

Methodology used to select stronghold sites

Summary

1. Habitat networks for red squirrels were identified using Geographic Information System (GIS). Habitat networks are connected woodland areas which red squirrels can readily move between. Networks were required to have at least 1 patch of conifer habitat greater than 200ha in size. This is the minimum patch size believed to be required to support a self-sustaining, viable population of red squirrels (Pepper & Patterson, 1998) and was included to act as a source for smaller patches of woodland within the network. The networks were also required to contain at least 2000ha of conifer forest in total, as areas above this size are considered to be “ideal to conserve a population of red squirrels with a high chance of success” (Pepper & Patterson, 1998).
2. Networks with no records of red squirrels within the boundaries within the last 10 years were excluded.
3. Networks with more than 5 grey squirrel records within the last 10 years were excluded.
4. Sites were scored for the following criteria using nationally-available datasets:
 - Functional distance (as the squirrel moves) to the nearest grey squirrel.
 - Proximity to grey squirrels with squirrelpox.
 - Percentage area overlap with ancient, semi-natural broadleaf woodland.
 - Area of network defined as conifer woodland.
5. Sites were scored for the following criteria by discussing maps of the sites with Forestry Commission Scotland and Scottish Natural Heritage field staff.
 - Proportion of large seeded broadleaves
 - Conflict with existing or planned built development
 - Conflict with other conservation objectives
 - Silvicultural factors constraining stronghold management
 - Likely defendability against grey squirrel incursion
 - Red squirrel presence
6. The objective criteria were scored from 0 to 4 or 5 while information gathered through staff consultation was scored from 0-2 or 3.
7. Scores were totalled, with the best 20 sites being presented as candidate Stronghold Sites.
8. The list of candidate Stronghold Sites was modified following discussions with land managers.

Identifying potential stronghold sites

Geographic Information System (GIS) analysis was used to identify potential Stronghold Sites based on information on squirrel distribution (at the 10km² scale) and woodland size and basic composition (broadleaf or conifer).

To generate a list of sites suitable for consideration as potential Stronghold Sites, it was necessary to use computer modelling to identify large networks of areas of woodland likely to be 'functionally connected' for red squirrels. This means that red squirrels could be expected to move readily between the individual woodland areas within these networks through daily movement, thereby being part of a functioning red squirrel metapopulation.

Networks were created using two GIS layers:

- a source layer of landcover data and
- a "resistance layer" reflecting the estimated ease of squirrel movement through the landscape.

Landcover data was derived from a composite dataset which contained data from a number of sources (Annex 2). To generate the resistance layer, it was necessary to gain expert opinion regarding the permeability of different land cover types to squirrels. It was recognised that red and grey squirrels have differing abilities to move through the landscape and this was reflected in the allocation of different resistance scores to different landcover types for each species. Scores for red squirrels were used to generate the habitat networks whilst the scores for grey squirrels were used to identify the functional distance of the networks from the nearest grey squirrel records.

To allow identification of sites believed to offer the best opportunity for the long-term conservation of red squirrels a number of rules were built into the GIS programme. Networks were required to have at least 1 patch of conifer habitat greater than 200ha in size. This is the minimum patch size believed to be required to support a self-sustaining, viable population of red squirrels (Pepper & Patterson, 1998) and was included to act as a source for smaller patches of woodland within the network. The networks were also required to contain at least 2000ha of conifer forest in total as areas above this size are considered to be "ideal to conserve a population of red squirrels with a high chance of success" (Pepper & Patterson, 1998). The models also factored in a maximum dispersal distance for a red squirrel of 2 km to ensure that all the woods within a stronghold were within the home range of a red squirrel.

To determine the proximity of grey squirrels to the habitat networks, red and grey squirrel records from the Scottish Squirrel Survey Database and from data held by the Save Our Squirrels Project (North of England) were used to run a cost-distance analysis. Only records from the last 10 years were used as it was felt that this would provide an accurate representation of current squirrel distribution in the country. Both datasets were corrected to remove erroneous records and those records with incomplete or incorrect grid references.

Networks which had no red squirrels recorded within their boundaries were excluded from the analysis. Networks which recorded more than 5 grey squirrels within their boundaries within the last 10 years were excluded from the analysis. This was necessary because the modifications necessary to allow strongholds to function as

such will take time; time which is not available if grey squirrels are already found at a site.

Once the list of sites had been produced and discussed with stakeholders, it became apparent that despite suitable forests on the Cowal peninsula, no candidate stronghold had been identified there. This was probably because of the particularly high proportion of young trees and felled areas identified through the National Inventory of Woodlands and Trees. Local Forestry Commission staff identified a candidate stronghold site in the area using updated GIS information and this was scored alongside the other strongholds in the ranking exercise. In addition, it became apparent that Arran was such a special case (being an island) that stronghold principles would not fully apply.

Scoring and ranking of sites.

Initial analysis produced 59 habitat networks, 15 of which were removed after being filtered based on squirrel distribution. One network in Cowal was added to the list and one on Arran was removed (see above). Additional criteria were then applied score and rank the list of 44 potential Stronghold Sites in order to identify a subset of networks that best meet the requirements of a Stronghold Site. These criteria and their associated scorings are discussed below:

A: Proximity to nearest grey squirrel.

Networks were scored on their functional proximity (rather than physical distance) to the nearest grey. For each network, the functional distance to the nearest grey squirrel was calculated using the cost-distance model. Cost (resistance) values of each land parcel are multiplied by the distance over that parcel. With each parcel crossed, the value is added to a total of the values of all parcels crossed since the source.

Grey squirrel records from the North of England (within 20km of the border) were also utilised to encompass the fact that in the south of Scotland the nearest grey squirrel may be found south of the border.

Maritime islands were assumed to be functionally isolated from grey squirrels. Networks for islands were generated using the same rules for those on the mainland.

Scoring was as follows:

Functional Distance (km)	Score
>5 Greys present	Excluded from analysis
greys in network	5
<20	4
21-50	3
51-100	2
>100	1
Maritime island	0

B. Proximity to Squirrelpox

In areas where Squirrelpox virus is present it is believed that pox virus may be a significant factor in the decline of local red squirrel populations, with the rate of red squirrel replacement by grey squirrels being around 20 times faster than in those areas where grey squirrels do not carry the virus (Gurnell *et al*, 2006). With the recent incursion of the virus into Scotland SqPV has become a significant additional threat to red squirrels and so this factor has been scored in addition to the “nearest grey squirrel” category. Networks were scored based on their proximity to records of grey squirrels known to be carrying antibodies to SqPV. Scoring was as follows:

Distance (km) to nearest SqPV +ve grey squirrel record	Score
<50	5
50-100	3
>100	0

C. Habitat Composition

It is generally accepted that red squirrels have a competitive advantage over grey squirrels in coniferous woodland. Therefore large areas of conifer woodland are believed to provide the best habitat for the long-term retention of red squirrels.

Networks were scored depending on the total area of conifer habitat within their boundaries.

Area of conifer within network (ha)	Score
2000- 4000	4
>4000-6000	3
>6000-8000	2
>8000-10 000	1
>10 000	0

D. Ancient semi-natural woodland

It is recognised that red squirrel conservation will not be the only management aim for woodlands selected as potential Stronghold Sites. It is important to select sites to be strongholds which have a low level of conflicting objectives or other constraints. Although a number of factors could potentially impact upon small areas of stronghold sites in the short term, only those constraints deemed to be likely to have a significant, long-term impact upon potential Stronghold Sites were considered.

The Scottish Forestry Strategy 2006 places a high priority upon conserving and improving native woodland, and especially those that are ancient semi-natural woodlands. These areas are of limited potential as strongholds as it would not be desirable for wider conservation reasons to alter the species composition (e.g. by planting conifers or removing oak). They therefore act as areas of constraint for potential Stronghold Sites.

To identify areas of constraint, Arc GIS was used to select areas of broadleaf woodland (as defined by the National Inventory of Woodland Trees (NIWT)) which are defined as

“ancient” by the Ancient Woodland Inventory (AWI) and are 80-100% semi-natural, as defined by the Scottish Semi-Natural Woodland Inventory (SSNWI).

To allow a fair comparison between networks, the percentage area of overlap was calculated for each network and was scored as shown below.

%area of overlap with ASNW	Score
>20	5
>15-20	4
>10-15	3
>5-10	2
1-5	1
0-<1	0

E. Large seeded broadleaves

Large seeded broadleaf woodland (oak, beech, chestnut, hazel) is believed to facilitate the spread of grey squirrels and therefore this habitat type will be a major constraint upon the selection of potential Stronghold Sites. Woodlands with 5-10% or more of their total area colonised by large-seeded broadleaf species are currently viewed as less favourable habitat for red squirrels (in the presence of grey squirrels) (Pepper and Patterson, 1998). Ideally the absence of large-seeded broadleaf species within a network should have been used as a site selection criteria. However, a national dataset with the required level of information is currently unavailable. Information on this criterion was sought through an internal FCS/SNH staff consultation exercise.

Large seeded broadleaf on site	Score
Many patches of LSBL and dispersed through more than half of the site	3
Many patches of LSBL or dispersed through up to half of the site	2
A few patches of LSBL totalling not more than 10% of area	1
Virtually no LSBL	0

F. Conflicting development objectives

This scoring criterion was added to reflect the fact that many sites are affected by current or approved developments which will at least cause disturbance to the habitat and may at worst damage or destroy some of the habitat which red squirrels use. The most common type of development proposed is a windfarm, though other major infrastructure developments (e.g. interconnectors), mines and housing expansion were also found.

Future development proposals would be expected to take account of the fact that an area has been chosen as a red squirrel stronghold.

Conflicting development	Score
Development involving significant change or disturbance to woodland proposed for more than half of the site	3
Development involving significant change or disturbance to woodland proposed for 20-50% of the site	2
Development involving significant change or disturbance to woodland proposed for up to 20% of the site or likely increase in neighbouring settlements to boundary	1
No developments proposed	0

G. Conflicting conservation objectives

This is probably the most subjective score used, but it adds a measure of the constraint that existing site conservation objectives will place upon management of strongholds. The kinds of conflicts taken into account include:

- Designation for native pinewood interest where conifer diversification is not possible. Note that this score would be additional to an Ancient Woodland score (applicable to many native pinewood sites) and therefore further biases the selection away from such sites. There are concerns that grey squirrels can live (albeit at relatively low densities) in pine and it is therefore appropriate that these sites are only chosen if of overriding value for other reasons.
- Designation for large seeded broadleaf interest, such as Atlantic Oakwoods. Again, this score will be additional to a large seeded broadleaf score, but enables the scoring to reflect that this cannot be changed over time.
- Deforestation for woodland edge species such as black grouse, where the area of suitable habitat for red squirrels will be reduced over time.

Degree of conservation conflict	Score
Majority of site covered by significantly conflicting conservation objectives	3
Localised significant conflict over 20-50% of the site, or more widespread but minor conflict	2
Localised significant conflict over up to 20% of the site, or more widespread but minor conflict	1
No conflicting conservation objectives	0

H. Silvicultural constraints on stronghold management

Retaining conifers well into coning age will be important in strongholds if food supplies for red squirrels are to be improved, and diversifying conifers is a way of helping to ensure food supplies in every year. In some areas, windthrow hazard or soil type will constrain these management options.

Degree of silvicultural conflict	Score
Habitat modification for red squirrels very significantly constrained by silvicultural factors across whole of site	2
Silvicultural factors constrain diversification on part of site but overall habitat could be significantly improved for red squirrels	1
No major silvicultural constraints on stronghold management	0

I. Defendability against grey squirrel incursion

Strongholds are chosen to be large woods where red squirrels have a competitive advantage over grey squirrels, hence they can persist even if grey squirrels establish populations nearby and the two species come into contact with one another. However, if squirrelpox should spread throughout Scotland's grey squirrel population, then the viability of red squirrel populations in strongholds would be questionable, and grey squirrel control to defend the red squirrels against contact with squirrelpox may be needed.

The best scoring sites for this criteria are those where grey squirrel control within limited geographical areas (pinchpoints) has a good chance of success.

Defendability	Score
No obvious pinchpoints at which grey control could be focussed	3
Part of site defensible	2
Most of site clearly defensible	1
All of site surrounded by obvious 'pinchpoints' and could be defended by focussed grey squirrel controls	0

J. Red squirrel population

All candidate stronghold sites have records of red squirrels in them, but anecdotal evidence shows that some sites hold squirrels at very low density. Though in theory it would be possible to choose a stronghold for its future red squirrel potential alone, it seems sensible to favour sites which have reasonable populations now.

Red squirrels	Score
Anecdotal evidence that red squirrel populations are extremely sparse within the site	2
No such anecdotal evidence	0

Results

The following results are based on the original maps of the sites, with modifications to the Area of Conifer score made as a result of boundary changes (and area changes) following landowner and land manager consultation. Other scores were not sufficiently affected by boundary changes to make any difference to the overall scores. In the time since the sites were scored, squirrelpox has moved closer to all sites in South Scotland and the consultees may wish to take this into consideration.

Network no.	Name	Region	Total network area (ha)	total woodland area (ha)	Area of conifer score	% ASNW score	Grey squirrel score	SqPV score	LSBL score	Development conflict	Conservation conflict	Silvi-cultural conflicts	Defendability	Red Squirrels	Modified total score	Rank
28 & 29	Eredine *	P&A	14,401	11,610	0	0	1	0	1	0	0	0	1	0	3	1
6	Ordiequish /Whiteash/ Ben Aigan	Grampian	6,210	5,696	3	0	1	0	0	0	0	0	2	0	6	2
27	Inverliever	P&A	9,426	8,549	1	1	1	0	1	1	1	0	1	0	7	3
3	Culbin Forest	Grampian	3,072	2,977	4	0	1	0	0	1	0	0	2	0	8	4
32	Kilmichael †	P&A	9,103	8,200	2	1	1	0	1	1	0	0	2	0	8	5
17	Glentochty	Grampian	2,404	2,224	4	0	5	0	0	0	0	0	0	0	9	6
24	South Rannoch	P&A	3,506	3,378	4	1	3	0	0	0	0	0	1	0	9	7
1	Morangie Forest	Highland	6,684	5,467	3	1	1	0	1	0	0	0	3	0	9	9
57	Fell of Fleet ‡	South	9,282	8,548	1	0	4	0	1	0	0	1	2	0	9	12
4	Black Isle	Highland	3,652	3,470	4	0	1	0	2	0	1	0	2	0	10	10
2	Glen Glass	Highland	5,198	4,523	4	1	1	0	1	0	0	0	3	0	10	11
22	Leanachan	Highland	4,013	3,643	4	1	1	0	0	0	0	1	2	2	11	13
40	Carsphairn	South	14,083	12,962	0	0	4	0	0	2	0	1	2	2	11	14
9	Daviot Loch Moy	Highland	4,322	3,751	4	1	1	0	1	0	0	1	3	0	11	15
19	Balmoral to Inver	Grampian	4,624	3,998	4	2	4	0	0	0	1	0	0	0	11	16
45	Eskdalemuir	South	12,563	12,055	0	0	4	5	0	0	0	0	2	0	11	17
99	Glenbranter	P&A	8,603	6,079	3	2	4	0	1	0	0	0	1	0	11	18

49	Galloway (North)	South	7,477	6,903	2	0	5	0	1	0	0	1	2	0	11	19
16	Inshriach and Glenfeshie	Highland	4,329	3,736	4	1	1	0	0	0	3	0	2	0	11	20
15	Abernethy, Nethy Bridge	Highland	4,836	3,476	4	1	1	0	0	0	3	0	2	0	11	21
8	Boblainy	Highland	3,540	3,171	4	1	1	0	3	0	0	0	3	0	12	22
18	Garrygualach	Highland	3,181	2,639	4	1	1	0	1	0	1	1	2	2	13	23
56	Urall Fell	South	4,635	4,162	3	0	4	0	1	0	0	1	2	2	13	24
12	Glen Affric/ Guisachan Forest	Highland	5,908	5,080	4	2	1	0	1	0	3	0	2	0	13	25
7	Darnaway	Grampian	13,693	12,273	1	1	1	0	3	1	3	0	3	0	13	26
5	Strathgarve	Highland	7,689	6,963	3	2	1	0	3	0	1	1	2	0	13	27
13	Glen Morriston	Highland	9,027	7,960	3	3	1	0	2	1	0	0	3	0	13	28
25	Glen Creran	P&A	3,712	3,127	4	2	1	0	2	0	2	0	2	0	13	29
10	Farigaig and East Loch Ness	Highland	6,447	5,578	4	3	1	0	2	0	0	0	3	0	13	30
11	Clashindarroch	Grampian	4,098	3,855	4	0	2	0	1	1	0	1	3	2	14	31
21	Durriss and Fetteresso	Grampian	2,870	2,470	4	0	4	0	0	1	0	2	2	2	15	32
35	Whitelee Forest	South	2,676	2,568	4	0	2	0	0	2	0	2	3	2	15	33
23	Erochty and Allean	P&A	5,517	5,094	4	2	5	0	1	0	1	0	2	0	15	34
14	Kinveachy and Carrbridge	Highland	3,431	3,156	4	2	1	0	2	1	2	0	3	0	15	35
55	Arcleoch Forest	South	2,462	2,319	4	0	4	0	0	3	0	1	2	2	16	36
46	Wauchope	South	4,739	4,574	3	0	5	5	1	0	0	0	2	0	16	37
59	Laurieston Forest	South	2,820	2,645	4	0	4	5	1	0	0	1	2	0	17	38
42	Ae	South	3,319	3,154	4	0	5	5	0	0	0	0	3	0	17	39
20	Durriss and Fetteresso	Grampian	4,077	3,699	4	0	5	0	1	1	0	2	3	2	18	40
50	Ae	South	6,150	5,473	3	0	5	5	0	2	0	0	3	0	18	41

30	Achray Forest	P&A	3,682	3,272	4	3	5	0	3	0	2	0	3	0	20	42
58	Mabie Forest	South	3,284	3,153	4	1	4	5	2	1	0	0	3	0	20	43
36	Elibank and Traquair Forest	South	2,454	2,323	4	0	5	5	1	2	1	0	3	0	21	44

* Two sites at Eredine now amalgamated into one site.

† Kilmichael – name change from Minard Forest

‡ Fleet Basin – name change from Fell of Fleet

Inshriach and Glenfeshie – name change from Inshriach, Rothiemurchus and Glenmore

Sites excluded from the analysis

59 networks were initially identified based on the GIS definitions. Sites which were not selected at this stage would have failed to meet the specified criteria of having at least 2000ha of conifer habitat and 1 source patch of 200ha within the network.

13 networks were excluded as they failed to meet the selection criteria for squirrel distribution:

- Red squirrel recorded within the network within the last 10 years.
- <5 grey squirrel records within the last 10 years.

Network number, name and region	Reason for exclusion
26 Finuary Forest Highland	No red squirrel records within the network
33 Kings Hill Central	No red squirrel records within the network
34 Carradale Perth & Argyll	No red squirrel records within the network
37 Lussa Loch Perth & Argyll	No red squirrel records within the network
39 Howcleuch South	No red squirrel records within the network
47 Cairn Head South	No red squirrel records within the network
52 Castlemaddy south	No red squirrel records within the network
53 Minnygryle Hill South	No red squirrel records within the network
54 Galloway Forest South	No red squirrel records within the network
31 Loch Ard Forest Perth & Argyll	More than 5 grey squirrels recorded within the network boundaries in the last 10 years
41 Craik South	More than 5 grey squirrels recorded within the network boundaries in the last 10 years
43 Wauchope South	More than 5 grey squirrels recorded within the network boundaries in the last 10 years
51 Galloway Forest South	More than 5 grey squirrels recorded within the network boundaries in the last 10 years

In addition networks 44 and 48 (Kielder) were excluded as they were located within England and are thus outwith the scope of this work.

Annex 1: References

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Annex 2: Data Sources

Data	Description	Value	Constraints
National Inventory of Woodland Trees (NIWT)	Derived from LCS88 dataset Provides information on woodland >2ha in size	Baseline data source for woodland for Scotland	Definition of "conifer" as 80% coniferous species means woodlands may contain up to 20% broad-leaved species Misses woodlands <2ha in size
Caledonian Pinewoods Inventory	Areas of pinewood		
Forest Enterprise data	Sub-compartment Information and Forest Plans		
Land Cover Map 2000 (LCM 2000)	Satellite derived remote sensed dataset providing broad habitat definitions	Covers whole Scotland	Problems with accuracy
Land Cover Scotland 1988 (LCS88)	Remote sensed dataset derived from aerial photography taken in 1988	Covers whole Scotland	Information may be out of date Potential for error transcribing from photographs
Ordnance Survey Data	MasterMap	The definitive large scale map for GB Gives accurate representation of woodland areas & boundaries Can identify linear features & roads, tracks etc	
Phase 1 Habitat Survey	Broad scale field mapping giving info on the extent and distribution of natural and semi-natural habitats	Good source of habitat information	Limited coverage
Scottish Semi Natural Woodland Inventory (SSNWI)	Constructed from 1995- 2001 using interpretation of aerial photographs taken in 1988 Map of all woodland >0.1ha classified according to degree of semi-natural character	Identifies all semi-natural woodland	Out of date
Ancient Woodland Inventory (AWI)	Map of all ancient woodlands >2ha in size	Identifies areas of importance for woodland biodiversity	
Scottish Forestry Grants Scheme (SFGS)	Regularly updated records of new planting	Gives composition and extent of new woodland areas	Scheme now closed
Woodland Grant Scheme (WGS)	Regularly updated records of new	Gives composition and extent of new	Scheme now closed

	planting	woodland areas	
UNION			
VARIOUS			
Conservancy Boundaries	Location of FC Conservancy areas	Allows division of sites into regional areas	
SAC, SPA, SSSI, NNR, National Park Boundaries	Boundaries of protected sites/ areas	Gives indication of high value conservation areas	
Black Grouse and Capercaillie Core Areas			
Scottish Squirrel Survey Data Base	Distribution of red and grey squirrels, based on sightings (data modified to include only records from last 10 years and to remove any erroneous records)	Represents known distribution of squirrels across Scotland	Relies on unconfirmed sightings. Lack of sightings in areas with low human population.
Save Our Squirrels Distribution data	Distribution of red and grey squirrels, based on sightings (data modified to include only records from last 10 years and to remove any erroneous records)	Represents known distribution of squirrels across North England	Relies on unconfirmed sightings. Pioneer individuals recorded but humanely destroyed.

Annex 3: Data Limitations

The main difficulties faced with data for the GIS analysis are listed below.

- In NIWT the “conifer” category refers to woodland composed of at least 80% conifers. Therefore it is possible that the potential Stronghold Sites may include a broadleaved component of up to 20%. Subsequent discussions with FCS and SNH staff have attempted to identify such sites.
- Woodland composition data was derived from data in the “National Inventory of Woodland and Trees” (NIWT) but as NIWT only identifies woodlands as conifer or broadleaf, identification of areas of large-seeded as opposed to small seeded broadleaf trees was not possible. Subsequent discussions with FCS and SNH staff have attempted to add such information.
- The data contained in the woodland datasets were compiled in 1988 and 1995 and so may be out of date in some categories. This may have restricted the size and extent of the habitat network in places or may have artificially split one large network into 2 smaller ones.
- The Scottish Squirrel Survey Database may not represent the actual distribution of red and grey squirrel in Scotland and there may be a bias towards areas where recorders have been active. Data is at the 10km² scale, creating the possibility that woodlands within the red squirrel range may not contain red squirrels and that networks recorded as containing grey squirrels may in fact be free of the species. Subsequent discussions with FCS and SNH staff have checked such information.
- A lack of quantitative data on the ability of red and grey squirrels to move through different landcover types resulted in a reliance on expert opinion to determine resistance scores for the generation of the habitat networks.