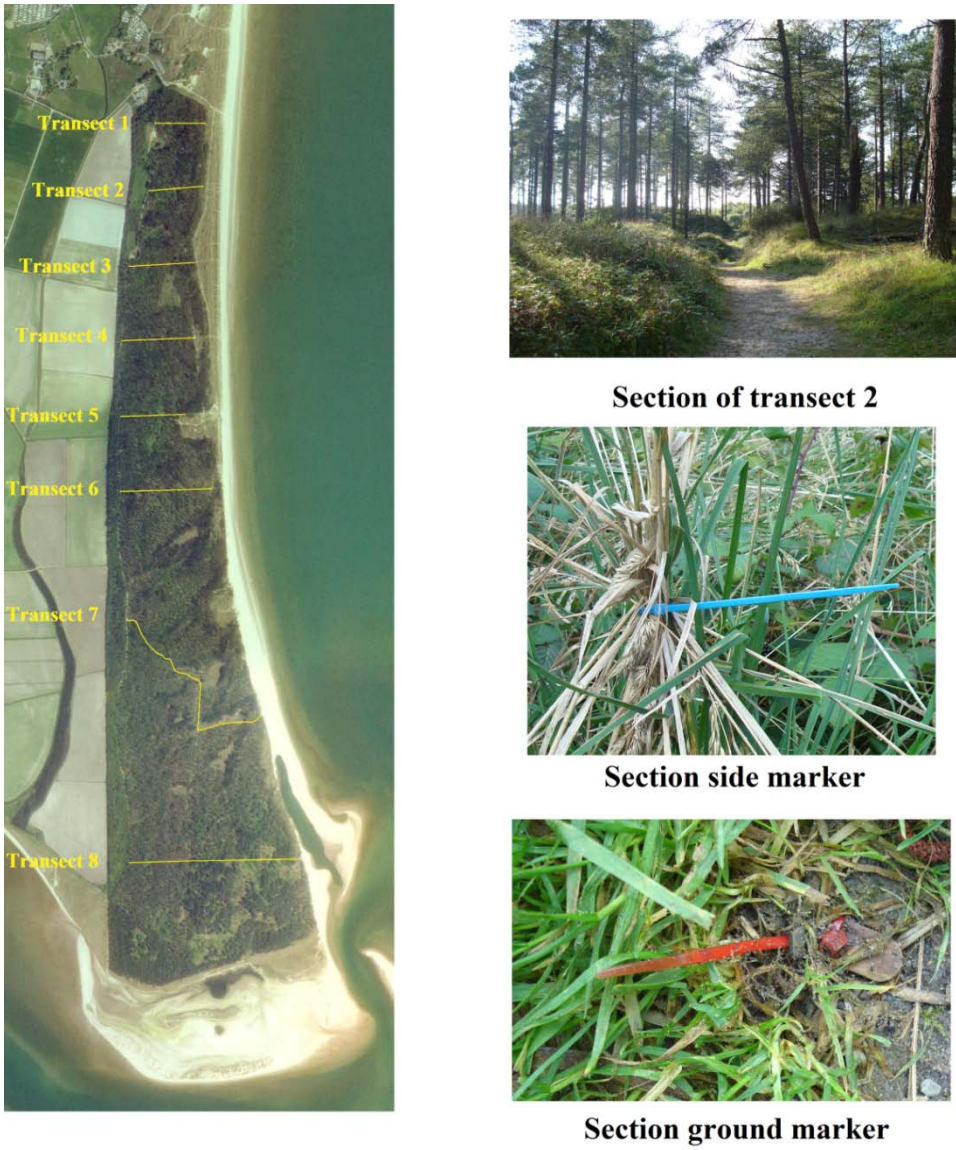

Figure 4: Aerial view showing the location of the 8 transects and examples of the section markers used.

Habitat data with the potential for affecting squirrel density were collected for each 25m section of the transect extending to ~10m either side of the path. This data included: (1) tree species (presence/absence); (2) ground cover type (categorized as grass, scrub [mixture of brambles, herbaceous plants and grass], bracken, bramble or bare ground) and (3) percentage of ground cover over 30cm. Trees were identified using the Collins *Field guide to trees of Britain and Northern Europe* (1978).

Transect surveys (n = 24) were conducted over 10 weekdays between 26/8/08 and 11/9/08. Weekends were avoided due to the increased use of the reserve by walkers. Surveys were only conducted in dry weather with either no wind or light breezes only. On most days (n = 7) three surveys (early morning, midday and late afternoon) were conducted during the day with a minimum of 45 minutes between consecutive surveys of the same transect (range 45 – 530, $\bar{x}$ = 221 ± 8 minutes).

Surveys were walked in silence at a slow steady pace ($\bar{x}$ = 41m per minute). Squirrels were detected both visually (sighting, movement and falling pieces of cone) and aurally (movement and feeding sounds). On detecting a squirrel, the observer moved to a position on the transect perpendicular to the squirrel and measured the distance to the squirrel with a laser rangefinder (Leica DISTO). Data also noted included the transect section, behaviour of the squirrel and the tree species (if feeding).

Density and abundance estimation:

Conventional Distance Sampling (CDS) line transect methods require that:

i) Transect lines are placed randomly with respect to the animals.
ii) Animals do not move prior to sampling or in response to the observer.
iii) Distances are measured accurately.
iv) Animals directly on the line are counted with certainty.

Due to the habitat structure of the reserve, transects were placed on paths. Whilst this facilitated the survey, locating samplers on paths could introduce bias into the data, as squirrels may avoid paths due to human disturbance. Consequently, the highest proportion of animals may be some distance from the observer. To counteract any bias, surveys were only conducted on weekdays when there was minimal human disturbance. There was no evidence of evasive movement away from the observer during surveys and distances were accurately measured with a rangefinder. The collected data was also examined for any evidence of bias.

Density (D), abundance (N) estimates and their associated coefficient of variation (CV) were obtained using the program DISTANCE 5.0. The data was right truncated to remove outliers. Twelve detection models were compared in the analysis of the detection function, i.e., uniform/hermite polynomials, uniform/ cosine, uniform/simple polynomial, half normal/hermite polynomials, half normal/cosine, half normal/simple polynomial, hazard rate/hermite polynomials, hazard rate/cosine, hazard rate/simple polynomial, negative exponential/hermite polynomials, negative exponential/cosine, negative exponential/simple polynomial. Based on Akaike's information criterion (AIC), the best model was determined and chosen for the subsequent density and abundance analysis. Estimates were conducted taking the reserve as a homogenous habitat and also stratified into habitat types based on the data collected during transect setup.

2.2 Diet:

The diet of the squirrels was assessed using data collected from sightings of individuals during the line transect surveys. A comparison of tree species availability within an area and feeding records was made.

2.3 Population parameters – body weight and breeding rates:

Data on population parameters were obtained from live-trapping sessions conducted under licence from NPWS. After accessing the forest for signs of recent feeding by squirrels, twenty squirrel traps were erected at two locations (10 at each) in August (transect 2 and transect 5 trap sites, see figure 5). Traps were placed in an additional site for 2009 trapping sessions (transects 7/8 trap site). The traps were secured open and pre-baited with a peanut and acorn bait mix for four weeks prior to trapping sessions. Trapping sessions occurred on five occasions: September 08 (9^{th} – 11^{th}), March 09 (22^{nd} – 24^{th}), April 09 (24^{th} – 26^{th}), June 09 (10^{th} – 12^{th} and 17^{th} – 19^{th}).

Figure 5: Location of trapping sites.

Trapping and handling procedures:

Squirrels were trapped using standard wire mesh cage traps with baseboard and nest box attached (see figure 6). The door mechanism is triggered by a pedal mechanism towards the rear of the trap. The nest box provides the squirrel with a place to hide out of view and out of any adverse weather conditions. Traps were attached securely to selected trees at approximately 3 meters above ground level. The nest boxes were filled with hay and the traps baited with a combination of acorns and peanuts. Once set, traps were checked at regular intervals throughout the day (dawn to dusk) and any trapped squirrels processed immediately upon discovery.

Figure 6: Red squirrel trap.

Squirrels were removed from the traps into a modified Koprowski cloth handling cone (see figure 7a; Koprowski 2002). Handling time was kept to a minimum. Squirrels were typically only handled for between 10 and 15 minutes, the minimum time taken to take body measurements and attach/implant tags (radio-collar, ear-tags and PIT tags). The handling cone is specially designed to allow access to various body parts while keeping the squirrel securely restrained (see figure 7b). Measurements taken included body weight (measured to nearest 5g using a Pesola spring balance) and hind foot/leg length. The reproductive status was also assessed using standard criteria (Wauters and Dhondt 1989; Wauters *et al.* 2000).

Radio-collars were attached via an opening in the back of the cone occurring at the back of the neck of the animal (see figure 7e).The radio-collars used were the standard design for red squirrels used in Great Britain and are manufactured by Biotrack Ltd (TW-4). They weigh 14g and the battery lasts for 6-8 months. PIT tags and ear tags were attached using the same opening in the handling cone (see figure 7c,d). PIT tags used were manufactured by Biomark Ltd. and are the smallest type currently available (Biomark tag type: TXP148511B, 8.5mm X 2.12mm, 134.2kHz ISO, 0.067g). Ear tags were manufactured by the National Tag and Band Company, USA and are the smallest available (tag style: 1005-1, 7mm X 2mm, self piercing plain monel tag). Squirrels were then released. Only adult squirrels were radio collared in this study. Any juvenile animals caught were only ear tagged and fitted with a PIT tag.

Figure 7: (a) Krowproski cloth handling cone containing a squirrel, (b) access to hind leg for measurement, (c) inserting of PIT tag, (d) ear tag *in situ*, (e) attachment of radio collar and (f) released tagged and collared squirrel.

2.4 Home range estimates and dispersal behaviour:

Radio collars were applied to 13 adult squirrels captured between 9th and 11th Sept (5 females and 8 males). Between the 18th September and 30th October, forty-five location fixes were collected for each squirrel. Location fixes were obtained from a triangulation technique using three points. At each point a compass bearing of the strongest signal was taken. These bearings were then plotted on a map of the study site and the position of the squirrel determined. Data were entered into RANGES IV for analysis of home range size. Home range sizes were calculated using minimum peeled convex polygons (95% core) centred on a harmonic mean centre. The 95% core is generally used in home range studies to remove the effect of animals' occasional exploratory visits outside of their normal range.

3. Results

3.1 Population distribution, density and abundance:

Distribution:

The distribution of fresh feeding signs indicated that squirrels were distributed throughout the woodland (see figure 8). The density of signs was highest near the entrance gate and at the southern end of the wood. Feeding signs were sparse in the centre.

Figure 8: Distribution of fresh feeding signs on the 25 Aug 08. Paths surveyed are represented by yellow lines. Feeding signs are indicated by green dots.

Habitat survey:

Overall, transects consisted of 124 sections, each of 25m. Surveys of tree species ~10m either side of the transect line identified 21 different tree species (see table 1). The woodland was dominated by six conifer species. Corsican pine (*Pinus nigra maritima*) was found in 90% of

all sections, Lodgepole pine (*Pinus contorta*) in 43% and the remaining four (Monterey pine *Pinus radiata*, Scot's pine *Pinus sylvestris*, Shore pine *Pinus contorta contorta*) each in about 20% of sections.

Table 1: Occurrence of tree species identified in transect sections (n = 124).

Species	Number of transect sections	% of sections
Coniferous species		
Corsican pine (*Pinus nigra maritima*)	111	90
Lodgepole pine (*Pinus contorta*)	53	43
Monterey pine (*Pinus radiata*)	27	22
Shore pine (*Pinus contorta contorta*)	26	21
Maritime pine (*Pinus pinaster*)	24	19
Scot's pine (*Pinus sylvestris*)	23	19
Norway spruce (*Picea abies*)	14	11
Monkey puzzle (*Araucaria araucana*)	3	2
Douglas fir (*Pseudotsuga menziesii*)	2	2
Cypress (*Cupressus* spp.)	1	1
Deciduous species		
Silver birch (*Betula pubescens*)	9	17
Lime (*Tilia platyphyllos*)	9	7
Oak (*Quercus petrea*)	5	4
Alder (*Alnus glutinosa*)	3	2
Hazel (*Corylus avellana*)	3	2
Ash (*Fraxinus excelsior*)	2	2
Walnut (*Jugkans nigra*)	1	1
Sycamore (*Acer pseudoplatanus*)	1	1
Understory species		
Creeping willow (*Salix repens*)	28	23
Holly (*Ilex aquifolium*)	5	4
Hawthorn (*Crataegus monogyna*)	2	2

However, the distribution between transects was not uniform for all species (see figure 9). Maritime pine was found only in the in the first 4 transects. Shore pine generally occurred in the centre of the woodland. While the remaining species occurred throughout, Lodgepole pine was most prevalent in the first 3 transects and in transect 8.

The mean % ground cover >30cm varied between transects from 51% on transect 7 to 90% on transect 6 (see table 2). This corresponded to the dominant type of ground cover on each transect. The lower values were for transects where the ground cover was dominated by either a mixture of grass and bramble or grass and bracken. The highest values occurred on transects 5 and 6 where the ground cover was dominated by tall, dense bracken.

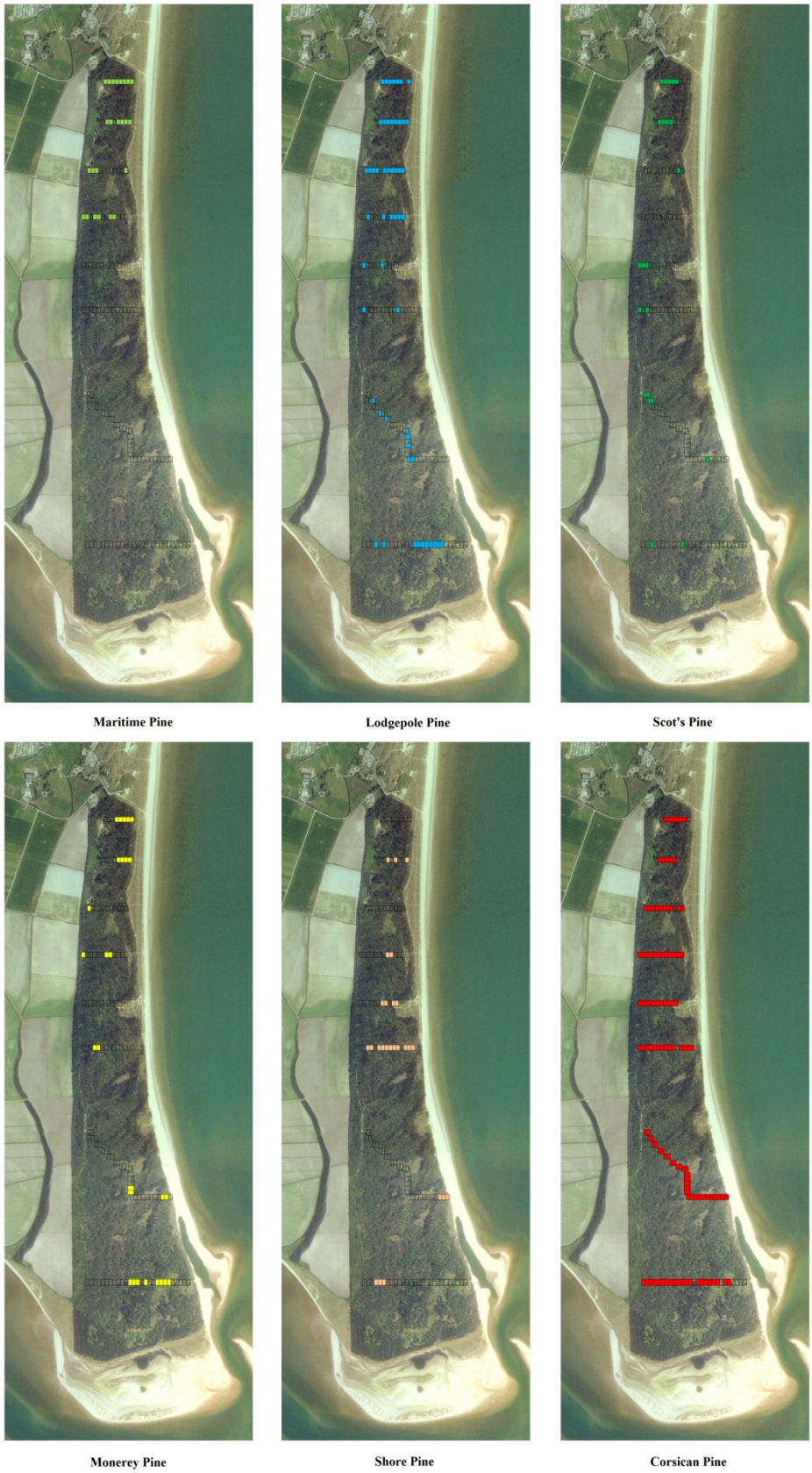

Figure 9: Occurrence of the six main tree species per 25m transect section.

Density and abundance:

A total of 74.4km was surveyed along the eight transects (24 replicates of each). Overall, 251 sightings of squirrels were recorded. Neither the time of day (morning, midday, afternoon) nor day of recording had have an influence on the number of squirrels sighted (time: $F_{6\text{-}14}$ = 1.893, p = 0.152, ns; day: $F_{2\text{-}18}$ = 2.178, p = 0.142, ns). However, the number of squirrels sighted varied between transects. The mean number of squirrels per 100 m surveyed ranged from 0.07 on transect 6 to 1.08 on transect 1 (see table 2). Squirrels were most frequently encountered on the first 3 transects nearest the entrance to the reserve. This region contained the greatest diversity of tree species, had an average ground cover of 62% and was dominated by an understory of bramble, grass and scrub. The remainder of the woodland was dominated by Corsican pine, had an average ground cover of 68.2% and was dominated by an understory of thick bracken. For analysis purposes, transects were grouped into 3 areas, each of which contained similar habitat types: area 1 = transects 1 and 2; area 2 = transects 3, 4 and 5 and area 3 = transects 6, 7 and 8.

Table 2: Summary of sighting data in relation to habitat variables on each transect.

Transect	Mean sq/100m	Mean tree species per section	Dominant tree species	Mean % ground cover	Dominant ground cover type
1	1.08	3.88	Maritime	55	Bramble/Grass
2	0.71	3.75	Lodgepole	61	Bramble/Grass
3	0.55	2.36	Corsican/Lodge	70	Bramble/Grass
4	0.26	2.42	Corsican	57	Bramble/Grass
5	0.30	1.82	Corsican	90	Bracken
6	0.07	2.07	Corsican	89	Bracken
7	0.18	1.66	Corsican	51	Bracken/Grass
8	0.31	1.63	Corsican	54	Bracken/Grass

-The mean tree species per section represents the mean number of species from the six most main food species found per 25m section.
-The dominant tree species represents the species found in the highest number of sections.
-The mean % ground cover represents the mean ground cover >30cm per section of the transect.
-The dominant ground cover type represents the most common ground cover on the transect.

Figure 10: Images of transect sections illustrating differences in habitats and canopy gaps.

The perpendicular distance data revealed a potential problem. There was a decreased number of sightings on or close to the transect line. The highest number of sightings occurred between 4m and 5m from the line (see figure 11). This means that the highest detection function would not be on the line and therefore violates the assumptions of CDS. Squirrels are arboreal animals and transects were located on paths typically without interlinking canopies and varying in the distance to the tree line from the path both between and on individual transects (see figure 10). Therefore, there was no available habitat on the line for squirrels. To counteract this, data within 5m of the line were pooled into one bin for analysis to make the detection function highest on the transect line. The remaining data were grouped into 3m intervals and right truncated at 20m to remove outliers.

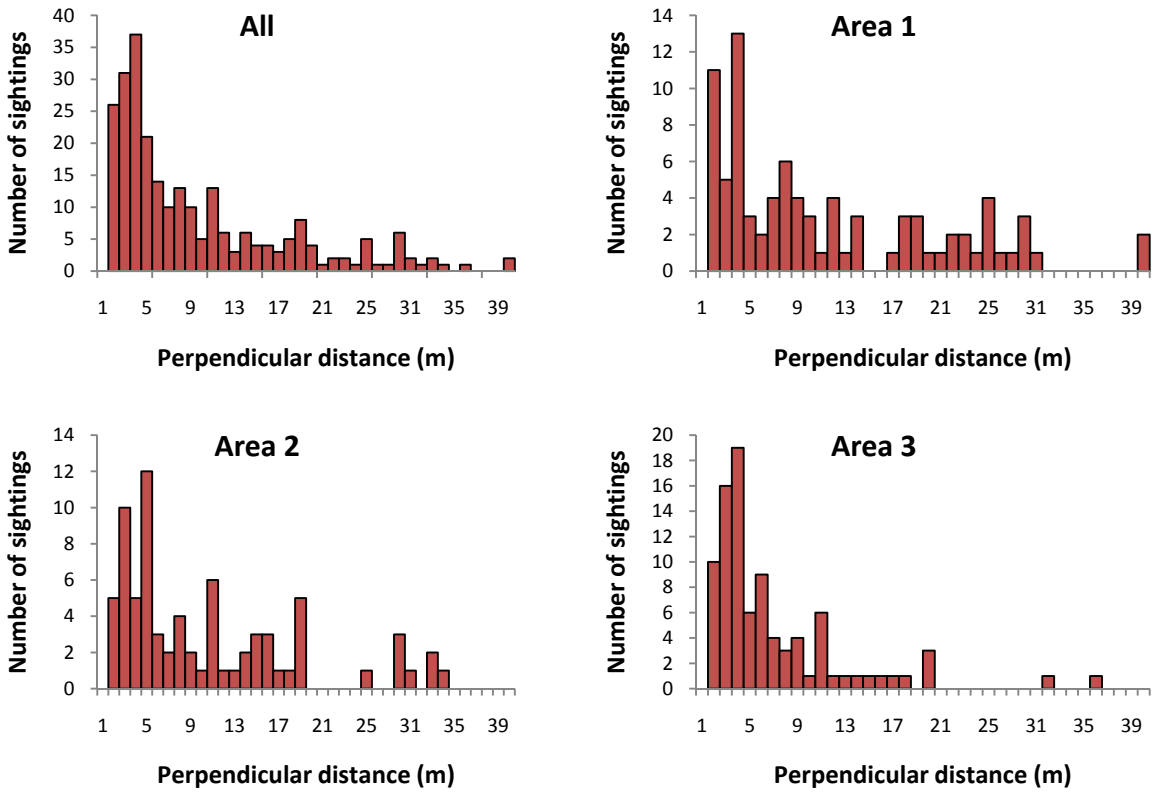

Figure 11: The number of sightings at each perpendicular distance from the line for all the data and for each area.

The data were analysed both grouped into areas and ungrouped to examine potential differences in density throughout the woodland given the habitat variation observed. The best model for the ungrouped data (hazard rate with no adjustment) produced a density estimate of 1.52 squirrels per hectare and an abundance estimate of 350 squirrels (see table 3). The grouped analysis (half-normal with cosine adjustment) produced a better model and indicated a density of 1.39 squirrels per ha and an abundance of 319 squirrels. The overall coefficient of variation for this model of 0.20 also indicated that sufficient effort had been put into the surveying to produce a robust estimate of density. The density of squirrels varied between areas from 3.47 down to 1.07. The highest density was nearest the gate with decreasing density further south through the woodland. Density was highest in the area with the greatest diversity of tree species available (area 1).

Table 3: Results of the DISTANCE analysis for grouped and ungrouped data.

	Area (ha)	AIC	X^2	Density	95% CI	Abundance	95% CI	CV
Ungrouped	240	656.758	X^2 = 0.75, df = 3, p = 0.86	**1.52**	0.82 - 2.82	**350**	189 - 647	0.29
Grouped								
area 1	20	210.522	X^2 = 4.61, df = 3, p = 0.20	3.47	1.55 - 7.77	69	31 - 155	0.26
area 2	53	218.153	X^2 = 0.48, df = 3, p = 0.92	1.55	0.74 - 3.26	82	39 - 173	0.29
area 3	157	226.376	X^2 = 1.17, df = 3, p = 0.76	1.07	0.31 - 3.68	167	49 - 578	0.33
Overall	240	653.250		**1.39**	0.79 - 2.44	**319**	182 - 560	**0.20**

3.2 Diet:

Behaviour of sighted squirrels:

The majority of sighting records (89%) were of feeding squirrels (see figure 12). Only 2 of the sightings were of squirrels on the ground and these were the only squirrels to make obvious avoidance movements from the observer. The remaining sightings of moving squirrels were of squirrels either moving towards the transect line or parallel to it and were not considered to be moving as a consequence of the observer.

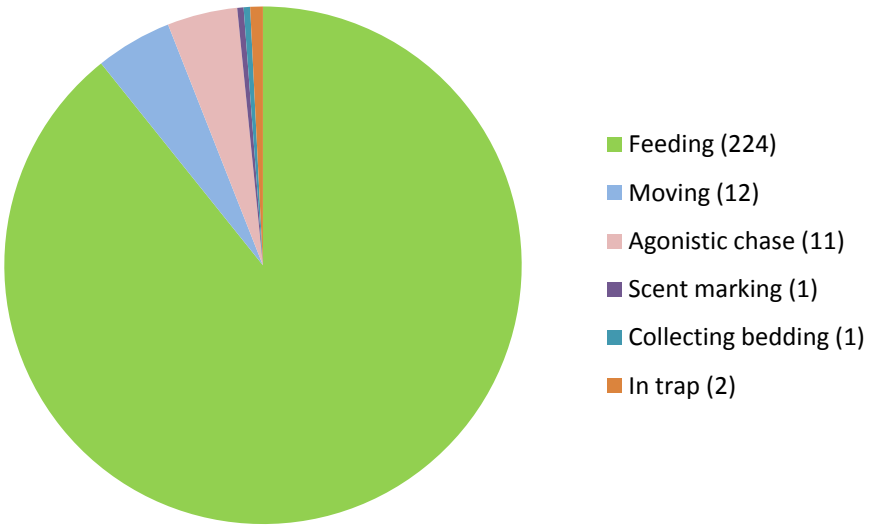

Figure 12: Behaviour of squirrels sighted during transects.

Diet:

Squirrels were observed feeding on five tree species (see figure 13): Corsican pine (*Pinus nigra maritima*), Lodgepole pine (*Pinus contorta*), Scot's pine (*Pinus sylvestris*), Maritime pine (*Pinus pinaster*) and Shore pine (*Pinus contorta contorta*). Corsican pine constituted the majority of records (68%) with Lodgepole pine being the next most frequently observed (23%). A selection of feeding signs and food available is shown in figure 14 below.

Figure 13: Feeding records for squirrels sighted during transects.

Figure 14: An example of the variety of food available during autumn. The seeds represented in the centre of the image illustrate the size differences between species. From the left these are Douglas fir, Norway spruce, Shore pine, Scot's pine (similar in size to both Lodgepole and Corsican seeds), Maritime pine, Monterey pine, Hazelnut and an acorn.

A comparison of occurrence versus feeding records (see figure 15) indicated that in general, the amount of feeding on an individual species was related to its occurrence ($r = 0.991$, $n = 6$, $p<0.001$). However, in area 1, the most dominant species in terms of occurrence were not the most frequently eaten. Lodgepole pine and Maritime pine were found in most sections (94% and 88% respectively) but feeding records were mostly of Corsican and Lodgepole (both 41%). In area 2 and area 3, the diet was dominated by Corsican pine (75% and 85% respectively). Thus, in area 1 which supported the highest density of squirrels, the diet was more varied.

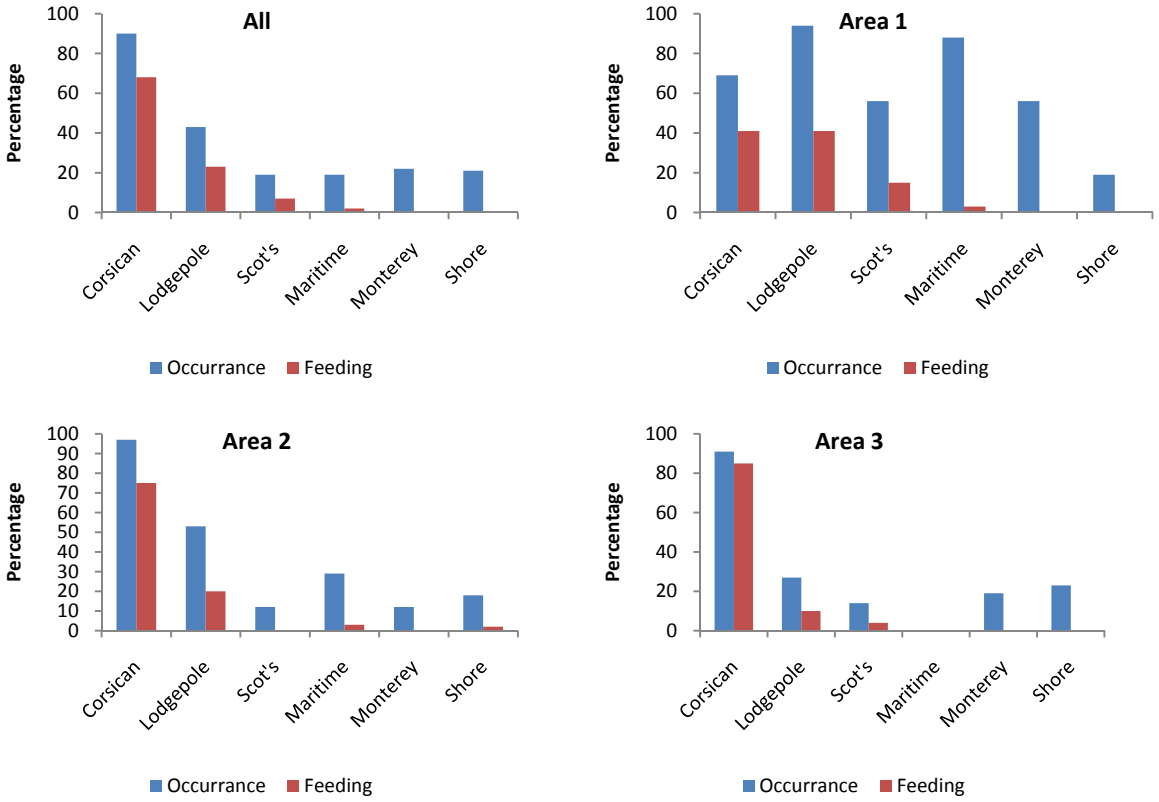

Figure 15: Comparison between the percentage of 25m sections in an area that a species occurs in and the percentage of feeding records for that species in the area.

It should be noted that these feeding records were collected over 10 days during 16 hours of transect surveys. During fieldwork, squirrels were also observed feeding on insects in bark (3 cases), blackberries (2 cases), Monterey pine (1 case) and Hazelnuts (2 cases). Thus the diet of the squirrels is far more varied than these records suggest.

3.3 Population parameters – body weight and breeding rates:

Trapping sessions:

Overall, 36 squirrels (17 female and 19 males) were captured between one and four times over the five trapping sessions (see table 4). Two of the male squirrels captured were juveniles. The remaining squirrels were over 190g and therefore considered adults (Tittensor 1970).

Table 4: Number of squirrels captured in each trapping session. Numbers in brackets represent first time captures.

Session	Males	Females	Juveniles	Total
September 2008	8 (8)	5 (5)		13 (13)
March 2009	4 (3)	7 (5)		11 (8)
April 2009	3 (1)	4 (4)		7 (5)
June 2009 (1)	5 (3)	8 (2)		13 (5)
June 2009 (2)	6 (2)	8 (1)	2 (2)	16 (5)
	26 (17)	32 (17)	2 (2)	58 (36)

Body weight:

Overall, the mean body weight of adult squirrels captured was 330g and there was no significant difference between males and females (see figure 16; t = 0.094, df = 53.536, p = 0.936, ns). There was no significant difference in body weights between capture sessions ($F_{3\text{-}56}$ = 2.569, p = 0.063, ns).

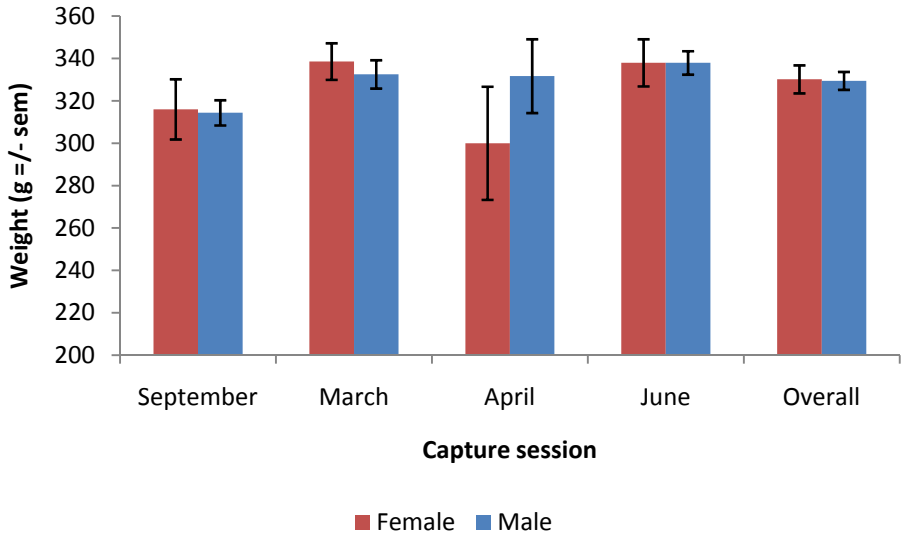

Figure 16: Mean weights of adult squirrels captured in each trapping session.

Breeding rates:

Of the 17 females captured, 12 had breed prior to spring 2009. Fifteen females were captured between March 2009 and June 2009. Of these, 11 showed signs of breeding activity (see table 5). Two females mated but failed to rear their litters as they were not lactating in a subsequent capture. The estimated breeding rate for the population was 0.73 ± 0.22.

Table 5: Breeding status of captured female squirrels in 2009.

	Previous status		
Breeding status	**Nulliparous**	**Parous**	**Total**
No evidence of mating	3	1	4
Mated	1	1	2
Pregnant	1	1	2
Mated but litter failed		2	2
Lactating		5	5

3.4 Home range estimates and dispersal behaviour:

Home range size:

Sufficient data was collected on 9 of the 13 squirrels to calculate home range size (see figure 17). Four of the squirrels demonstrated behaviour consistent with dispersal during tracking. The mean home range size for males and females were 7.35 ha and 7.43 ha respectively (see table 6). There was no significant difference in home range size between the sexes ($t = 0.057$, df = 7, p = 0.956, ns).

Table 6: Home range size for each of the non-dispersing squirrels.

Tag number	**Sex**	**Home range size**
7	Female	5.02 ha
9	Female	8.46 ha
12	Female	9.96 ha
17	Female	6.27 ha
8	Male	9.16 ha
10	Male	8.15 ha
11	Male	8.86 ha
15	Male	6.03 ha
20	Male	4.54 ha

Figure 17: Home ranges for Raven red squirrels. Map on the right indicates animals showing ranging behaviour consistent with dispersal.

Dispersal behaviour:

Four of the 8 squirrels captured and collared on transect 2 moved permanently midway during tracking. Two of them, t14 and t16, both males moved to transect 5 and remained there. The remaining 2, t18 and t19, a male and female moved past transect 5 and took up residence between transect 7 and 8. These dispersal movements were between 1 – 3km. Prior to the discharge of the collar batteries in spring 2009, signals indicated that all 13 animals were alive and had remained in the areas they were tracked to in October 2008. Five of the previously collared animals were recaptured in the 2009 trapping sessions and had their collars replaced. Four were captured in the same location as they had previously been collared and one, t12 a female, had moved from transect 2 to transect 5 (see table 7).

Table 7: Transect locations of the radio collared squirrels. Numbers represent transects (see figure 18 below).

	Location			
Tag number	**Capture 2008**	**Tracking**	**January 2009**	**Recapture 2009**
7	5	5	5	5
8	5	5	5	5
9	5	5	5	5
10	5	5	5	5
11	5	5	5	-
12	2	2	2	5
14	2	2 - 5	5	-
15	2	2	2	-
16	2	2 - 5	5	-
17	2	2	2	-
18	2	2 – 7/8	7/8	-
19	2	2 – 7/8	7/8	-
20	2	2	2	-

Figure 18: Locations of radio collared squirrels.

4. Discussion:

Although it is not known when red squirrels first became established within the Raven, the results of this study indicate that the Raven is home to a substantial healthy population of ~319 red squirrels. The overall estimated density of 1.39 squirrels per hectare is similar to previous studies in Ireland. O Teangana (1999) indicated a population density of 1.2 squirrels per hectare in coniferous forest. The density of squirrels is directly related to the habitat available (Gurnell 1987; Kenward *et al.* 1998). Red squirrels typically exhibit densities of 0.3 – 1.5 squirrels per hectare irrespective of whether the woodland is deciduous or coniferous (Gurnell 1987). However, in extremely food rich habitats such as a Scot's pine forest, density can reach a peak of 7.5 squirrels per hectare (Harris *et al.* 1995). Densities are highest in mixed deciduous and conifer mixtures dominated by pine and lowest in those dominated by Sitka spruce (*Picea sitchensis*) and in forests just reaching cone-bearing age (Gurnell 1983, 1991; Lurz, Garson and Rushton 1995; Lurz, Garson and Ogilvie 1998; Tonkin 1983; Wauters and Lens 1995). Mixtures of tree species provide a more reliable year-to-year seed food supply than do single-species forests because of differences in mast intervals, seed size, and timing of seed dispersal (Lurz *et al.* 1995).

Evidence of habitat related density is observed in the Raven. Density varied significantly throughout the woodland ranging from 3.47 squirrels per hectare in the northern section to 1.07 squirrels per hectare in the southern section. The variation in density coincided with variation in tree diversity (see table 8). As the diversity of tree species decreased, the density of squirrels also decreased. The highest density section also had the lowest amount of ground cover >30cm. Although red squirrels typically spend >70% of their time foraging in the canopies of trees, they will come down to the ground to forage and move between trees when the canopy gaps become too great to jump. Movement between trees is inhibited in area 3 due the dense ground cover and increased canopy gaps (see figure 19) which may be resulting in a portion of the food supply being unavailable to the squirrels. The lower diversity of species and reduced tree density may be the cause of the lower squirrel density observed in this section of the woodland.

Table 8: Summary of squirrel densities and habitat variables for each woodland section.

Area	Density (sq/ha)	Tree diversity	Dominant tree species	% Ground cover	Ground cover type
Area 1	3.47	3.81	Maritime/Lodgepole	58	Bramble/grass
Area 2	1.55	2.21	Corsican	72	Bracken/grass
Area 3	1.05	1.73	Corsican	60	Bracken
Overall	***1.39***	***2.13***	***Corsican***	***63***	***Bracken***

-Tree diversity represents the mean number of species from the six most main food species found per 25m section.
-The dominant tree species represents the species found in the highest number of sections.
-The % ground cover represents the mean ground cover >30cm per area.
-The ground cover type represents the most common ground cover in the area.

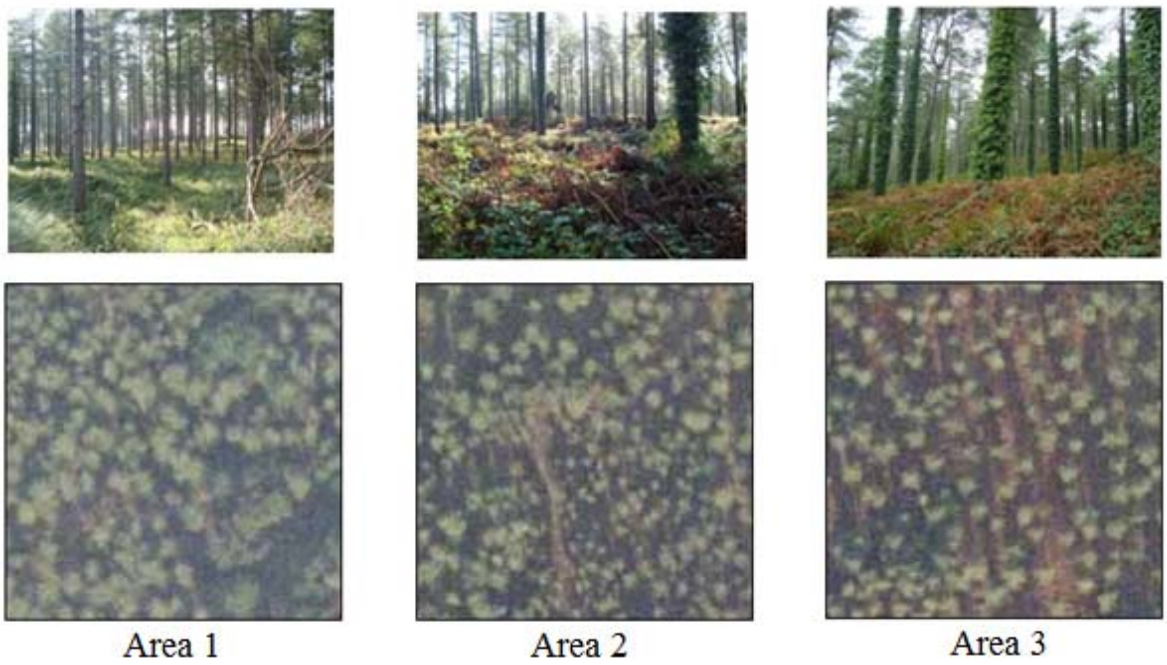

Figure 19: Illustration of the variation in ground cover and tree density between areas. Boxes represent a randomly selected 1 ha square from each area.

The diversity of tree species was also reflected in the feeding observations. Corsican pine (*Pinus nigra laricio*) was the dominant tree species found throughout the woodland with six other conifer species also found to a significant extent: Lodgepole pine *Pinus contorta*, Monterey pine *Pinus radiata,* Scot's pine *Pinus sylvestris*, Maritime pine *Pinus pinaster* and Shore pine *Pinus contorta contorta* and Norway spruce *Picia abies*. There was no evidence of feeding on Norway spruce either from feeding observations or feeding signs under trees. There was limited evidence of feeding on Monterey pine from direct observations (1 case) and evidence of feeding signs. Overall, the majority of feeding observations were on Corsican pine cones (68%). However, in area 1 where the diversity of trees was higher, the diet was more evenly spread between Corsican pine and Lodgepole pine with Scot's pine also representing a significant proportion of observations. This area also supported the highest density of squirrels indicating that more diverse habitats have the capacity to support more squirrels. This is similar to previous studies of red squirrels in Europe where higher densities were found in mixed conifer woodlands (Wauters and Lens 1995, Wauters *et al.* 2004). Densities are typically more variable in monocultures where the availability of seed crops can fluctuate greatly depending on the species (Wauters and Lens 1995, Wauters *et al.* 2005). Of the three main species in the Raven, Corsican pine is the most variable in terms of seed production (see table 9) with good seed crops only occurring every 3-5 years (Seal, Matthews and Wheeler 1962). This is likely to be an issue in the lowest section of the woodland where the availability of other species is reduced. In the middle section, the presence of Lodgepole pine may compensate for a bad Corsican pine seed crop.

Table 9: Tree seed crop patterns.

Species	Age (years) First crop	Age (years) First good crop	Good crop intervals (years)	References
Corsican pine *Pinus nigra maritima*	5 - 10	25 - 30	3 - 5	Seal *et al.* 1962; Brown and Neustein 1972
Lodgepole pine *Pinus contorta*	5 - 10	15 - 20	1 - 3	Matthews 1955; Hibberd 1991; Owens and Molder 1984
Scot's pine *Pinus sylvestris*	5 - 10	15 - 20	2 - 5	Matthews 1954, 1989

Adult red squirrel body weights range from 200g – 480g with a mean of 300g being found in coniferous habitats (Lurz and Lloyd 2000). The mean body weight of the Raven squirrels of 330g indicates a healthy population. The lack of differences between trapping sessions also indicated that over the period of this study there (Sept 2008 – June 2009) there was no significant variation in food availability. This is further substantiated by the estimated breeding rate of 0.73 which is comparable to previous studies of red squirrel reproductive rates (Shuttleworth 2002, Gurnell *et al.* 2004). Juvenile squirrels were observed both in Sept 2008 and in June 2009 of which 2 were captured in the final trapping session. Overall, the population parameters indicate a healthy and increasing population of squirrels.

Home range size in red squirrels can vary substantially between habitats and locations, but males typically have larger home ranges than females. Average sizes (ha, females then males, respectively) include 2.4, 6.2 on the island of Jersey, Channel Islands (n = 11, 22); 6.22, 20.44 and 19.7, 31.4 in conifer-dominated habitats in northern England (n = 56, 4) and Scotland (n = 5, 7: Halliwell 1997; Lurz 1995; Magris 1998; Wauters *et al.* 2000); and very large ranges (up to 47 ha) in mixed high-altitude forest in Bavarian National Park (Munch 1998). The estimates for the Raven of males and females, 7.35 ha and 7.43 ha respectively fall well within these estimates although there was no difference between sexes. This may be due to the range estimates being conducted outside of the breeding season. The high degree of overlap of home ranges also indicates abundant food.

Four of the adult collared squirrels dispersed from their capture site during tracking. Two moved from transect 2 to transect 5 with the other 2 moving from transect 2, past transect 5 and settling between transects 7 and 8. Dispersal distances ranged from 1 – 3 km. These dispersal movements were permanent as the squirrels remained in these new locations. These movements suggest that the northern section of the wood is reaching carrying capacity which is not surprising given a density of 3.47 squirrels per hectare. The movement past transect 5 also suggests that this area with a lower diversity of available food sources is also approaching capacity.

Suitability of the Raven as a red squirrel preferred area (RSPA):

Reynolds and Bentley (2001) suggest the use of 4 criteria in the assessment of a potential reserve. These include: (1) the magnitude of the threat from grey squirrels, (2) the extent and suitability of habitat, (3) site defendability and (4) site management.

Magnitude of the threat from grey squirrels:

The Raven is rated as excellent (see table 10). Only red squirrels are currently present and the nearest known grey squirrel population is located 6km away. Although the estimated rate of range expansion for grey squirrels is 5km/yr. (Carey *et al.* 2007), the habitat surrounding the Raven is either unsuitable or only moderately suitable for grey squirrel movement (see site defendability section below). This is likely to slow or reduce the likelihood of grey squirrels reaching the site.

Table 10: Magnitude of threat criteria (Reynolds and Bentley 2001).

Red squirrel presence/absence	**Rating**
Only red squirrels present	**Excellent**
Only red squirrels present but greys expected to arrive soon	Very good
Red squirrel population and very few grey squirrels present	Good
Red squirrel population and many grey squirrels present	OK
Reds recently disappeared and no greys are present	Poor
Only grey squirrels present	Very poor
Uncertain	Find out

Extent and suitability of habitat:

The Raven is rated as very good under both woodland type and size (see table 11 and 12). The wood is coniferous with ~240 ha of trees and <5% mature large seeded deciduous trees. Currently, there are some mature oaks, beech and hazel trees within the Raven but these are patchily distributed. However, recent planting of young oak trees has occurred. If the Raven is to become an RSPA, this practice should not continue as mature deciduous trees make invasion by grey squirrels easier. The planting of more conifer species will be required to ensure a continued supply of food as the current trees were all planted between 1930 + 1950 and there are no young trees coming on to replace these as they die/stop seed production.

Table 11: Extent of habitat criteria (Reynolds and Bentley 2001).

Woodland type and size	**Rating**
Coniferous woodlands: 2000+ ha	Excellent
Coniferous woodlands: >200 – 2000ha	**Very good**
Mixed woodland: containing 2000+ ha contiguous conifer	Good
Mixed woodland: containing 200 – 2000 ha contiguous conifer block	OK
All other woodlands	Poor

Table 12: Suitability of habitat criteria (Reynolds and Bentley 2001).

Suitability of the habitat	**Rating**
No mature large-seeded deciduous trees	Excellent
<5% mature large-seeded deciduous trees	**Very good**
>5% mature large-seeded deciduous trees	Poor

Site defendability:

The Raven is rated as good under landscape defendability and excellent under buffer size (see table 13 and 14). The Raven is naturally protected from grey squirrels invasion on three sides. To the east and south the site is protected by the sea and to the west by the Wexford slobs. This leaves only a narrow strip through which squirrel movements could occur. The hedgerows in the surrounding area are also only moderately favourable for dispersal of grey squirrels (see figure 20). The nearest known grey squirrel population is located ~6km away in Ballyregan, Castlebridge (see figure 21). An examination of the 1km surrounding the entrance of the Reserve indicates no direct corridor of trees and few mature trees (see figure 22). The hedgerow along the road is dominated by hawthorn. Local residents indicated that only red squirrels are found in the area between The Raven and Curracloe village.

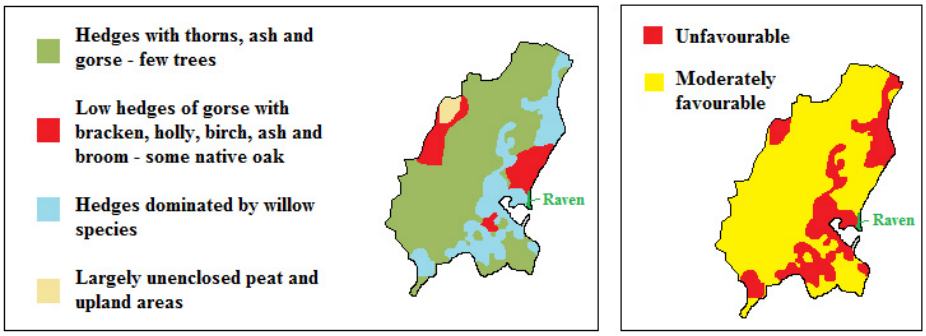

Figure 20: Types of hedgerows found in Wexford and their suitability for grey squirrel dispersal (adapted from Carey *et al.* 2007).

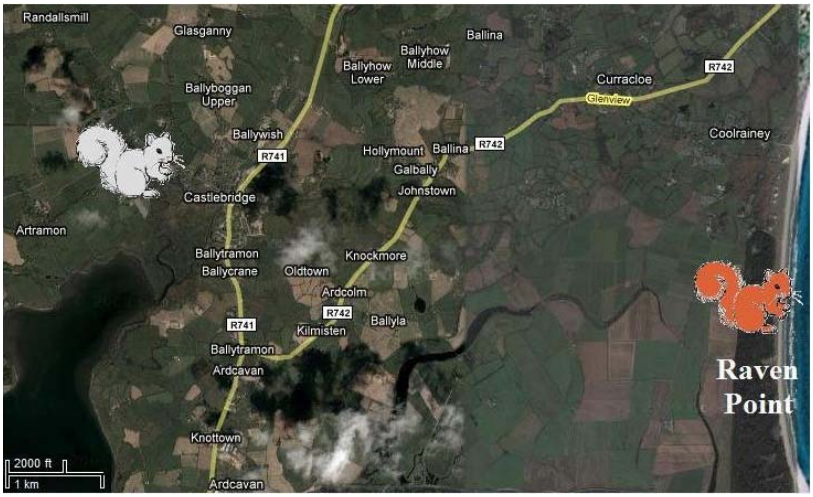

Figure 21: Location of the nearest known population of grey squirrels.

Figure 22: Aerial photograph of the 1km strip outside the entrance to the Raven Reserve indicating a lack of trees and any distinct corridors for squirrel movement.

Table 13: Landscape defendability criteria (Reynolds and Bentley 2001).

Landscape defendability	**Rating**
Expected to be a highly effective barrier	Excellent
Expected to be a reasonably effective barrier	**Good**
Expected to be only a slight barrier	OK
Expected not to act as an effective barrier	Very poor

Table 14: Buffer size – woodland perimeter (km) criteria (Reynolds and Bentley 2001).

Buffer size – woodland perimeter (km)	**Rating**
5 - 8	**Excellent**
8 - 12	Good
13 - 15	Poor
15+	Very poor

Site management:

In terms of the potential for forest and buffer zone management, the Raven is rated as excellent (see table 15). The area is already designated as National Nature Reserve, a Special Area of Conservation (SAC, site code 000710) and a Special Protected Area (SPA, site code 004019). In addition to this, the local residents indicated an interest in red squirrel conservation.

Table 15: Site management criteria (Reynolds and Bentley 2001).

Management potential of forest and buffer zone	**Rating**
Highly suited	**Excellent**
Good potential, a few compromises	Good
Some scope. Conservation value may arise but not as a major consideration.	OK
Unsuitable and/or many conflicts with red squirrel conservation.	Poor

Overall, the Raven is rated in the highest category for 3 of the 4 criteria and in the next best category for the remaining criteria. It is also home to an extensive healthy red squirrels population. It is unlikely that any of the remaining red squirrel populations in the Leinster region will be as highly rated given that most are found within large commercial plantations in Wicklow and the Laois-Offaly region which would prove impossible to defend from grey squirrel invasion. It is therefore recommended that the Raven be considered of the highest priority for protected and designation as an RSPA.

Recommendations:

1. Designation of the Raven as a Red Squirrel Preferred Area (RSPA).

2. Continuation of the on-going research on the squirrel population within the woodland.

3. Further assessment of a 3km buffer zone between Curracloe village and the Raven to include hedgerow habitat assessments as potential corridors for grey squirrel movements, red squirrel distribution within the area and local opinions to red squirrel conservation.

4. Education of local residents on the issue of conservation of red squirrels to potentially include liaison visits to the local schools and a permanent display in the Wexford Wildlife Reserve visitor centre with a view to encouraging the reporting of squirrel sightings to monitor for grey squirrels immigrating into the area.

5. Discouragement of the planting of large seed bearing deciduous species within the buffer zone.

6. Management of the Raven woodland for continued conservation of the red squirrel. Since the woodland is dominated by Corsican pine which is at its peak of seed production between 60 – 90 yrs, this would involve replanting with red squirrel favouring conifers and not grey squirrel favouring large seed bearing deciduous species. Such species include: Scot's pine (*Pinus sylvestris*), Lodgepole pine (*Pinus contorta*), Norway spruce (*Picea abies*), European larch (*Larix decidua*) and Douglas fir (*Pseudotsuga menziesisi*) (The Durham Trust for nature Conservation 2001). It is recommended that this planting be conducted using under-planting techniques rather than clear-felling and replanting as this would lessen the risk of any detrimental effects on the squirrel population due to habitat destruction resulting from tree cutting and clearance.

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