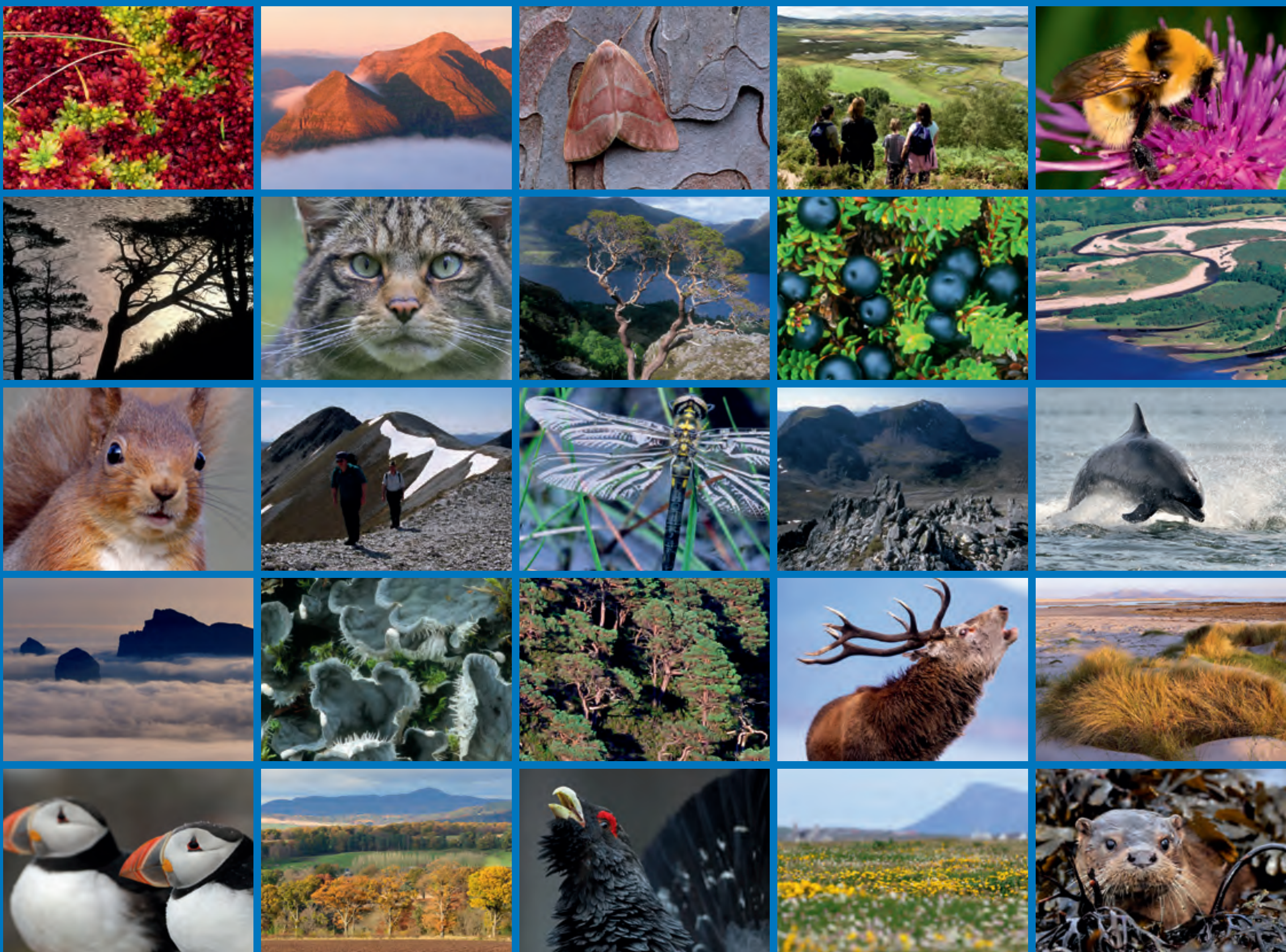
Scottish Natural Heritage
Commissioned Report No. 678

Montane scrub site characterization



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COMMISSIONED REPORT

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Montane scrub site characterization

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COMMISSIONED REPORT
Summary

Montane scrub site characterization

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Background

Montane scrub encompasses different vegetation communities occurring within the treeline ecotone, above high forest. Dwarf birch scrub, alpine willow scrub and alpine juniper scrub occur uncommonly in Scotland, with little documented information about existing sites, or the dynamics of populations. There is a perception that populations of tall-shrubs associated with the vegetation are threatened and action is required to safeguard their future.

This document reports on a 2008 survey of *Betula nana, Salix myrsinites* and *Juniperus communis*. It identifies site characteristics for the Scottish populations of each species, based on data collated during field survey and analysis of the relationships between plant condition and environmental parameters. For *J. communis* additional data from previous surveys in 2000 and 2002-2003 have been included. Information on aspects of site characteristics that can help guide management of the populations is highlighted.

Main findings

- *Betula nana* populations are mainly relatively small with scattered, low growing individuals, below the height of the surrounding vegetation. Recruitment is limited. Analysis showed a trend to larger plant size and denser populations on less wet soils. This species could occupy wet heath sites as well as the blanket bog where it is principally found at present, and might grow better on shallower soils. Many *B. nana* populations need management to facilitate taller growth and more frequent flowering, either through reducing browsing, or a cessation of burning or both. There is a possibility that in the absence of a moss carpet *B. nana* may be killed by burning.
- *Salix myrsinites* sites have relatively high plant-available calcium content, but low soil pH. This suggests the shrub may be more dependent on the underlying bedrock than the soil. *S. myrsinites* predominantly grows on unstable, northerly facing steep slopes at high altitude, in situations generally inaccessible to large herbivores and where the competition from surrounding vegetation is low.
- Many populations of *Juniperus communis* are relatively even-aged with mature and over mature plants. Recruitment appears to be slow, probably as a result of browsing, and populations are vulnerable to catastrophic events.

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1. INTRODUCTION

The term montane scrub is used in the UK to refer to the tall-shrub element of a mosaic vegetation community which is associated with treeline woodland and forms part of the altitudinal transition from high forest to open montane heaths. There are three main vegetation communities included as montane scrub in the UK: dwarf birch scrub, alpine willow scrub and alpine juniper scrub, all of which feature in Annex 1 of the European Habitats Directive (Table 1). These communities are not only uncommon in the UK but there is very little documented information about existing sites. The remaining populations are generally found in remote inaccessible areas and, unless they coincide with protected sites, have been little visited or documented. This report brings together the results of three investigations into the site characteristics of high altitude *Juniperus communis* populations, one investigation of *Betula nana* populations and one of *Salix myrsinites* populations. The purpose was to characterise the existing sites and identify features which provide an insight into their dynamics and thus can provide guidance for their future management.

Table 1. The UK montane scrub types and their classifications in terms of the UK National Vegetation Classification (NVC - Rodwell, 1991a, 1991b) and EC Habitats Directive equivalents (EC DG Environment 2007)

Montane scrub Category[1]	Primary NVC[2] community	Other NVC communities where scrub plants occur[3]	EC Habitat equivalent of the NVC community (EC code). All are Annex 1 habitats[4]
Alpine Willow Scrub	W20 *Salix lapponum – Luzula sylvatica* scrub	CG14[5], U15[6], U16[7], U17[8], M11[9]	Sub-arctic *Salix* spp scrub (H4080)
Alpine Juniper Scrub	H15 *Calluna vulgaris – Juniperus communis* spp *nana* heath	7 woodland, 8 heathland, 4 mire, 6 grassland communities in the uplands	Alpine & Boreal heaths (H4060)
Alpine Juniper Scrub	W19 *Juniperus communis* ssp *communis – Oxalis acetosella* scrub		Caledonian Forest (91C0) *Juniperus communis* formations on heaths or calcareous grasslands (H5130)
Dwarf Birch Scrub	M19ci *Calluna vulgaris – Eriophorum vaginatum* mire *Vaccinium vitis-idaeus – Hylocomium splendens* sub-community *Betula nana* variant	M19b[10], M17[11], M15[12], H12[13]	Blanket bogs (H7130)

[1] Horsfield and Thompson (1997), [2] National Vegetation Classification, [3] Averis *et al* 2004, MacKenzie 2000; Scott, R 1997, [4] EC DG Environment 2007, [5]*Dryas octopetala-Silene acaulis* ledge community; [6]*Saxifraga aizoides-Alchemilla glabra* banks; [7]*Luzula sylvtica-Vaccinium myrtillus* tall-herb community; [8]*Luzula sylvatica-Geum rivale* tall-herb community; [9]*Carex viridula* ssp *oedocarpa-Saxifraga aizoides* mire; [10]*Calluna vulgaris-Eriophorum vaginatum* Blanket mire, *Empetrum nigrum* ssp *nigrum* sub-community; [11]*Trichophorum cespitosum-Eriophorum vaginatum* blanket mire; [12]*Trichophorum cespitosum-Erica tetralix* wet heath; [13] *Calluna vulgaris – Vaccinium myrtillus* heath

1.1 Background

There is a perception that UK treeline scrub is currently threatened and that it was once more widely spread. This has led to a growing interest in taking action to protect its future. However, the limited information available about the dynamics of existing populations and the greater investment required due the challenging conditions at montane scrub sites is a current serious hindrance to more widespread activity. The generalities of the return of forest to Scotland following the retreat of ice (approximately 10 thousand years ago) have been well documented and debated by a number of authors (Birks 1989, Bennett 1996, Tipping 1994, to name three). However, although it is known that montane scrub species, including *Salix* spp. *Juniperus communis* and *Betula nana*, were among the first to colonise they were largely replaced by high forest trees. The debate about the extent and causes of deforestation in the UK, particularly the differing roles of climate and land use, has not considered the fate of montane scrub (Bennett 1996, Tipping 2003, Fenton 2008). This gap is partly explained by the lack of clear evidence for these species in the pollen record (Ives 1977, Tipping 1997), with the exception of specific areas or sites (for example northern Scotland and western islands, Bennett 1995), and the paucity of data for montane scrub macro-fossils, perhaps because palynological work at higher altitudes in the uplands has been limited (Tipping 1997). There is a difference of opinion between vegetation historians about the maximum upper limit of the forest in the current interglacial (Tipping (1994) and Bennett (1996) give the main extremes of opinion) and thus over the area of open ground available for montane scrub between the forest and mountain summits. The accuracy of pollen data in recording the current and historical presence or otherwise of montane scrub species has also been debated and cannot be relied upon to provide an indication of past distributions (Birks 1968, Ives 1977, Bos *et al.* 2004). In addition a study of the function of montane scrub species in the arctic (Bliss 1971, Bélisle & Maillette 1988) suggested that these tall-shrubs, including *Salix* species and *Betula nana*, depend more on vegetative spread than flower and seed production. As a consequence it is possible that the relatively low levels of tall-shrub pollen evident in existing pollen profiles simply reflect the relative levels of flowering across species rather than their frequency.

Historical data have shown that environmental conditions, including climate, longer term land use impacts and the quantity and chemical properties of rainfall, have been continuously changing in the UK (Birks 1988, Rodwell 1991a). It seems likely that in combination the current conditions are quite different from any earlier period in this interglacial. As a result it may be unreasonable to suggest that the past can provide a realistic template for the distribution of vegetation types at the present time or into the future (Tipping *et al*. 1999, Willis *et al*. 2007).

1.2 Existing data

Scottish records for montane scrub were collated by MacKenzie (2000) and have been updated on an ad hoc basis through a general web-based botanical recording system (National Biodiversity Network 2010). In over 40% of cases the data indicates presence in a 1 or 10 kilometre square with limited additional information. Conversely, there may be a ten figure Ordnance Survey grid reference with additional information about other species present and physical site characteristics. MacKenzie (2000) highlighted these and other inconsistencies in quality and quantity across the records. The most complete information was available for specifically targeted rarer species, and those on sites with conservation designations. There is an assumption that most sites are known, although the lack of adequate location information for many records suggests these may be difficult to re-locate.

There is no reliable source of current objective information about 'representative' populations on which to base an assessment of species requirements or dynamics. If treeline scrub was more widespread in the past it suggests that there are or were 'suitable' areas not currently under scrub. These areas may still be suitable or may have become unsuitable either due to changes in climate (Birks 1988, Tipping 1997) or to land management in terms of browsing or burning. Some changes caused by land management may be reversible; others may not, or may take a very long time to become so.

1.3 Objectives

In order to further the likely success of measures to protect or enhance existing areas of montane scrub, or establish new ones, there is an urgent need for better information on the range of site types that support the tall-shrubs and where possible on the factors that affect the condition of the sites.

The main objectives of this report are:

- To report on a field survey undertaken in 2008 (Gilbert 2011) to learn more about the sites currently occupied by the montane scrub species *Betula nana*, *Salix myrsinites*, and *Juniperus communis* as they occur in the treeline ecotone.
- To characterise, as far as possible, *Betula nana*, *Salix myrsinites*, and *Juniperus communis* sites, and to present management guidance that has been distilled from the site characteristics, the ecology and population dynamics of each species. The evidence for both the site characterisation and the guidance has been drawn from three sources: the results of the field survey of all three species; a study of sites for *Juniperus communis* ssp *nana* (Sullivan 2001); and the high altitude sites (above 350 m above sea level, asl) selected from a sample survey of *Juniperus communis* from across the whole of Scotland (Sullivan 2003).

2. SELECTED SPECIES INFORMATION

This section provides a brief overview of what is known about the three species surveyed, focusing on information that is pertinent to the future of the species in the UK. The three species were chosen as representatives of the key montane scrub vegetation communities. In the case of alpine willow scrub *Salix myrsinites* was chosen (out of four main alpine willow species) because the two characteristic willows *S. lanata* and *S. lapponum* have both attracted previous attention in Scandinavia and the UK (Walker 1987, Henry and Gunn 1991, Oullet 1994, Sullivan 1997, Ross 1998, Totland and Sottocornola 2001, Anon 2007). *Salix myrsinites* is little researched but has recently attracted heightened conservation status (listed as "endangered") due to the declining populations (Preston *et al.* 2002, Cheffings and Farrell 2005) and requires better understanding.

2.1 *Betula nana* biology, distribution and ecology

2.1.1 Biology

Betula nana belongs to the Betulaceae, a family of deciduous, monoecious, generally catkin bearing trees or shrubs (*Corylus* is the nut-bearing exception), and is the only non-tree, shrub member out of three UK *Betula* species. The *Betula* tend to be relatively short-lived, in the order of 100 years, but can spread rapidly given the right weather and site conditions (Harding 1981, Stewart 1996) due to the production of large volumes of small, light, wind-pollinated and wind-dispersed, short-lived seeds, a characteristic of northern colonising species. *Betula nana* may not conform exactly to this description. There is no clear data on the age of plants, and none from the UK. One hundred and forty-seven annual rings have been counted on individual stems in Greenland (De Groot *et al*. 1997) but it is suggested that between 50 and 80 is more common. Given that the shrub spreads vegetatively Whittaker (1993) acknowledged that it was appropriate to provide minimum ages and gives >75 years, but suggested >50 years was more common on the glacial foreland in Norway. It has been suggested that plants close to the centre and southern edge of its range produce more flowers and seed (De Groot *et al*. 1997). However, vegetative reproduction is common in the UK (Ashton 1984, *pers. obs.*) and Ashton (1984) reported low seed viability, and poor germination and establishment success, both of which might account for the lack of young plants at most sites. Whether this apparent dependence on vegetative spread is a feature of the more oceanic, and less suitable UK climate on the edge of the *B. nana* range, is not known but it does suggest that UK plants may be longer lived than the ages given above.

In the UK *B. nana* is a relatively short tall-shrub which can reach 1m in height, but is most commonly less than 0.5 m, at or below the height of the surrounding vegetation (De Groot *et al*. 1997). Scandinavian populations readily reach 1.5 m in height, although on the glacial foreland in Norway Whittaker (1993) described it "as a tree growing on its side" and suggested fragments of horizontal stems regenerate easily.

2.1.2 Distribution and status

Betula nana is a northern circumpolar plant with two geographically separated subspecies, *B. nana* ssp. *nana* and *B. nana* ssp. *exilis*. Only *B. nana* ssp *nana* occurs in the UK where it is on its southern oceanic boundary, being absent from Ireland. Inland in Europe it extends as far south as the Alps but is confined to high ground.

During the compilation of the most recent atlas of British flora (Preston *et al.* 2002) between 1987 and 1999, native *B. nana* was found in 74 10 km squares spread from Northumberland to Caithness, but was not relocated in 51 squares from which it had previously been recorded. This loss of populations tends to have been along the western margins of the UK distribution. It is relatively widespread across upland Scotland, extending from Stirlingshire up to Caithness, and from Wester Ross across to Deeside, but there are no recent records from the Southern Uplands (Preston *et al*. 2002). There are extensive populations in central Ross and Inverness-shires, and one on Deeside, but outside these areas it tends to occur in relatively small groups of scattered plants and it is possible that such populations consist of only a few clonal individuals. *B. nana* is listed as of least concern in the red data book for British vascular plants (Cheffings and Farrell 2005).

In the UK *B. nana* is found between 100 m asl in Sutherland and over 855 m asl in the Angus Glens (MacKenzie 2000), but most commonly between 400 and 600 m asl. De Groot *et al*. (1997) suggest that the plant grows at lower altitudes in the drier east of Scotland than in the more oceanic west. In the database of existing records (Highland Birchwoods 2000) all those below 400 m asl are from the western counties including Sutherland, Wester Ross and Lochaber. Although described as a plant of deep peat in the UK (> 2 m deep, Ashton 1984, De Groot *et al*. 1997) it does also grow on shallower peats and on steep ground with damp mineral soils. Some of the largest plants in Scotland are growing on such ground (*pers. obs.*).

De Groot *et al*. (1997) report that in the UK *B. nana* tends to occupy cool areas with relatively high mean annual maximum temperatures (just less than 21°C) and rainfall (1200 – 2000 mm per annum). Across the remainder of its range mean minimum temperatures in winter of -25°C and in summer of 3°C, with rainfall of 300 – 400 mm per annum, are common. It has been suggested that it may not tolerate higher temperatures, but Ashton (1984) points out this may relate to increased competition. Certainly plants survive in domestic gardens at sea level (*pers. obs*.). Tolerance of low temperatures is high and appears to be a response to day length as demonstrated by Biebl (1967) who induced frost resistance and leaf reddening in response to a simulated seven hour day in July in West Greenland.

2.1.3 Ecology

Kirkpatrick & Heal (2001) measured the growth of *B. nana* in relation to ground water and soil water nutrient content at a blanket mire site in the Monadhliath (619 m asl) to the west of the Cairngorms. Plant size and growth correlated positively with water table depth below the surface, but not with the nutrient status of the soil water. There have been few other UK studies and comparison of these findings with similar studies on different site types would be very useful. The apparent differences in habitat preferences of *B. nana* in the UK compared to, for example, Scandinavia and Greenland where there has been some research (Kallio & Mäkinen 1978, Whittaker 1993) further increases the need for research on this species in the UK context.

In the UK *B. nana* is valued as the only host plant of the rare red data book yponomeutid moth *Swammerdamia passerella* Zetterstedt, and the nepticulid *Stigmella betulicola nanivora* Petersen (Bland *et al*. 1997). Other invertebrates specific to *B. nana* in Scandinavia are yet to be found in the UK, but the invertebrate fauna is only now being investigated.

The majority of *B. nana* sites are below 600 m asl, on relatively level blanket mire sites, mainly on areas managed either for agricultural stock grazing or as hunting ground (red grouse *Lagopus lagopus* or red deer *Cervus elaphus*). In many cases this means the ground may be part of a rotational burning programme. It also means that the populations are generally below the altitude of persistent winter snow cover in Scotland at the current time. As a result populations tend to be available to wild and domestic herbivores throughout the year, and young suckers and stems at ground level are also accessible to small vertebrate herbivores such as voles (*Myodes glareolus* and/or *Microtus agrestis*). *B. nana* tends to have higher levels of secondary compounds than willows, but lower than juniper and tree birches, or pine (Bryant and Kuropat 1980, Bryant *et al*. 1983). Over much of its range in the UK it would be the only tall-shrub available to herbivores but there have been no studies comparing the preference of herbivores for dwarf birch relative to *Calluna vulgaris*. Bryant and Kuropat (1980) reported that in sub-arctic forest areas of Alaska, Iceland and Fennoscandia three species of grouse (*L. lagopus, L. mutus* and *L. leucurus*) all eat *B. nana* catkins and foliar buds over winter as second choice to willow. In contrast, British red grouse (*Lagopus lagopus scoticus*) apparently do not eat *B. nana* (Smith *pers comm*). Scott (2001) reported that east of the Cairngorm massif a reduction in red deer population to 3 to 4 per square kilometre reduced stem browsing pressure on *B. nana* sufficiently to allow a four-fold increase in stem numbers. Crête and Doucet (1998) showed that the effects of heavy summer foliage browsing of *Betula glandulosa* in northern Canada appeared to persist for several years. This was demonstrated by an increased stem to foliage ratio, and lighter leaf and wood dry weights compared with lightly browsed birch stands.

2.2 ***Salix myrsinites*** **biology, distribution and ecology**

2.2.1 Biology

Salix myrsinites is a member of Vetrix sub genus of *Salix*, one of two genera in the Salicaceae. Vetrix as described by Christensen *et al.* (2000) appears to be an amalgamation of both Vetrix and Chamaetia as described by Meikle (1984) who included *S. myrsinites* in the latter. These are dioecious plants and in the Vetrix group are primarily spring flowering and insect-pollinated (Christensen *et al*. 2000). Peeters and Totland (1999) demonstrated a minimum 2% wind pollination rate for *S. myrsinites*. Vegetative reproduction by layering is also important, except in *S. caprea* (Christensen *et al.* 2000). Christensen *et al*. (2000) suggested that mountain species seeds usually germinate the following spring. Sullivan (1997) demonstrated high levels of *S. lapponum* germination in seed sown 3 days after collection, but zero germination when sown after 16 days. His seeds were stored at ambient temperature in an unheated building at low altitude before sowing; contrasting with conditions in the field and this may explain the difference. Seedling establishment was reported by Christensen *et al*. (2000) as frequent in unstable or disturbed habitats. As with many other northern mountain willows *S. myrsinites* tends to have a relatively low stature. In Norway mature plants can attain 1 m tall (Christensen *et al*. 2000) but in the UK Meikle (1984) described it as decumbent and spreading up to 0.4 m.

2.2.2 Distribution and status in the UK

In European terms *S. myrsinites* is a northern boreal/arctic species (Myklestad & Birks 1993) and does not occur in the Alps. Historical records from the Alps and Pyrenees have subsequently been re-classified as either *S. alpina* Scop. or *S. breviserrata* B. Flod. (Meikle1984). In the UK the twentieth century distribution of *S. myrsinites* shows a spread from the Southern Uplands (55° 3'N) north to the Orkney Islands (59° N), but with the main centre of the population in the central uplands (57° N). The most recent botanical atlas for the UK and Ireland shows the loss of the two most southerly sites for *S. myrsinites* as well as an overall loss of 21 sites since the collation of the previous atlas in 2000 (Preston *et al.* 2002). Subsequent to these findings, with a presence in 32 ten-kilometre squares, *S. myrsinites* was added to the British Red Data Book for Vascular Plants as endangered (Cheffings and Farrell 2005). It has a wide altitudinal range, from 274 m asl in the north west to 980 m asl in the east (MacKenzie 2000), mainly on moist base-enriched sites (Preston *et al*. 2002).

2.2.3 Ecology

Preston *et al*. (2002) reported that *S. myrsinites* is apparently not very tolerant of browsing and is primarily confined to un-grazed or lightly-grazed areas. The atlas does not provide any evidence, but the nature and location of many populations might suggest that herbivory has influenced their distribution. The interactions between some sub-arctic willows and a range of herbivores, including the Eurasian elk or moose *Alces alces,* hare *Lepidus* spp, the grouse family Tetraonidae, and voles have been reported by a number of authors (Bryant and Kuropat 1980, Maschinski and Whitham 1989, Stölter 2005, Shaw 2006). A key aspect that has attracted increasing research attention is the different ecologies of the two sexes of willows (Crawford & Balfour 1983, Danell *et al*. 1991, Jones *et al.* 1999, Elmqvist *et al*. 1988) – particularly important here is that the response of willows to herbivory is also species specific (Stölter 2005) and so it is difficult to extrapolate the results of many of these studies to *S. myrsinites* except in the most general sense.

Many *Salix* species support specific sawfly larvae (Bland *et al*. 1997). There are very few records for sawfly on *S. myrsinites*, but *Pontania myrsiniticola* Kopelke was recorded from *S. myrsinites* at Inchnadamph in 2005 (Liston & Blank 2006).

2.3 *Juniperus communis* biology, distribution and ecology

2.3.1 Biology

Juniperus communis, a member of the large family Cupressaceae, is wind pollinated, cone-bearing and dioecious, although monoecious specimens were reported in 1905 and 1909 (Thomas *et al*. 2007). The genus is large (60 – 80 species) and is primarily confined to the northern hemisphere. *J. communis* is the only member of the Cupressaceae in the UK and is one of only three native gymnosperms. There are three native sub-species: *J. communis*. ssp *communis*, *J. communis* ssp *nana* and *J. communis* ssp *hemispherica*, with only the first two occurring widely. In Britain the latter sub-species is confined to a few sea-level populations in the extreme south western tip of England and in Wales and is not considered here. The species has a wide distribution across most of Europe (Jalas & Suominen 1996) with a wide altitudinal range (sea level to 975 m in the UK, Preston *et al*. 2002). Regeneration is a slow process with fertilisation of seeds delayed by up to 13 months following flower opening and pollination, and germination normally occurring the following spring (24 months from pollination); but it can take up to 5 years after female flower opening (Thomas *et al.* 2007). The timing of these processes varies slightly between the two sub-species. *J. communis* ssp *nana* is always prostrate and generally less than 10 cm high, although bushes with a spread up to 5 x 5 m have been found. *J. communis* ssp *communis* varies considerably in size and morphology, from tall, (up to 10 m high), single stemmed trees to low-growing, multi-stemmed, semi-prostrate bushes less than 1 m high (Sullivan 2001). At higher altitude or increased exposure the morphology tends towards the latter type.

2.3.2 Distribution and status in the UK

Juniperus communis occurs from the south to the north coast, including the northern isles, of the British Isles, but within the treeline ecotone it is primarily confined to upland areas of Wales, northern England, Scotland and Ireland. Populations tend to be discrete and local (Sullivan 2003). There are concerns regarding the future of the species in southern England because of a lack of regeneration and retraction of populations (Clifton *et al*. 1997). Sullivan's (2003) survey of *J. communis* in Scotland suggests that the future of a high percentage of populations may be at risk if recruitment does not occur in the foreseeable future. No distinction between populations below or above the treeline is made. It is not clear whether issues with recruitment in the UK relate to climate, biological and/or land management drivers. García *et al*. (2000) suggested that populations are receding from the south of Europe due to loss of dependable pollination coupled with poor vegetative growth in summer following cold winters and dry summers.

2.3.3 Ecology

Juniperus communis is evergreen and normally a complex structured plant which provides considerable shelter for other plants and animals, particularly in the treeline ecotone. Generally information from literature does not distinguish between the forest and treeline ecotone zones. Bland *et al*. (1997) identified two dipteran, two lepidopteran and two hemipteran species recorded from higher altitude *J. communis* in the UK. Generally, it is the least preferred woody browse for red deer and mountain hares (*Lepidus timidus*) in Scotland, but the actual damage depends on herbivore density and the nature of other vegetation at a site (Miles and Kinnaird 1979). Miller *et al*. (1982) demonstrated no seasonal variation in browsing damage to *J. communis* in one area with high herbivore densities, but the pressure was always less than on *Pinus sylvestris*. MacGowan *et al*. (2004) proposed that the reduction in reproductive capacity in *J. communis* at four sites in the west of Scotland was likely to be due to herbivore preference for female plants, rather than males. They also reported that the browsing occurred in the winter, rather than summer, over the period of their study.

3. METHODS

This section describes the methods used in the collection of field data in 2008 and its subsequent presentation. The methods used to collect the data from *Juniperus communis* populations in 2002-2003 (Sullivan 2003), and those for *Juniperus communis* ssp *nana* in 2000 (Sullivan 2001) are given in Appendix 4.

The 2008 field survey was composed of two parts. An initial desk-based data collation exercise brought together available information about the existing populations of *Betula nana, Salix myrsinites* and *Juniperus communis*. Through analysis of this data it was possible to identify a range of categories of site types for each species. From these categories 15 field survey sites for each species were selected to include the widest range of the combinations of geographic and environmental characteristics represented. This section focuses on the field survey. Details of the field survey site selection process are given in Appendix 1.

3.1 Field survey

3.1.1 Site definition and data collection

Each site was visited once between May and October in 2008 and held at least 10 individuals not more than 5 m apart, within an area of 1 ha or less. The boundaries of the site were established and data and samples were collected at the whole site level during a walk through the site, at the centre of the site, or within 10 2m x 2m quadrats per site, depending on the nature of the data. Full details of the data collected, and the protocols used, are in Appendix 3 Fig. A3.1 and A3.2.

Where a population occupied more than 1 ha, the site was sub-sampled and natural breaks, such as runnels, were used to identify the boundaries of the area surveyed. Most of the data collected was independent of the time of year, although two sets were not and do change: leader length and the plant available nutrients (potassium, calcium, phosphorous and magnesium) present in site soils.

3.1.1.1 Whole site data

Variables recorded were:
Density, cover, and growth form of the scrub species; Soil moisture class; amount of bare ground; evidence of regeneration, burning, browsing and presence of herbivores; aspect, slope, altitude and TOPEX angles.

A plant species list was compiled for the whole site.

Most *Salix myrsinites* populations were on steep, rough, unstable slopes making precise location of the centre of the site difficult. For these sites the location and altitude was recorded at each sample point. A number of *S. myrsinites* sites were surveyed despite having failed to meet the minimum 5 m spacing criterion due to plants being separated by solid rock or scree.

3.1.1.2 Sample point (quadrat) data

Ten equally spaced sample points were placed within the site systematically on transects usually running up and down-slope. At several sites vegetation was sparse and it was necessary to opportunistically locate sample points to avoid bare rock or scree.

If the quadrat did not contain an individual of the target shrub species the nearest individual was sampled.

Variables recorded were:
Percentage cover of the 4 most dominant species and height of vegetation layers; Gross morphological characteristics and form of the scrub species; Browsing intensity and age of the scrub species, Soil depth; Any evidence of regeneration; Notable features such as presence of galls on the shrub species or flowering.

At each of four sample points a soil core of approximately 5 cm diameter by 15 cm deep was taken from each quadrant. Cores from each sample point were amalgamated except for one sample point at a *S. myrsinites* site where the cores were visually and texturally very different.

3.2 Population condition assessment

A subjective, comparative judgement of the condition of each population for each of the species was made based on a combination of the size of plants, in terms of height and spread, the distribution of the plants across the site, taking physical site factors into account, and the presence of seedlings or saplings. The current year's leader length could only provide additional indications of condition for those populations surveyed after the middle of June. Presence of flowers or fruit suggested plants may be in reasonable health, but their absence in one year did not indicate poor health. Burning, browsing impacts and surrounding vegetation provided additional evidence of the population condition in relation to future potential.

3.3 Soil chemistry analysis

Soil samples were chilled within four hours of collection, frozen within 48 hours and subsequently air-dried at 30°C for a minimum of five days before being passed through a 2 mm sieve. In order to measure pH, between 2 g and 15 g of each sample was re-wetted in 40 cm^3 de-ionised water and mechanically shaken for 2 hr, 5 cm^3 of 0.1 molar solution (M) $CaCl_2$ was then added to create a 0.01 M $CaCl_2$ and mechanically mixed for a further 30 minutes before leaving to stand for 2 hr. Calcium chloride ($CaCl_2$) is considered to provide a more accurate measure of pH for organic soils because the soil particles absorb hydrogen ions on drying and re-wetting in H_2O is less effective at releasing them than a weak $CaCl_2$ solution (Sumner 1994). pH measuring in de-ionsied water generally gives results in the order of 0.5 pH points higher than in 0.01 M $CaCl_2$ for organic soils. The pH was measured in the supernatant above the soil according to The Hutton Institute quality assured procedures.

Plant available calcium (Ca), phosphorus (P), potassium (K) and magnesium (Mg) were measured in each soil sample. The cations were extracted using 0.43 M acetic acid (CH_3COOH), approximately 40 cm^3 of which were added to accurately measured weights (to four decimal places), in the order of 2.5 g, of the air-dried and sieved soil. The solution was mechanically agitated on an end-over-end shaker for two hours before being filtered through Whatman No. 542 filter paper. The sample was washed through the filter paper with a further 40 cm^3 of 0.43 M acetic acid before being made up to 100 cm^3 and passed to MLURI analytical section for analysis by inductively coupled plasma-atomic emission spectroscopy (ICP-AES). Soil moisture content was determined by placing between 1 g and 5 g of accurately measured (to four decimal places) sample of each soil in a porcelain crucible in an oven at 105° C for at least two hours. The hot samples were placed in a desiccator until cool before re-weighing accurately (to four decimal places). The soil moisture content allowed the conversion of available cation content, provided in parts per million (or ml/litre of solution) to mg/kg of dry soil, which was used in the analysis as follows:

$$X = 100 . x . m / w$$

Where X is the concentration of cation provided by the ICP-AES in ml/l, w is the original weight of the soil sample, and m is the moisture factor of the soil. m was calculated as follows:

$$m = 100/(100-h)$$

where h is the moisture content of the soil expressed as a percentage of the air-dried weight.

The total elemental nitrogen (N) and carbon (C) content of the soil samples was measured from samples of each soil which had been processed in a ball mill to a uniform fine powder. Prior to analysis the samples were further dried at 50°C for at least two hours and then stored in a desiccator until weighing. Up to 15 mg of each sample was accurately weighed into 3 mm tin cups on a Mettler MT5 Microbalance (to three decimal places). The tin cups were crushed in order that no material could be lost prior to analysis. The weighed batches of samples were passed to the MLURI Analytical Section for analysis in a Thermo Finnigan Elemental Analyser (FlashEA 1112 Series). Total N and C measures were provided as percentage by weight.

3.4 Statistical analysis

The quantitative data collected from the ten quadrats per site were pooled for each population and summarised as medians, maximums and minimums. The site means for total soil C and N and available cations (Ca, P, K and Mg) were each separately tested across the whole dataset in a one-way analysis of variance (ANOVA) in GenStat 10©.

The relationship between shrub condition and site characteristics was analysed using the constrained linear ordination technique Redundancy Analysis (RDA) with the computer package CANOCO version 4.5 (©Ter Braak and Smilauer 2002). The analyses were undertaken separately for each target species. The shrub condition parameters replaced species presence data in the RDA while the site characteristics replaced the environmental variables and the forward selection option in Canoco was used to identify the significant site characteristics.

The plant size parameters used in the analysis of shrub condition were the site means for vertical height, plant volume and stem diameter, calculated from the measurements recorded at the sample points (n = 10 per site). Shrub distribution: continuous, clumped, medium or sparse, at a site was also considered to be an indicator of condition. The sum of the percentages across the distribution classes was 100% at each site and the class values were dependent on each, contrary to the requirements of the RDA analysis. To make each distribution value independent the class with the least number of zeros was identified for each species (medium distribution in all cases) and each of the other classes was expressed as a ratio of it, resulting in only three distribution classes. Across the data there was a range of scales, from in the order of 100 cm and more to in the order of 1 mm and less, and ratios of less than 1. As a result all parameters were centred, standardized and log transformed prior to analysis to avoid bias.

A number of site characteristics used in the analysis of shrub condition required modification to fit the requirements of the analysis. Aspect angles were adjusted by subtracting 45°, and then transformed, by calculating the cosine and sine of the angle in radians, in order to relate each to the NE and NW. This transformation relates each site to the prevailing south-west to north-east alignment of high ground in Scotland, and provides an indication of the exposure of a site to morning sunlight. Browsing percentage classes were expressed as the centre percentage value for each class (e.g. class 1, 0-20%, was expressed as 10). Soil moisture for the site had been recorded in percentages and the total of the different classes across each site always summed to 100%. For analysis the inverse hyperbolic sine of these percentages was used in order to create linear values.

Data for the following site characteristics, which were considered potentially important to shrub condition, were available remotely and so were included in the analysis:

distance to coast (MLURI 1993);
mean January temperature (Perry and Hollis 2005);
mean July temperature (Perry and Hollis 2005);
and annual rainfall (Perry and Hollis 2005).

4. RESULTS

The results of the survey of *Betula nana, Salix myrsinites* and *Juniperus communis* undertaken in 2008 are reported here. Data are reported collectively for factors and characteristics which bear comparison, and for efficiency and clarity. This is followed by a specific section for each species. Within the section for *J. communis* data from two earlier reports Sullivan (2001) and Sullivan (2003) have been included in order to further increase the understanding of site characteristics and population condition. It was not possible to include these additional data in the analysis because of the very different methods used in their collection. However, where possible they have been included in comparisons.

4.1 Field site selection

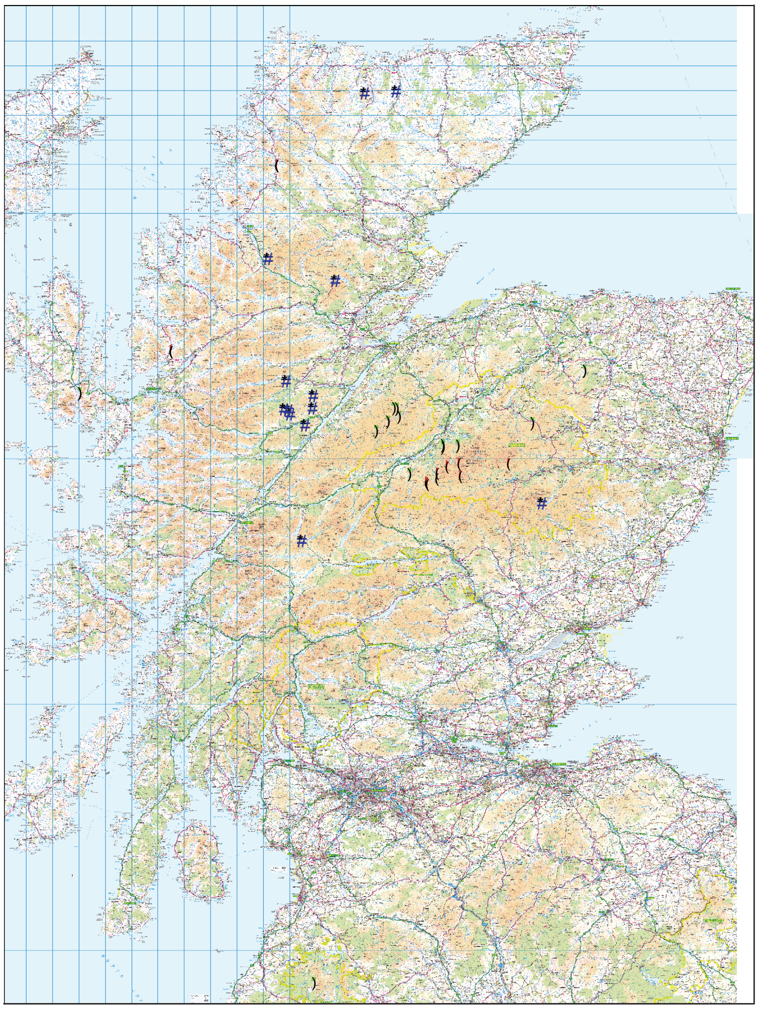


Figure 1. Map showing the location of Betula nana *(blue triangles), Salix myrsinites (red discs) and* Juniperus communis *(green squares) sites which were surveyed over the summer of 2008. (© Crown copyright and database right (2007). All rights reserved. Ordnance Survey Licence Number 100019294)*

Of the 15 sites selected for field survey for each species 13 sites were surveyed for *Betula nana*, 12 for *Salix myrsinites* and 13 for *Juniperus communis* (Fig. 1, Table 2). At two *B. nana* sites no plants were found within the 1 km square of the record. In one area an alternative population was identified in the neighbouring 1 km square on very similar ground. At the other no alternative population was found on similar ground. One *S. myrsinites* site was not surveyed because on arrival at the site it became clear that it would not be possible to carry out the full survey safely. At another location no *S. myrsinites* plants were found within the 1 km square of the record, but a suitable population was found in a neighbouring area and although not of the same site type as the original it was a contrasting type to those on the list. One *J. communis* site was not surveyed because, once in the field, it was clear that it was below the treeline ecotone zone. Another *J. communis* site was moved as there were no plants in the 1 km square of the selected record. The new site was about 1 km north west on similar but more sheltered ground. The remaining sites selected were not surveyed due to lack of time.

Table 2. List of sites surveyed in 2008 with date of survey and location information.

Species	Site number	Site name	Date	10Km	XCOORD	YCOORD
Betula nana	1010	Beinn Enaiglair	18/06/2008	NH28	222410	881260
	1036	Loch na Beinne Baine	30/07/2008	NH21	228926	819752
	1052	Beinn a' Chairein	19/06/2008	NH23	229876	831072
	1064	Carn Dubh, Dundreggan	30/07/2008	NH31	231242	817659
	1066	Carn nan Earb	31/07/2008	NH31	230334	819256
	1096	Port Clair	13/06/2008	NH31	236986	813615
	1114	Loch na Fearnaig	10/07/2008	NH32	239571	820106
	1118	Loch na Meur	18/07/2008	NH32	239845	825285
	1159	Corravachie, Ben Wyvis	22/06/2008	NH47	248214	872386
	1186	Ben Loyal	03/07/2008	NC54	259547	948288
	1192	Cnoc Maol Malpelly	04/07/2008	NC74	271481	949304
	1229	Glen Muick	26/07/2008	NO23	326681	731237
	1231	Corrour	28/08/2008	NN36	235292	766252
Salix myrsinites	2001	Creag an Dail Beag	27/07/2008	NO19	314960	798272
	2002	Slochd Beag	04/08/2008	NN88	283981	789787
	2003	Creag na h'Iolaire	03/08/2008	NN89	283558	790682
	2004	Beinn Bhrotain	17/08/2008	NN99	296449	793291
	2016	Coire Garbhlach	05/08/2008	NN89	287678	794289
	2017	Coire Odhar	23/07/2008	NN99	291326	797153
	2022	Druim na Bo	21/07/2008	NN89	287358	792247
	2055	Garbh Choire	16/08/2008	NN99	295982	798343
	2086	Sgurr a' Gharaidh, North	21/05/2008	NG84	186297	844110
	2088	Sgurr a' Gharaidh, South	20/05/2008	NG84	186298	844030
	2102	Inchnadamph enclosed	02/07/2008	NC21	226576	919810
	2103	Inchnadamph unenclosed	01/07/2008	NC21	226367	919824
Juniperus communis	3029	Caimhlin Mòr	08/07/2008	NH61	268690	815475
	3032	Carn Ruigh na h-Easgainn	07/07/2008	NH61	264548	811726
	3038	Carn Mòr	09/07/2008	NH71	273080	817324
	3052	Pluc Mòr	17/07/2008	NH72	270905	820803
	3054	Allt Fearna	19/07/2008	NH72	272448	820667
	3056	Creag Fhiaclach East	07/10/2008	NH80	289697	805081
	3057	Creag Fhiaclach North	05/10/2008	NH80	289604	805554
	3064	Castle Hill	23/06/2008	NH90	295185	806129
	3127	Craigs of Succoth	28/07/2008	NJ43	343747	836183
	3171	Croidh-la	24/08/2008	NN79	276879	794136
	3285	Beinn Dearg Mheadonaidh	03/09/2008	NG52	151338	827160
	3290	Lecht	19/10/2008	NJ21	323644	814980
	3324	Kirriereoch	05/09/2008	NX48	240502	586588

4.2 Field survey findings

4.2.1. Inter-species comparisons

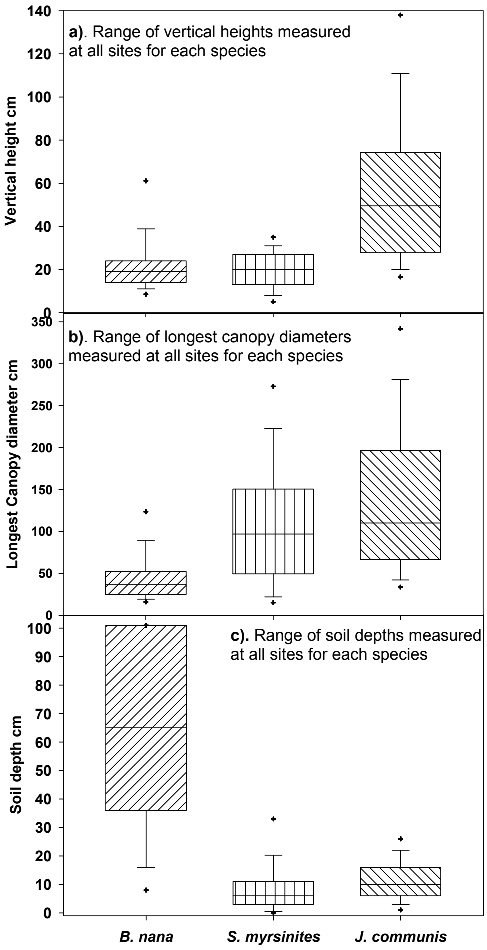


Figure 2. Boxplots of the range of variation in a) vertical plant height (cm) b) maximum crown diameter (cm) and c) soil depth (cm) for B. nana*,* S. myrsinites *and* J. communis*. The box gives the median +/- 25 percentile and each + gives the 5*th *and 95*th *percentiles.*

When the data for plant height, crown diameter and soil depths were compared across the three species the results were as expected (Fig. 2). *J. communis* ssp *communis* tends to grow much taller than either of the other two species which largely overlap in size. However the more prostrate form of *S. myrsinites* is confirmed by relatively short plants with the least variation between maximum and minimum. *J. communis* had the largest maximum crown diameter values and although there was considerable overlap with *S. myrsinites* this was not the case with *B. nana* (Fig. 2b). *B. nana* sites had the deepest soils and widest range of depth measured in the survey while *S. myrsinites* and *J. communis* sites had similar, much narrower ranges of soil depths (Fig. 2c).

Across the populations of each species the soils at *S. myrsinites* sites showed the widest range of pH values, ranging from below 4 to above 7. Related to pH, Ca and Mg content of soils varied widely across *S. myrsinites* sites compared to *B. nana* and *Juniperus communis* (Table 3). Conversely there was little variation in the relatively low P content of *S. myrsinites* site soils. There was greater variation in P content between *B. nana* site soils while *J. communis* sites had the widest range by virtue of one site with exceptional variability, from close to zero up to 152 mg/kg. Nitrogen presence in soils was low in general and in both *B. nana* and *S. myrsinites* the apparent variation is exaggerated by sites with exceptionally low or high percentages, respectively. *Juniperus communis* showed a more even and wider range of variability.

The ANOVA separated the three species across most of the soil components (Table 4). *B. nana* site soils had significantly higher concentrations of C, N and P than soils at either *S. myrsinites* or *J. communis* sites (P < 0.05) and significantly lower pH values (P <0.05). Potassium levels in *B. nana* site soils were significantly higher than in *S. myrsinites* site soils (P <0.05), but not *J. communis* site soils. Soil concentrations of C, N and K were significantly lower in *S. myrsinites* site soils (P <0.05) than in either the *B. nana* or *J. communis* site soils, and the P concentration was significantly lower than in *B. nana* site soils (P <0.05). *Salix myrsinites* site soil concentrations of Ca and their pH values were significantly higher than in either of the other species' site soils (P <0.05). *J. communis* site soil values tended to be in between the other two species and for C, N and pH the different species were all significantly different from each other (P <0.05). *J. communis* site soil Ca and K concentrations were similar to those for *B. nana* site soils, and P concentrations were similar to those found in *S. myrsinites* site soils. There was no significant difference between the soil concentrations of Mg in the three species site soils.

Table 3. Maximum, minimum and median values for different site characteristics of Betula nana*,* Salix myrsinites *and* Juniperus communis *populations.*

	Maximum	Median	Minimum	*N*
Betula nana				
Soil depth (cm)	> 100	> 60	0	520
Soil pH ($CaCl_2$)	4.38	3.25	2.98	52
Soil Carbon (%/weight)	53	47	7	52
Soil Nitrogen (%/weight)	2.2	1.6	0.3	52
Soil calcium (mg/kg^{-1})	1,571	607	49	52
Soil phosphorus (mg/kg^{-1})	118	63	0	52
Soil potassium (mg/kg^{-1})	723	256	71	52
Soil magnesium (mg/kg^{-1})	1,342	738	35	52
Field vegetation height (cm)	70	20	7	520
Moss height (cm)	16	5	0	520
Slope(^{0})[1]	38	7.5	0	16
TOPEX	131	42	12	13
Altitude(masl)	642	506	140	13
Salix myrsinites				
Soil depth (cm)	70	6	0	480
Soil pH ($CaCl_2$)	7.53	5.24	3.77	48
Soil Carbon (%/weight)	34	9	3	48
Soil Nitrogen (%/weight)	2.0	0.6	0.2	48
Soil calcium (mg/kg^{-1})	40,500	2,280	78	48
Soil phosphorus (mg/kg^{-1})	24	6	1	48
Soil potassium (mg/kg^{-1})	386	113	62	48
Soil magnesium (mg/kg^{-1})	15,486	257	32	48
Field vegetation height (cm)	55	13	0	480
Moss height (cm)	30	4.5	0	480
Slope(^{0})[1]	50	37	8	13
TOPEX	211	153	48	12
Altitude(masl)	876	681	231	12
Juniperus communis				
Soil depth (cm)	54	10	0	520
Soil pH ($CaCl_2$)	6.01	3.96	3.16	52
Soil Carbon (%/weight)	42.9	21.7	2.13	52
Soil Nitrogen (%/weight)	2.28	1.13	0.159	52
Soil calcium (mg/kg^{-1})	5,341	622	46	52
Soil phosphorus (mg/kg^{-1})	152	10	1	52
Soil potassium (mg/kg^{-1})	814	265	54	52
Soil magnesium (mg/kg^{-1})	6,223	274	31	52
Field vegetation height (cm)	77	23	0	520
Moss height (cm)	24	6	0	520
Slope(^{0})[1]	44	26	1	15
TOPEX	164	90	29	13
Altitude(masl)	605	524	392	13

1 At several sites the topography was complex and more than one slope value was recorded, in such cases the mean value is provided. At some sites either the whole or part of the site was level and slope = 0.

Table 4. ANOVA output from one-way test of difference between chemical concentrations in Betula nana*,* Salix myrsinites *and* Juniperus communis *site soils.*

Element	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Species means and significance[1] *Betula nana* n=13	*Salix myrsinites* n=12	*Juniperus communis* n=13	Average LSD
Carbon (% by weight)	Species	2	6898.32	3449.16	43.19	<.001	43.0	10.3	22.1	7.21
	Residual	35	2795.06	79.86			c	a	b	
	Total	37	9693.38							
Nitrogen (% by weight)	Species	2	4.8417	2.4208	13.65	<.001	1.57	0.698	1.14	0.34
	Residual	35	6.208	0.1774			c	a	b	
	Total	37	11.0497							
Calcium (mg kg-1)	Species	2	159617371	79808685	6.68	0.003	652	5190	923	2790
	Residual	35	418371450	11953470			a	b	a	
	Total	37	577988820							
Phosphorus (mg kg-1)	Species	2	13339.8	6669.9	13.21	<.001	52.6	7.39	22.5	18.1
	Residual	35	17672.9	504.9			b	a	a	
	Total	37	31012.7							
Potassium (mg kg-1)	Species	2	225514	112757	10.38	<.001	299	133	299	84.1
	Residual	35	380132	10861			b	a	b	
	Total	37	605646							
Magnesium (mg kg-1)	Species	2	8732364	4366182	1.36	0.271	659	1650	587	1450
	Residual	35	112624844	3217853			a	a	a	
	Total	37	121357208							
pHCaCl2	Species	2	15.0596	7.5298	23.82	<.001	3.20	4.73	3.72	0.454
	Residual	35	11.0631	0.3161			a	c	b	
	Total	37	26.1226							

[1] means for each chemical component with same letter (a, b, or c) are not significantly different at P <0.05, using Least Significant Differences (LSD).

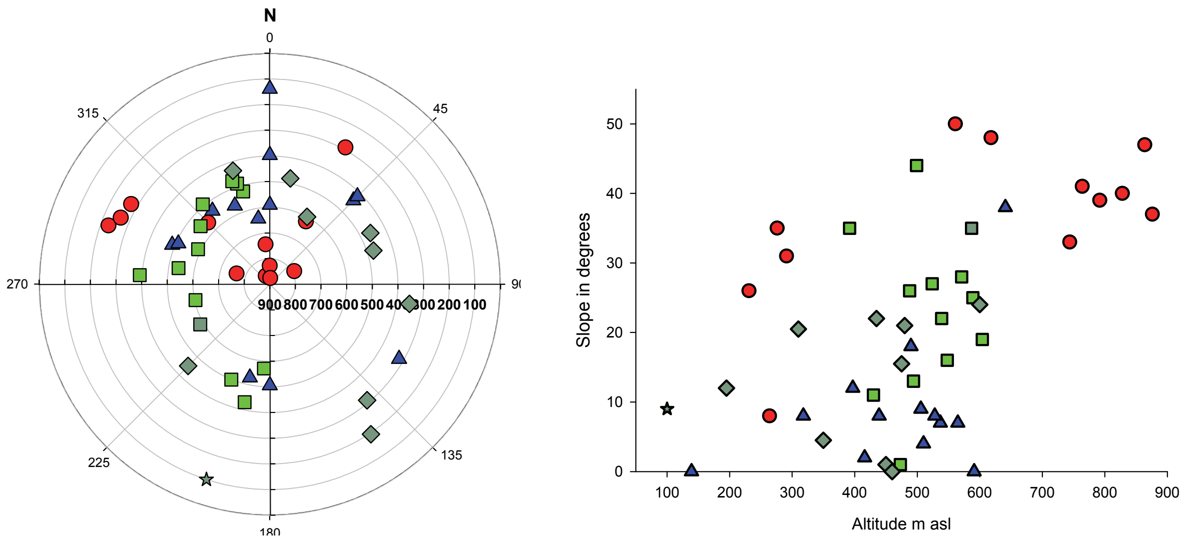


Figure 3. a) The distribution of survey sites for all species according to aspect and altitude. b) The relationship between slope and altitude. Data includes Juniperus communis *sites from Sullivan (2001).*

▲ *Betula nana* sites (2008)
● *Salix myrsinites* sites (2008)
■ *Juniperus communis* ssp *communis* (2008)
■ *J. communis* ssp *nana* (2008)
◆ *J. communis* ssp *nana* (2001)
☆ *J. communis* intermediate characteristics (2001)

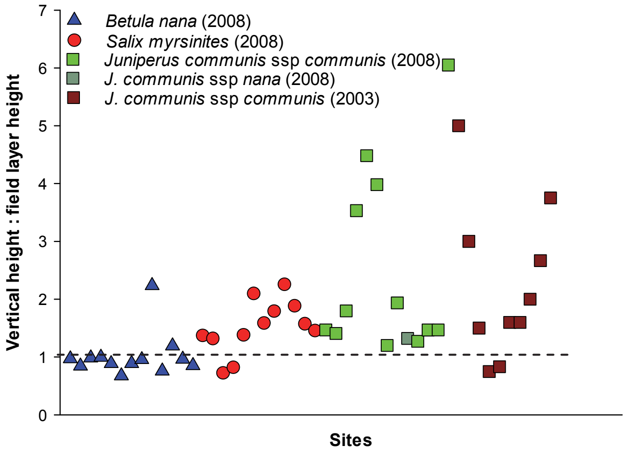


Figure 4: The ratio of mean site plant heights to mean field layer heights for all three species. The dashed line represents a ratio of 1 where the vegetation and shrubs are the same height. Data includes Juniperus communis *sites from Sullivan (2003).*

There was no clear association between aspect and altitude in any species, however the aspect of all the *S. myrsinites* sites surveyed fell within a range of 134° centred about 355° and so generally faced north, and all the *J. communis* ssp *communis* sites surveyed in 2008 have an aspect between 180° and 360° (Fig. 3a). Neither *B. nana* nor *J. communis* ssp *nana* showed any clear association with aspect. There was also no clear association between slope and altitude (Fig. 3b). The majority of *B. nana* sites surveyed were on shallow slopes at lower altitudes, and high altitude and steep slopes were common at *S. myrsinites* sites, but at least one site for each species showed a contrasting location. Generally, *B. nana, S. myrsinites* and *J. communis* ssp *communis* can grow to heights which would normally exceed the surrounding vegetation as illustrated by all but two *J. communis* ssp *communis* sites, and all but two *S. myrsinites* sites (Fig. 4). But there were only two sites for *B. nana* where the mean tall-shrub height was above the mean height of the surrounding vegetation.

4.2.2 *Individual species site characterisation* – Betula nana

4.2.2.1 *Betula nana* physical site characteristics

The sites surveyed extended from Sutherland in the north, as far south as Lochaber and as far east as Aberdeenshire. Eleven sites were between 400 and 650 m asl, the remaining two sites were lower and were in the north west. Aspect does not appear to be important, which might be expected when 10 out of 13 sites have a slope of less than 10° (Fig. 3). One population, Glen Muick, was growing on a slope of > 20° (38°) to the horizontal. This site also had the lowest soil depth statistics (maximum 50 cm, mean 6 cm, and minimum 0 cm). A total of five sites had mean soil depth values of < 50 cm, while for four the mean was > 100 cm. At three sites the soil depth varied from a minimum < 10 cm to a maximum > 100 cm (Fig. 5). The Glen Muick population was growing in Alpine soils, on a leucogranite igneous intrusion, and was the only site not on peat-based soil, as evidenced by the comparatively low total C content of its soils (< 20% by weight) (Fig. 5). Nine of the remaining populations were on sedimentary Psammite bedrock, five of these were growing in peaty gleys which have medium peat content and are wet with a small mineral content; two in subalpine peat soils, which have medium peat, are comparatively dry and have some mineral content; and two in blanket peat with no mineral content. The Corrour Station population is on a sedimentary schist and quartzite pelite bed rock growing in a peaty podzol of very variable depth. Podzols tend to be wet, low in mineral content due to leaching with a relatively impermeable layer below the organic material, and are thought to have developed as a result of land management, particularly the conversion of forest to open moorland. The Cnoc Maol Malpelly population is on a Psammite and gneissose semipelite, overlain with deep peat.

Overall the pH of site soils was acid. All the values were below 4.4, and the majority of sites ranged between 3 and 3.7, with only two with values above 4.3. These two sites (Port Clair and Beinn Enaiglair) also had the highest mean available Ca concentrations and lowest mean available P concentrations. Total C concentrations were generally relatively high (Table 2) with the exception of Glen Muick, which also had the lowest total N concentrations, and the lowest values for all the plant-available nutrients (Fig. 5). There was no clear pattern of variation in the mineral content of the soils across the sites.

At 12 out of 13 sites, the cover of moist soils was 90% or more. At six of these sites the balance was made up by wet soils, while at two it was made up by dry soils. The remaining site, Corrour Station, was the most variable with mainly moist soils (87% cover), the highest percentage cover of wet soils (10 % cover) and dry soils (3 % cover). Glen Muick, on the steepest ground (38°) had the highest percentage cover of dry soils (10 %). Loch na Beinne Baine was the only other site with any cover of dry soils (5 %).

4.2.2.2 *Betula nana* plant distribution and size

The primary distribution pattern of plants at seven of the 13 sites was clumped (between 0.5 and 1 m spacing), and over 90% of plants at 11 sites were multi-stemmed. The mean height of the plants was only taller than the mean height of the surrounding vegetation at two sites (Fig. 4). At Glen Muick all the *B. nana* plants were taller than the surrounding vegetation and taller, with a larger mean crown diameter, than found at any other site. At Loch na Beinne Baine, the mean height of plants was taller than the mean height of the surrounding vegetation. Glen Muick was the only site where the mean stem diameter was more than 10 mm (12.9 mm), more than double the second largest at Loch na Beinne Baine (5.8 mm). The two northern sites (Ben Loyal and Cnoc Maol Malpelly) had the smallest mean stem diameters (3 mm and 2.8 mm). It is difficult to compare leader lengths between sites due to the variation in timing of the individual site visits, and the longest leaders were recorded from sites surveyed towards the end of the year. However among sites surveyed after the middle of July three (Loch na Meur, Carn Dubh and Carn nan Earb) had relatively short mean leader lengths and small maximum crown diameters, closer in size to those measured a fortnight or more earlier than to those measured within a few days or later.

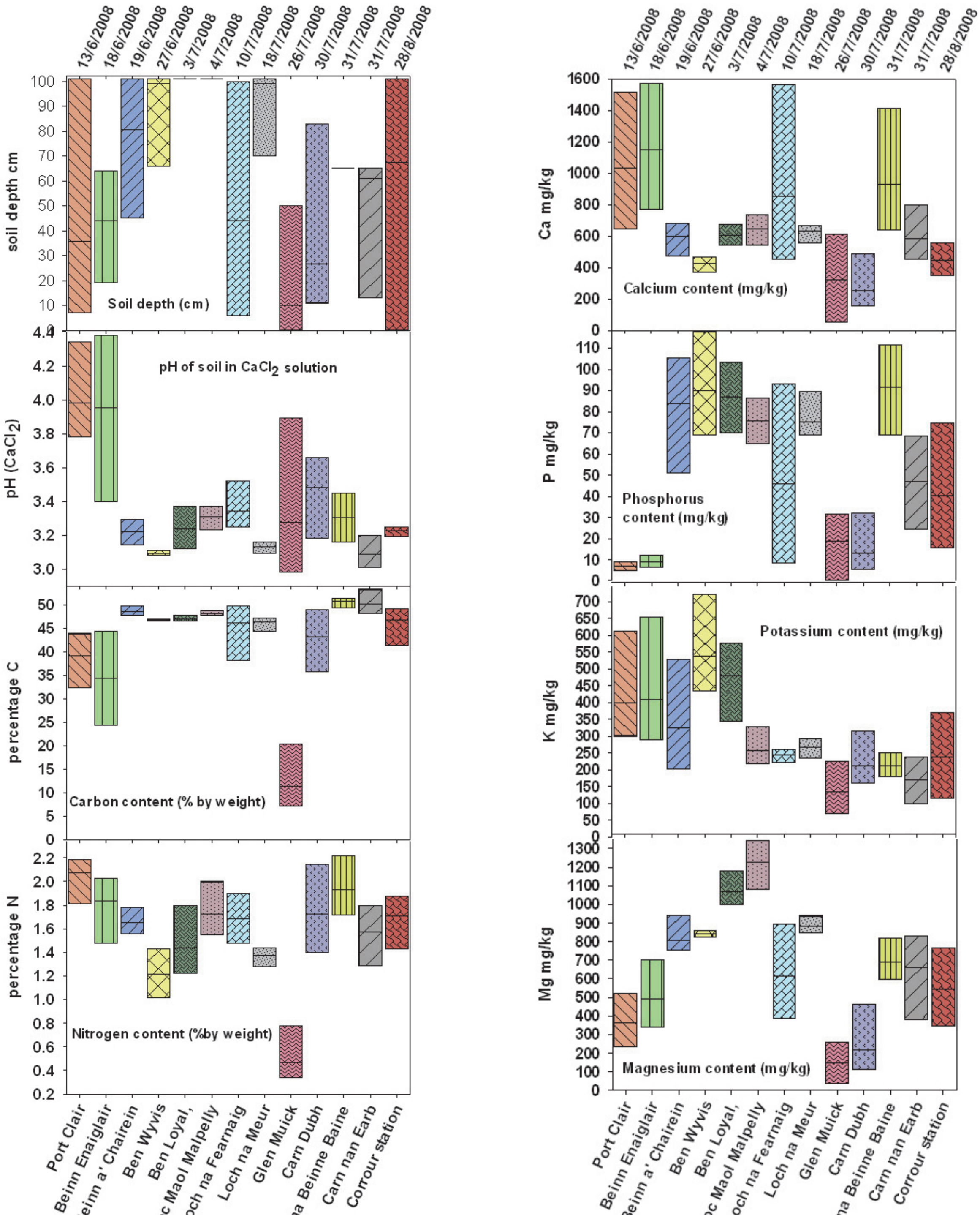


Figure 5. Betula nana *soil sample means, maximums and minimums for soil depth (cm), pH, total elemental carbon and nitrogen (%/weight), and proportional weights (mg/kg) of plant-available calcium, phosphorus, potassium and magnesium.*

4.2.2.3 *Betula nana* surrounding vegetation

Calluna vulgaris was the most constant (though not necessarily dominant) species across all the sites. The most frequent and co-dominant associates were *Trichophorum cespitosum*, *Eriophorum vaginatum* and a ground cover of mire community *Sphagnum* spp, and *Erica tetralix* was also co-dominant at seven sites. This combination of species suggests a mire vegetation community. The key exception was Glen Muick where the co-dominants to *C. vulgaris* were *B. nana*, with *Vaccinium myrtillus* and *Sphagnum capillifolium*, more consistent with wet heath vegetation.

At every site there was a high level of moss cover, most commonly *Sphagnum* species but at some sites pleurocarpous mosses. At the majority of sites there were frequent horizontal stems running along the surface of the soil below this moss layer. On the sites with deep peat and actively growing *Sphagnum* the stems were within the *Sphagnum* layer (Loch na Meur, Loch a'Chairein, Ben Loyal, Cnoc Maol Malpelly, Port Clair).

4.2.2.4 *Betula nana* herbivory

All the sites showed some recent browsing (Fig. 6). At the majority (11 out of 13) at least 5 out of 10 plants examined showed evidence of continuous browsing (defined as evidence for annual damage over a number of years). There were some plants with no recent browsing (within the last three years) at an equal number of sites (11 out of the 13). At Ben Wyvis there was some evidence for some selectivity by herbivores with 40% of plants apparently unbrowsed over the previous three years and another 40% heavily browsed (> 60% of each plant browsed) over several years. There was no obvious topographical reason for choosing one plant over another at the site. Glen Muick showed the lowest levels of browsing of all sites.

Red deer dung, tracks, footprints and/or hair were consistently found at all but one site, while it was the opposite for sheep (*Ovis aries*) with no evidence of their presence seen at any site. Most of the red deer dung was old (dung duration varies but can be up to six months, The Deer Initiative 2008) and only three sites had fresh dung, suggesting that deer were using the sites at the time. In most cases the evidence was assessed as occasional, however, at six sites it was frequent and at Cnoc Maol Malpelly it was abundant, but this may have been due to confusion with sheep dung. Although there was no clear evidence of sheep at Cnoc Maol Malpelly it was croft-land and it was possible that sheep were put on the hill at other times of the year. Evidence of roe deer (*Capreolus capreolus*), from twigs with stripped bark, was present at only one site. Hare droppings and diagonally severed shoots were found at three sites and one individual was seen. At Ben Wyvis, although no droppings were seen, several *B. nana* had some shoots severed with a diagonal cut which suggested the presence of hares. Voles were seen at Glen Muick, and holes and runs were found at Carn Dubh and Beinn a'Chaireinn.

4.2.2.5 *Betula nana* land management

B. nana is primarily found in open expansive moorland areas, and all the sites surveyed conformed to this situation. These areas have historically, or more recently, been subject to drainage, rotational burning and grazing. There was no evidence of recent drainage at any site, although at Loch na Meur the population was on the edge of an old (probably more than 100 years old) peat excavation site. Although there was no evidence that any site had been recently burned, with the exception of Glen Muick, most sites appeared to have been burned in the past (probably within the last twenty years) and all the *B. nana* aerial stems appeared to be relatively young.

At every site there was a high level of moss cover, most commonly *Sphagnum* species but pleurocarpous mosses dominated at some sites. At the majority of sites there were frequent horizontal *B. nana* stems running along the surface of the soil below the moss layer. On the sites with deep peat and actively growing *Sphagnum* the stems were within the *Sphagnum* layer (Loch na Meur, Loch a'Chairein, Ben Loyal, Cnoc Maol Malpelly, Port Clair).

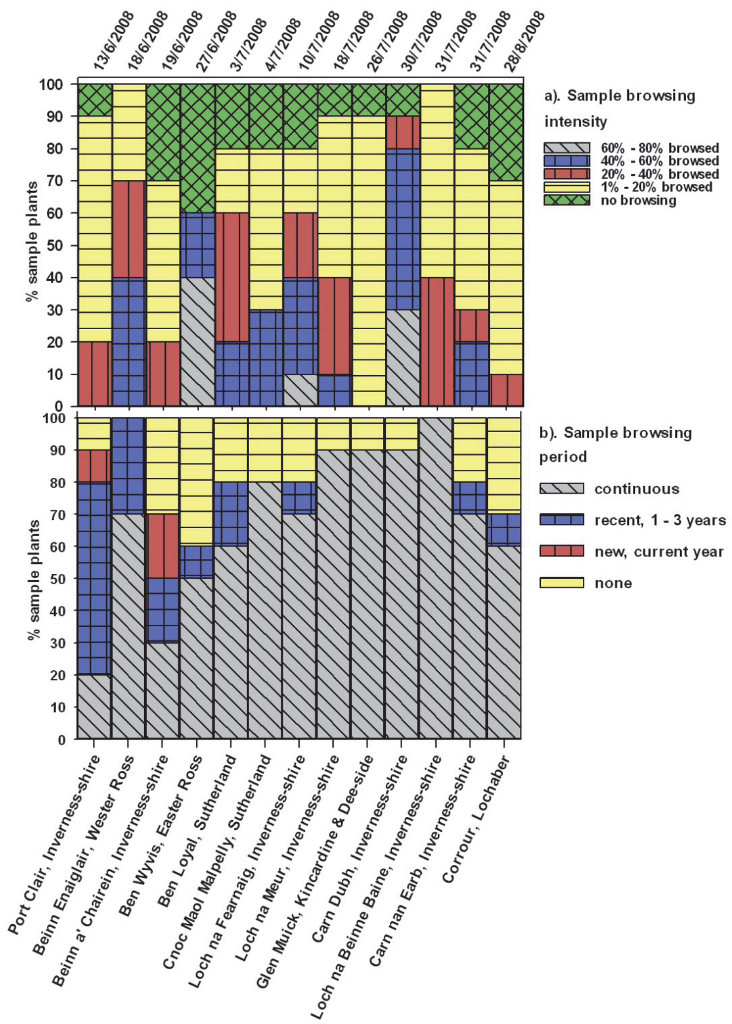


Figure 6. Herbivore impacts on individual Betula nana *plants at each population a) the percentage of sample plants browsed at different intensities; b) the percentage of plants browsed for different time periods (over years).*

Two *B. nana* populations identified for field survey that had been last recorded in the 1980s were not found at the grid references provided. In both cases the land appeared to have been relatively recently burned and there was no moss layer present. At one site there was also evidence of relatively recent drainage.

4.2.3 Individual species site characterisation – Salix myrsinites

4.2.3.1 *Salix myrsinites* physical site characteristics

The populations of *S. myrsinites* surveyed ranged from Sutherland in the north to the southern border of Badenoch and Strathspey in the south and from wester Ross across to Aberdeenshire. Although populations at the lowest altitudes (< 300 m asl) were found in the oceanic west and north there was no clear relationship between altitude and geographic location. Eleven of the 12 populations were found on slopes > 20°, with the steepest at

Creag na h'Iolaire, over 50°. The remaining site, at lower altitude in the north-west had a slope of 8°. All the populations were found on slopes facing between west-north-west and east-north-east and had relatively shallow soils with a mean soil depth of 10 cm or less at nine of the 12 sites, and the deepest mean < 20 cm (Fig. 7). The soils at all the sites had at least some mineral content and for the eight sites in the Cairngorms these were rankers, sitting directly on the base rock which for Druim na Bo, Slochd Beag, Creag na h'Iolaire and Coire Garbhlach was Psammite (medium-grained, sedimentary sandstone). Three populations further east were all on older metamorphic rocks, at Beinn Bhrotain and Garbh Coire granites while Creag an Dail Bheag was on felsitic intrusions which are generally alkaline. The four north-western sites were all on much younger Dolostone, a type of limestone with relatively high magnesium content, and all were overlain with young rendzina soils, derived from the bedrock, which had a peaty podzol element.

The majority of soils sampled were acid and the lowest values were below pH4, only the two sites at Sgurr a' Gharaidh had pH values at or above 7 (Fig. 7). Coire Odhar had the highest values for both total elemental C and N, but also had the highest soil content of plant-available K (280 mg/kg), and the second highest for P (13 mg/kg). The other site soils all had mean values for C below 15 % and for N below 1.0%. Craig an Dail Beag had the lowest values for both elements. The two Sgurr a'Gharaidh sites had both the highest maximum and mean soil weights of plant-available Ca and Mg, and widest variation across the sites. Beinn Bhrotain had the lowest mean soil content of plant-available Ca at 188 mg kg^{-1}, which was lower than the lowest *B. nana* site mean.

The five sites with highly basic bedrock also had the highest percentage cover (60% or more) of well drained, dry soils. All the other sites had predominantly or wholly moist soils. Wet soils were present over 10% of Sgurr a'Gharaidh north and Coire Odhar sites, and 2% of Slochd Beag and Creag na h'Iolaire sites.

4.2.3.2 *Salix myrsinites* plant distribution and size

Generally the cover of *S. myrsinites* at each site was low. The maximum, 30%, was at Sgurr a' Gharaidh south where two thirds of the population was medium spaced (1 – 3 m spacing) and the remainder was clumped (0.5 - 1 m spacing). At Creag an Dail Beag most of the population was clumped onto relatively small areas holding soil, while at six sites the populations were primarily sparsely distributed (> 3 m spacing), reflecting the rocky nature of most sites. The tallest individual plants, at nearly 50 cm, were at Slochd Beag, but the site with the largest mean was Coire Odhar (c. 27 cm). The shortest plants were at Inchnadamph-unenclosed, although there was little difference between the maximum crown diameters in the enclosed and un-enclosed populations. Druim na Bo had the greatest range in maximum crown diameter and the largest *S. myrsinites* diameters found during this survey (383 cm). Garbh Coire had similar maximum diameters but the mean at this site was the largest. The smallest plants were at Sgurr a'Gharaidh north and both Inchnadamph populations, despite the long period of protection from browsing at one population. The leader lengths across all the sites are not comparable due to the three month duration of the survey. However, it is worth noting that the longest leaders were recorded at Creag na h'Iolaire early in August, and the longest mean leaders were at Creag an Dail Beag at the end of July.

4.2.3.3 *Salix myrsinites* surrounding vegetation

Field layer vegetation heights at all the sites were relatively low, only exceeding 15 cm at three, and only exceeding the mean height of the *S. myrsinites* plants at the two Inchnadamph sites (Fig. 4). Inchnadamph-enclosed had the tallest mean field and moss layers of any sites, and Sgurr a' Gharaidh north the shortest. Mean litter layer values for all sites were below 3 cm, although at Garbh Choire the maximum was 17 cm, and at Beinn Bhrotain and Coire Odhar it was 11 cm.

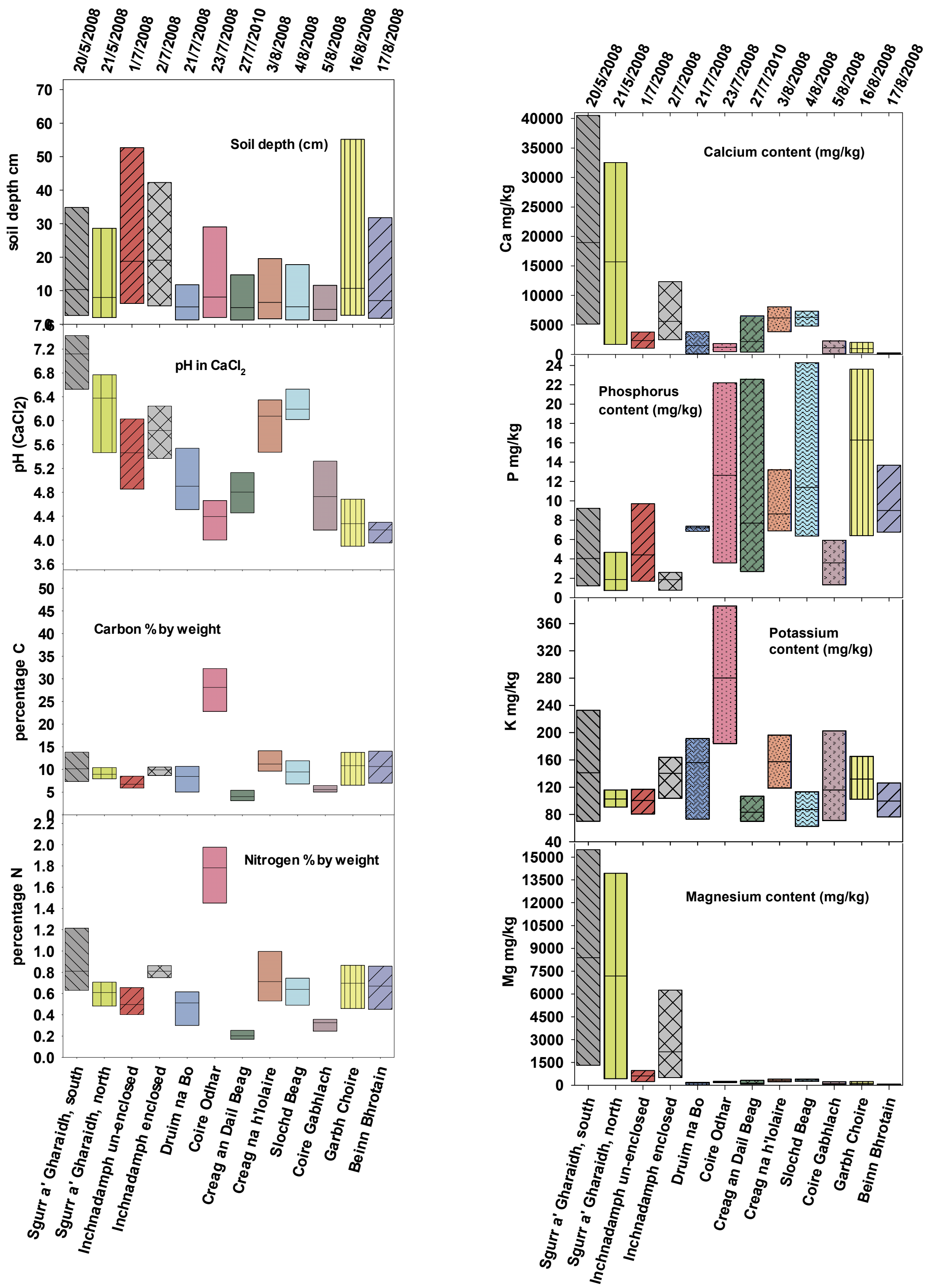


Figure 7. Salix myrsinites *soil sample means, maximums and minimums for soil depth (cm), pH, total elemental carbon and nitrogen (%/weight), and proportional weights (mg/kg) of plant-available calcium, phosphorus, potassium and magnesium.*

Bare rock was a component of the ground surface at all the sites and dominant at eight. All the sites had at least some areas of bare ground (in terms of a relatively soft substrate potentially suitable for seedling establishment) but at Craig an Dail Bheag the un-vegetated, eroding slope covered more than half the site. The vegetation associated with *S. myrsinites* across the sites falls into three main groups: those with *Calluna vulgaris* dominant and the consistent presence of *Empetrum nigrum* agg., (Craig an Dail Bheag, Slochd Beag, Coire Garbhlach and Inchnadamph-un-enclosed); those with a mixture of grasses dominant (Beinn Bhrotain, Coire Odhar, Druim na Bo, Garbh Coire and Sgurr a' Gharaidh north); and those with a *C. vulgaris* – grass mosaic (Creag na h'Iolaire, Inchnadamph-enclosed and Sgurr a' Gharaidh south). Creag na h'Iolaire, Sgurr a' Gharaidh north, Sgurr a' Gharaidh south, and Inchnadamph-enclosed all have areas of flushed vegetation associated with some of the *S. myrsinites* plants.

4.2.3.4 *Salix myrsinites* herbivory

The first site to be surveyed (20th May, 2008), Sgurr a'Gharaidh south, showed no evidence of browsing while all other sites showed some evidence of damage in recent years, including Inchnadamph-enclosed where one of the sample plants showed recent damage over nearly 60% of the canopy. At all other sites the damage was predominantly continuous, but at a relatively moderate level (Fig. 8).

With the exception of Sgurr a' Gharaidh south and Inchnadamph-enclosed red deer dung and footprints were found at all the sites, although rarely at Coire Odhar, Coire Garbhlach and Garbh Coire. Hare droppings were the next most widespread herbivore evidence, only absent from both Sgurr a'Gharaidh sites, Inchnadamph-un-enclosed and Coire Odhar. Grouse, either red grouse or ptarmigan (*Lagopus mutus*), droppings were frequent at Beinn Bhrotain, occasional at Garbh Coire, Creag an Dail Bheag, and Coire Odhar and rare at Coire Garbhlach and Druim na Bo. Vole holes were the only herbivore evidence at Sgurr a' Gharaidh south and there was no evidence of any damage to the *S. myrsinites*. Voles were also evident at the two Inchnadamph sites, Creag na h'Iolaire, Coire Garbhlach and Garbh Coire. Sheep were seen on the Creag an Dail Bheag site and in the general area at Sgurr a'Gharaidh north and Inchnadamph-unenclosed, otherwise they were absent from sites.

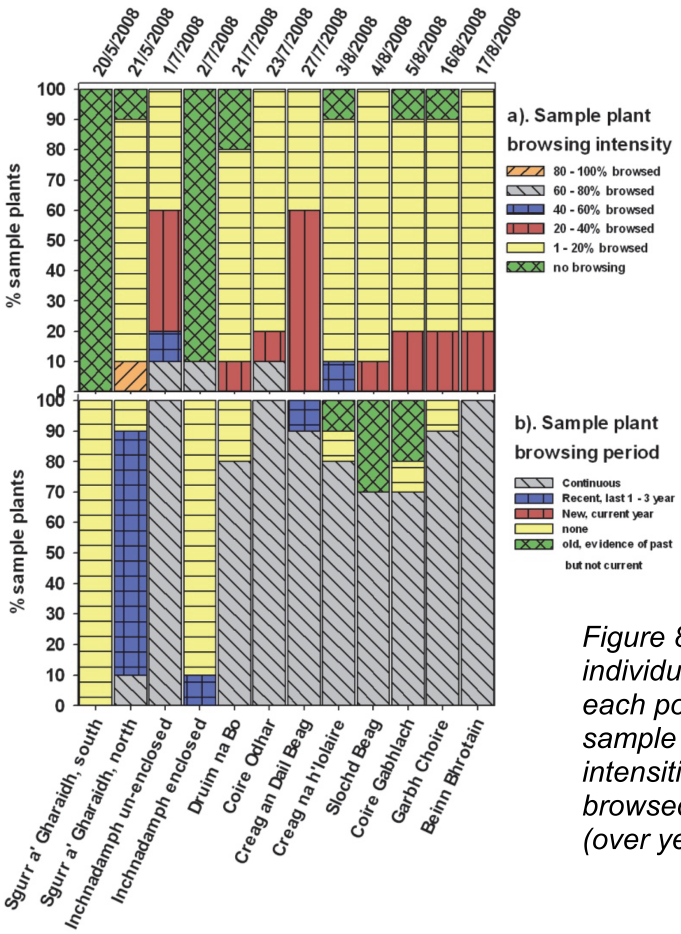


Figure 8. Herbivore impacts on individual Salix myrsinites *plants at each population a) the percentage of sample plants browsed at different intensities; b) the percentage of plants browsed for different time periods (over years).*

4.2.4 Individual species site characterisation – Juniperus communis

The results presented here focus on those from 2008 incorporating compatible or complementary results from site characteristic data available for *J. communis* ssp *nana* and *J. communis* ssp *communis* populations from Sullivan (2001) and Sullivan (2003).

4.2.4.1 Juniperus *communis* physical site characteristics

Juniperus communis populations surveyed in 2008 were spread from the island of Skye in the west to Aberdeen-shire in the east, and south as far as Galloway. All the sites faced between 184° and 342° N, essentially all having a westerly element to their aspect (Fig. 4). A minimum altitude of 350 m asl was a criteria for site selection of *Juniperus communis* ssp *communis* populations but the highest mean altitude was 604 m asl (Fig. 4). For those sites surveyed in 2002-2003 (Sullivan 2003) the highest modal altitude for the same subspecies was just over 600 m asl, while for *J. communis* ssp *nana* the highest modal altitude was 700 m asl. There was no clear relationship between altitude and slope, and although the most frequent slope for populations was below 18° across both the 2002-2003 and 2008 surveys, both subspecies of *J. communis* were found on slopes of more than 45° (Fig 4). In 2000 the *J. communis* ssp *nana* populations surveyed by Sullivan (2001) were all on slopes less than 25°. The 22 *J. communis* ssp *communis* populations occur on a relatively wide range of bedrocks including sedimentary sandstones, and metamorphosed gneisses, quartzites, schists and Ordovician rocks. *J. communis* ssp *nana* populations, despite their more restricted geographical spread, also occur on both sedimentary sandstones and metamorphic quartzites and schists, but in addition they occur on volcanic basalts and ultrabasic outcrops. All the soils were relatively simple and undeveloped and evenly split for *J. communis* ssp *communis* between rankers, podzols, gleys and subalpine soils. Eleven *J.*

communis ssp *nana* populations were on surface-water gleys, perhaps related to the western geographical distribution, while the remaining populations were on 'organic soils' (probably peats, two populations) or podzols (three populations). For the 2008 sites the soils were of medium depth (Fig 9) with all the site means below 20 cm, and the majority had similar within site variability.

The pH values for soils sampled during the 2008 survey were all acid with the majority between 3.2 and 5.4. The only exception was Craigs of Succoth where the soils ranged from 4.8 to 6 (Fig. 9). Beinn Dearg Mheadonaidh and Kirriereoch were notable for their lack of within-site variation (< 0.15 range compared to > 0.2 at all other sites). Beinn Dearg Mheadonaidh and Lecht had similarly consistent, relatively low values for total C and N concentrations and most plant-available nutrient contents. The soil concentrations of Ca were higher across Creag Fhiaclach east than at any other site except the highest values found at Craigs of Succoth. This latter site had the highest values for Mg content reflecting the relatively high pH and its ultrabasic clinopyroxenite bedrock, although this site has non-calcareous, gleyed soils with similar C and N concentrations to the majority of surveyed sites.

All the sites had predominantly dry or moist soils and only three had any soils which were described as wet with the largest area, 10% of the site, at Creag Fhiaclach east. Bare ground was uncommon at all sites with the largest value (10% of the site) at Kirriereoch which also had greatest range of patch sizes. At all other sites the area of bare ground was 5% of the site or less. At Craigs of Succoth there was no bare ground, apart from directly under the canopy of the *J. communis* plants which was not measured. Bare ground estimates do not take account of the area of bare rock, for example at Beinn Dearg Mheadonaidh 90% of the site was entirely un-vegetated scree.

4.2.4.2 *Juniperus communis* plant distribution and size

The Juniper populations surveyed in 2008 displayed a wide range of plant spacings. The populations with the highest percentage cover also tended to have the closest spacing. Five populations in Strathspey occupied more than 50% of their sites, primarily in continuous cover stands. Three populations were primarily clumped, and one was 95% medium spaced. The final four were sparsely spaced with low percentage site cover (20% or less) and had primarily small plants. Three of these populations, Croidh-la, Beinn Dearg Mheadonaidh and Kirriereoch, were on the steepest slopes (at least 35°). In the 2002-2003 sample survey (Sullivan 2003) the distribution of populations at the majority of sites was sparse with only four out of 25 populations recording plants at medium (less than 3 m spacings) or closer spacings.

Most populations were multi-stemmed although Croidh-la, Castle Hill and Caimhlin Mòr had significant proportions of single stemmed plants. Most *J.communis* ssp *communis* populations had plants which were classified as intermediate in form, being multi-stemmed with a wide, lax crown. The population at Croidh-la was the only one surveyed in 2008 where more than 10% of the population had a distinctly upright growth. Sullivan (2003) had used six classes to describe plant shape at the *J.communis* ssp *communis* populations he surveyed. Two of his categories (columnar and inverted pyramid) equated to upright, the prevalent form at three populations, two to intermediate (pyramid and low upright), prevalent at five populations and two to prostrate (low spreading and prostrate). All *J. communis* ssp *nana* were classified as prostrate, as was Kirrereoch, a population of indeterminate subspecies surveyed in 2008.

The tallest *J. communis* ssp *communis* plant in the 2008 survey was over 4 m at Pluc Mòr and plant heights were over 1 m at 3 other sites, and at 6 out of 10 sites in the 2003 survey.

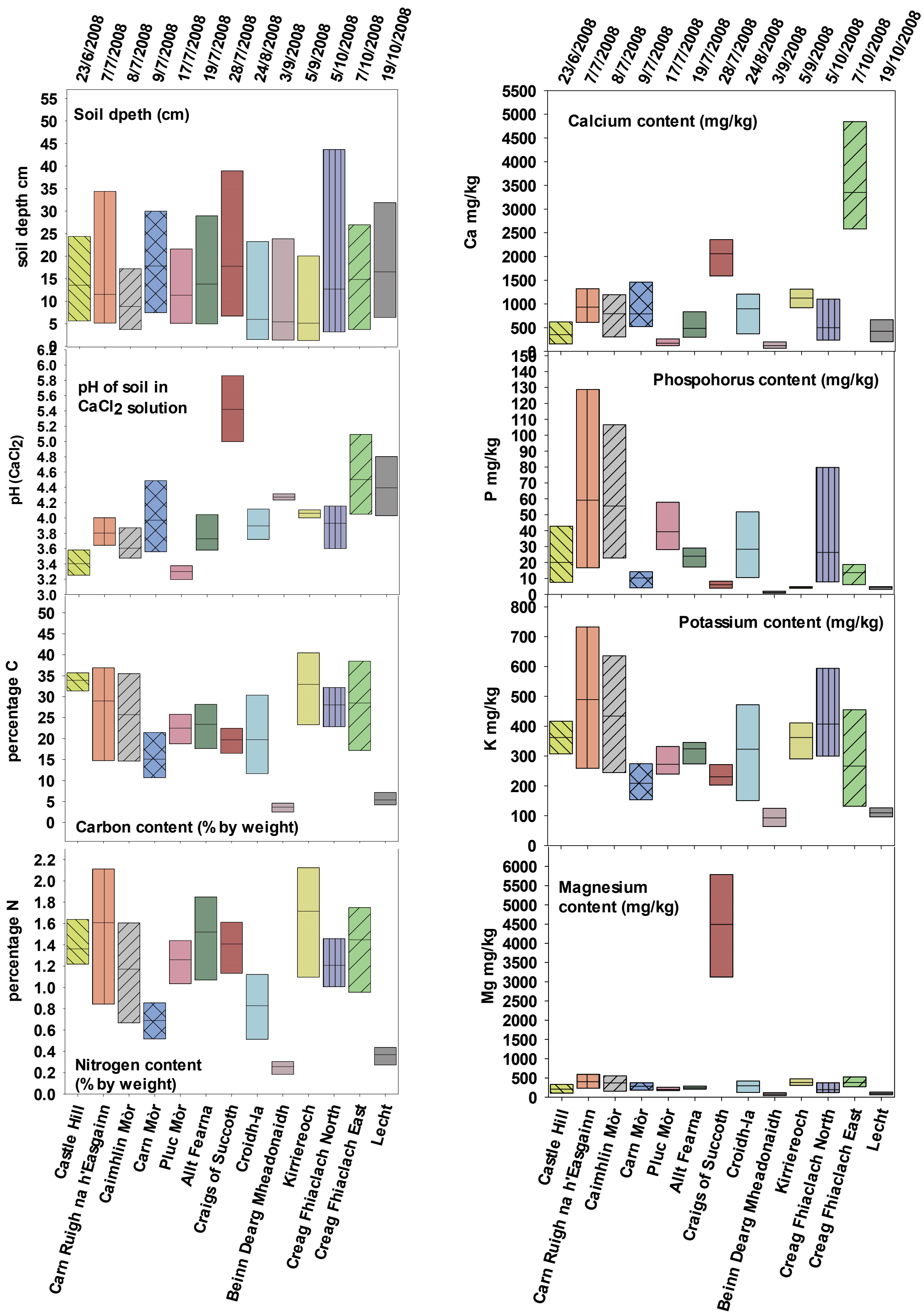


Figure 9. Juniperus communis *soil sample means, maximums and minimums for soil depth (cm), pH, total elemental carbon and nitrogen (% by weight), and proportional weights (mg/kg) of plant-available calcium, phosphorus, potassium and magnesium.*

The Lecht had the largest mean plant height at 1.23 m. The greatest maximum crown diameters were found at the Lecht, whilst the shortest and smallest mean maximum crown diameters were at Carn Ruigh na h'Easgainn. At nine out of 18 *J. communis* ssp *nana* populations surveyed in 2002-2003 the majority of plants spread to more than 1 m in diameter, as was the case at the two prostrate-form populations surveyed in 2008. Leader lengths measured during the survey were not comparable due to the length of time over the growing season between the first and last surveys, but it is notable that the mean leader length at Creag Fhiaclach North (measured on 5.10.2008) was nearly half that measured a month previously at Kirriereoch (5.09.2008) and that measured at Creag Fhiaclach East at the same time (7.10.2008).

4.2.4.3 *Juniperus communis* surrounding vegetation

At all 2008 sites the *J. communis* plants were taller than the surrounding vegetation (Fig. 4). As with *B. nana* and *S. myrsinites* most of the field layer vegetation was below 50 cm with little between-site variation.

The field layer vegetation at all 13 2008 sites had a heath element, predominantly of *C. vulgaris* at nine sites, but of *Vaccinium myrtillus* at Caimhlin Mòr and Carn Mòr. At Lecht, in addition to the slopes of *C. vulgaris* heath, there was an area of lower lying, level, grazed grassland, and at Allt Fearna the *V. myrtillus* was present in grazed grassland. Two sites had a high percentage of bare rock, at Beinn Dearg Mheadonaidh this was in the form of scree, while at Kirriereoch it was bedrock in the form of cliffs.

4.2.4.4 *Juniperus communis* herbivory

All the sites had evidence of browsing with the most intense at one of the most sparsely populated sites, Castle Hill, where six plants had up to 80% of their canopy affected. Kirriereoch plants showed the lowest intensity of browsing, with seven plants showing no recent browsing at all, and the least signs of herbivore presence. At eight sites all 10 plants had been continuously browsed over a number of years (Fig. 10). During his sample survey Sullivan (2003) recorded browsing using a different methodology (Appendix 4) which for all the 10 high altitude *J. communis* ssp *communis* populations was assessed as predominantly low on each age class present. Carn a'Bhadhain was an exception with a high browsing impact on the whole population which comprised building and mature age-classes, but no pioneer or old. No evidence of summer browsing was recorded at any of the 10 sites, although as the survey period spanned the whole summer this may under-represent this activity. The predominant impact of browsing on *J. communis* ssp *nana* populations was low at 11 out of 18 populations surveyed in 2002-2003. At four populations it was high, and at two of these, composed solely of mature or old plants, 100 % showed high browsing impact. At a third the building stage plants present all showed high browsing impact, but within the mature and old classes some plants showed medium and low levels of impact. The fourth site in this category, Beinn Liath Mhor Fannich, was the only population to show evidence of summer browsing. Only one *J. communis* ssp *nana* population had pioneer plants present, and only six had building stage plants. Across the whole survey for both subspecies every growth stage had some browsing impact.

Red deer presence was evident at every 2008 field survey site, and sheep were present at five, Carn Mòr, Allt Fearna, Beinn Dearg Mheadonaidh, Lecht and Kirriereoch. The relative presence of each was difficult to judge due to the similarity between their droppings but apart from Lecht there was frequent presence of large herbivores. Goats (*Capra hircus* L.) were also seen at Carn Mòr and Carn Ruigh na h-Easgainn (Appendix 4: 2008 Site Survey data). An individual roe deer was seen at Craigs of Succoth and there was evidence of hare there and at a further six sites (Caimhlin Mòr, Carn Ruigh na h-Easgainn, Allt Fearna, Lecht, Creag Fhiachlach East and Carn Mòr). Evidence of rabbit (*Oryctolagus cuniculus*) was seen at Carn Ruigh na h-Easgainn, and there was evidence of grouse, either red or ptarmigan, at six sites (Castle Hill, Caimhlin Mòr, Carn Ruigh na h-Easgainn, Craigs of Succoth, Creag Fhiachlach East and Creag Fhiachlach North), although it was rare at Craigs of Succoth. There was evidence of voles at nine sites, all except Caimhlin Mòr, Carn Ruigh na h-Easgainn, Carn Mor and Creag Fhiachlach East.

Sullivan (2003) found that sheep were the predominant herbivore browsing *J. communis* ssp *communis* at five sites, red deer at two and rabbits at one, while it was not possible to determine the identity of the browsers at a further three sites. Sheep and red deer were also the predominant herbivores at *J. communis* ssp *nana* sites, although cattle were the primary cause of impact at one and hares at another. There was no evidence of goats or voles recorded at any of the sites in 2002-2003.

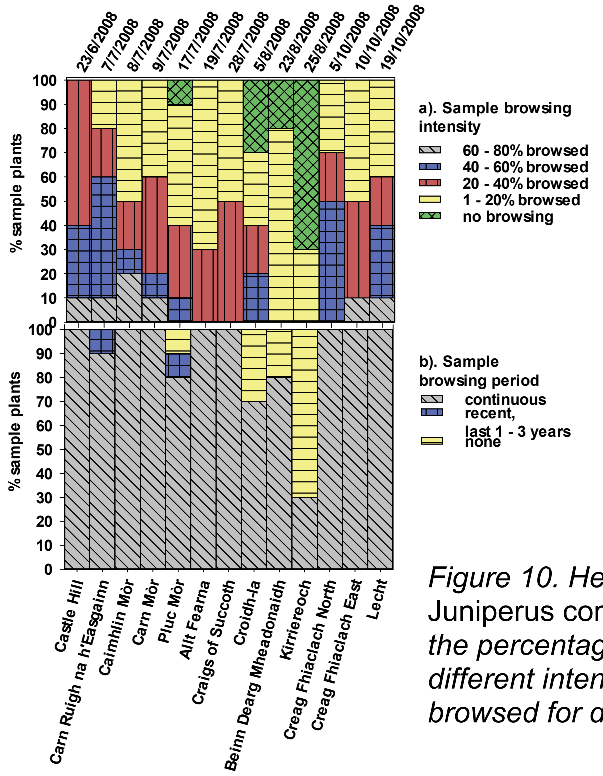


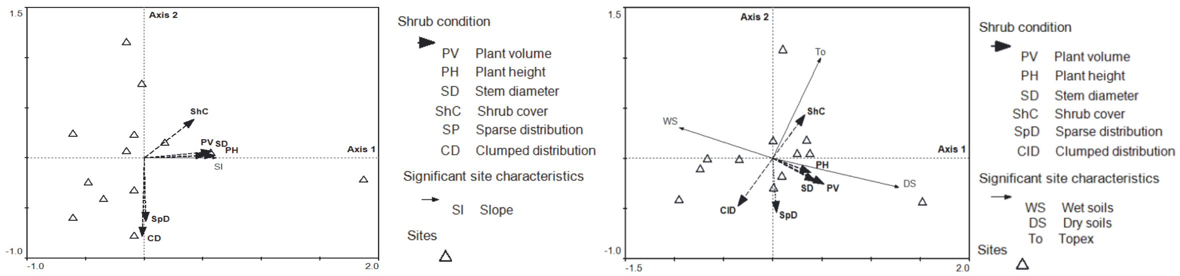
Figure 10. Herbivore impacts on individual Juniperus communis *plants at each population a) the percentage of sample plants browsed at different intensities; b) the percentage of plants browsed for different time periods (over years).*

4.3 Analysis of the relation between shrub condition and environmental parameters

4.3.1 Betula nana *shrub condition analysis*

The first Redundancy Analysis (RDA) examining the correlation between shrub condition and site characteristics included the data from all 13 sites surveyed and identified a significant relationship (P = 0.004). Axis 1 accounted for 62.5 % of the variation explained by the model. It was very strongly positively correlated with slope, which was the only site characteristic that explained a significant amount of the variation ($P < 0.05$) in shrub condition. Plant volume, height and stem diameter were all strongly positively correlated with Axis 1, and so slope (Fig. 11a). Glen Muick had the largest plants and was on the steepest slope (38° compared with 18° or less at all other sites) and on the RDA diagram (Fig. 11a) was isolated from all other sites at the positive end of Axis 1. This suggested that it may be skewing the RDA and consequently the analysis was repeated without this site.

In this second RDA (Fig. 11b) the relationship between the shrub condition and site characteristics was again significant (P = 0.003) and Axes 1 and 2 explained 53 % of the variation in shrub condition (Table 5). Axis 1 (38.9 % of the variation) was strongly and positively correlated with the percentage of the site assessed as having well drained (dry) soils, and negatively correlated with the percentage of the site assessed as having wet soils. Axis 2 (14.4% of the variation) was strongly, positively correlated with TOPEX (or shelter). Plant volume, height and stem diameter all positively correlated with dry soils suggesting that larger plants are found on sites assessed as having at least some dry soils, and negatively correlated with a high percentage of wet soils. Populations with a higher percentage of clumped and sparsely distributed plants were negatively correlated with shelter, compared to populations with a higher percentage of medium spaced plants. A higher overall percentage shrub cover was positively correlated to shelter. On the RDA plot six sites out of 12 were distributed positively on the shrub condition parameter trend lines suggesting that they support reasonable sized plants. One site could be considered uncorrelated with the growth trend lines, while the remaining five sites had relatively small plants (Fig. 11b).



a **b**

Figure 11. Plot of output from Redundancy Analysis of the relationship between Betula nana *shrub condition and site characteristics a) including all sites; b) excluding Glen Muick, which was considered to be skewing the analysis.*

The Glen Muick population stands out as in better condition than all others. The plants were the largest, the population occupied the largest proportion of the site (30%) and generally the plants were in large clumps (90%) or had medium spacing. Six plants were flowering, and one seedling was seen at this site. The fact that this population showed one of the lowest herbivore impacts and had no burning is notable. Otherwise, Ben Wyvis, Port Clair and Loch na Beinne Baine were all considered in reasonably good condition, with relatively large plants and low levels of browsing impact. None of these populations had any young plants but the latter two sites had flowers on at least 50% of the plants measured. Despite a relatively high density of plants the Beinn Enaiglair population was only ten plants which were among the smallest (height and spread) surveyed. Carn Dubh which also had a clumped distribution, only occupied 2 % of the site and the plants were the smallest. Both these populations were heavily browsed and could be considered in poor condition. Despite this Carn Dubh had mid-range leader lengths, suggesting that a change in browsing pressure might allow year on year growth and improve the health of the plants. All the other populations tended to poor condition with small plants and persistent browsing impacts. Corrour Station was among these, but the recent browsing pressure was low and leader lengths relatively long. If this new growth is sustained then this population may be considered to be recovering.

4.3.2 Salix myrsinites *shrub condition analysis*

The RDA testing the correlation of shrub condition with site characteristics for *S. myrsinites* was significant (*P* = 0.001), and Axes 1 and 2 collectively explained 57.5% of the variation in shrub condition (Table 5). Axis 1 was dominated by a positive correlation with mean January temperature. The percentage of the site with wet soils was positively correlated with both Axis 1 and 2 while soil carbon content, the only other significant site characteristic, was very strongly correlated with Axis 2. Plant volume, height and stem diameter were all negatively correlated with Axis 1 (mean January temperature and wet soils) and plant height was weakly positively correlated with Axis 2 (soil carbon and wet soils) suggesting that larger plants are primarily associated with cold January temperatures (Fig. 12). Compared to medium distribution both sparse and clumped shrub distribution were more strongly correlated to low soil carbon content than with cold January temperatures. Percentage shrub cover was similarly correlated with low soil carbon content but also showed a very weak positive correlation with January temperature.

On the RDA plot the four populations at the positive end of Axis 1 were all in the north-west at relatively low altitudes where January temperatures would be relatively warmer than at other locations, and these populations had the smallest plants recorded in the survey. At the negative end of Axis 1, associated with taller plants of greater volume, were populations from the Cairngorms which are at much higher altitudes with colder January temperatures and where the larger plants in the survey were found (Fig. 12).

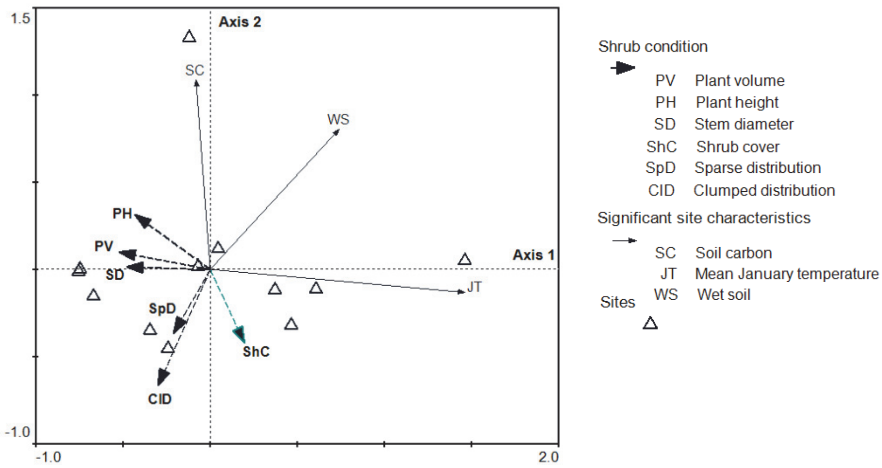


Figure 12. Plot of output from Redundancy Analysis of the relationship between Salix myrsinites *shrub condition and site characteristics.*

As this is a dioecious and insect pollinated plant the proximity of individuals of both sexes is an important factor in the condition of populations. The population at Sgurr a'Gharaidh south had the greatest percentage cover (30 % of the site area) at its site and all the plants were within 3 m of each other. The size of plants was in the middle of the range across the sites, and three plants were flowering at the end of May, one of which was male but the other two were indeterminable. There was no evidence of browsing because this population is on an inaccessible ledge within a broken cliff formation and its potential for browsing-protected expansion is very limited. Druim na Bo and Creag an Dail Beag also had relatively high shrub cover (20 % and 15 % respectively) and, on the areas occupied, plants which were primarily within 3 m of each other, but both populations are spread across the face of eroding crags (severely eroding in the latter case). Druim na Bo had large plants, although the mean leader lengths in July were lower than the species mean, and four plants had female catkins. Browsing levels were low and there appeared to be potential for recruitment, although none was seen. Erosion damage was relatively local and this population was considered to be in reasonable condition. Creag an Dail Beag had smaller than average plants but longer leader lengths, and five plants had female catkins. The willows occupied all the relatively stable ground that was less accessible to herbivores. Despite this browsing

Table 5. Eigenvalues and intra-set correlations from the Redundancy Analysis of shrub condition and site characteristic parameters, using forward selection of significant site characteristics in Canoco.

	Axis 1	Axis 2	Axis 3	Axis 4
Betula nana (for 12 sites)				
Eigenvalues:	0.389	0.144	0.042	0.151
Shrub condition-site characteristic correlations:	0.871	0.794	0.646	0
Percentage variance of shrub condition data:	38.9	14.4	4.2	15.1
Percentage variance of shrub condition-site characteristic relation:	67.6	25	7.4	0
Intraset correlations:				
Dry soils	0.7237	-0.2689	0.6355	
Wet soils	-0.5365	0.2827	0.7952	
TOPEX	0.2744	0.9243	-0.2653	
Salix myrsinites				
Eigenvalues:	0.387	0.189	0.097	0.129
Shrub condition-site characteristics correlations:	0.9	0.894	0.78	0
Percentage variance of shrub condition data:	38.7	18.8	9.8	12.9
Percentage variance of shrub condition-site characteristic relation:	57.5	28	14.5	0
Intraset correlations:				
Wet soils	0.4693	0.7301	-0.4968	
Jan Temp	0.9265	-0.1193	0.3569	
Carbon content	-0.0512	0.9873	0.1505	
Juniperus communis				
Eigenvalues:	0.43	0.23	0.174	0.03
Plant condition-site characteristics correlations:	0.968	0.968	0.956	0.798
Percentage variance of plant condition data:	43	23.1	17.3	3.0
Percentage variance of plant condition-site characteristic relation:	49.1	26.3	19.8	3.4
Intraset correlations:				
Wet soils	-0.0774	0.6452	-0.3242	0.401
Moist soils	0.4741	-0.0061	-0.4581	-0.2112
Mean annual rainfall	0.5532	-0.4787	-0.0288	0.6066
Mean soil carbon content	0.5165	0.4968	0.2311	-0.6497
North-easterly aspect	-0.6961	0.3146	0.228	0.1565
Tall-shrub browse	0.154	0.3921	0.399	0.0296

was still evident on all plants on the parts within reach and, combined with the levels of erosion, this suggests that the long term future of this population must be in doubt. Inchnadamph-enclosed also had 15 % cover of willows, most of which were within 3 m of each other. Two plants carried catkins, one male and one female. The size of the plants was smaller than the species average although the leader lengths in early July ranged from some of the longest to the shortest. This site had the tallest field and moss layer vegetation, with the mean field layer taller than mean willow heights. The lack of recruitment and relative height and density of the surrounding vegetation, despite exclusion of large herbivores, suggests this population is not in good condition, but not immediately at risk. The majority of plants at Beinn Bhrotain, Garbh Coire and Coire Odhar were within 3 m of each other and all were larger than average. At all three sites eight of the measured plants were flowering: at the first five had female catkins; at each of the other two seven had female catkins while the other had male. These three sites could be considered to be in reasonable condition. The remaining six populations were composed of plants at more than 3 m spacings, and because of the broken nature of the sites sometimes more than 5 m apart. At Slochd Beag, Creag na h'Iolaire, and Coire Garbhlach the individual plants were growing well, and at Coire Garbhlach three plants had male and six had female catkins. Below Creag na h'Iolaire, off the surveyed site, there were a number of young plants in scree suggesting that the main population is producing viable seed. Both Sgurr a'Gharaidh north and Inchnadamph-unenclosed had small plants and relatively high browsing pressure and were in relatively poor condition, but at the start of July Inchnadamph-unenclosed had plants with some of the longest leader lengths measured. This suggests there may be potential for some of these plants to respond to reduced browsing pressure.

4.3.3 Juniperus communis *shrub condition analysis*

Six site characteristics (north-easterly aspect, mean soil carbon content, mean annual rainfall, percentage of site with wet soil, percentage browse of tall-shrubs, and percentage of site with moist soil) were identified through the RDA as explaining significant amounts (P = 0.05) of the variation in shrub condition across the 13 sites (Table 5). Overall the model explained 86.4% of the variation in shrub condition with the first two axes accounting for 43% and 23% respectively. Axis 1 was most strongly positively correlated with mean annual rainfall (lowest value 1131 mm, highest 3515 mm), soil carbon content and percentage of site with moist soils, and negatively correlated with a north-easterly aspect. Axis 2 was positively correlated with the percentage of the site with wet soils, soil carbon content and, less strongly, with the level of browsing on the juniper, and negatively correlated with annual rainfall. Plant height, volume and stem diameter were strongly positively correlated with a north-easterly aspect, relatively low annual rainfall, a low percentage site cover of moist soils (Figure 13). Plant height and stem diameter were also positively correlated with a relatively high percentage cover of wet soils, while plant volume was negatively correlated with soil carbon content and browsing of juniper plants. All three shrub distribution parameters (continuous, clumped and sparse) were strongly negatively correlated with soil carbon content and percentage site cover of wet soils and more weakly with browsing of the juniper plants. Percentage shrub cover on site was highly correlated with the shrub dimension parameters and so with a north-easterly aspect, low annual rainfall (within the range of values for these sites), and to sites with a low percentage cover of moist soils.

On the RDA plot six sites sit towards the negative end of Axis 1, correlated with larger plants. Another six sites which sit towards the positive end of Axis 1, with smaller plants, tend to be those at higher altitude, or have a western location in higher rainfall areas.

Juniperus communis is dioecious and wind pollinated thus the density and ratio of different sex plants are important factors in ensuring recruitment. Plant density was unlikely to have been an issue at any site surveyed in 2008, except Castle Hill and, more importantly, Kirriereoch where the plants were not only sparsely spaced but, due to the nature of the ground, often more than 5 m apart among cliffs. Nor did pollination appear to be a major issue with seedlings and or saplings present at nine of the 13 sites, including Kirriereoch, although in all cases they were in low numbers. At Creag Fhiaclach east, although there were saplings present, female cones were only found on two of the sample plants suggesting that there had been poor seed production for several years. Caimhlin Mòr, Allt Fearna, Castle Hill and Beinn Dearg Mheadonaidh were the four sites with no recruitment. The first two populations are within areas of sheep grazing which are also open to red deer and goats and although the mature plants themselves are closely spaced and generally above the height when they may be vulnerable to browsing this would not be the case for an establishing seedling. Both populations were flowering, with a near 1:1 ratio of male to female plants in those sampled at Caimhlin Mòr, suggesting that despite the lack of recruitment these populations are in reasonable condition in the short-term. The mature plants at Castle Hill and Beinn Dearg Mheadonaidh were short and sparsely distributed and thus remain vulnerable to browsing due to poor growth at the former site and their prostrate nature at the latter. At the time of the survey only one male plant was seen to be flowering at Castle Hill. At Beinn Dearg Mheadonaidh the plants occupy vegetated islands among mobile scree and were also vulnerable to trampling, rock fall and erosion. Neither of these populations can be considered to be in good condition.

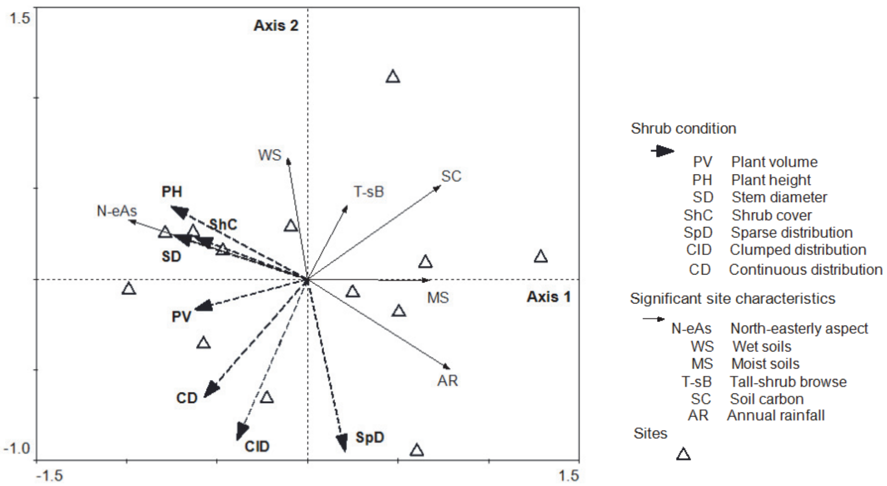


Figure 13. Plot of the output from Redundancy Analysis of the relationship between Juniper communis *shrub condition and site characteristics for 13 sites.*

Populations at Pluc Mòr and Carn Mòr were closely spaced with at least half the sampled plants flowering and some young plants present. The levels of browsing were light to moderate and these populations could be considered to be in reasonable condition. The Lecht had some of the largest plants, but at the time of the survey very few plants with cones and relatively high levels of browsing. Despite tall plants this population had been subject to browsing of the top shoots, probably by hares sitting on snow in the winter. Both Lecht and Pluc Mòr border grouse moors and the upward expansion of these populations is restrained through management of the heather, primarily through burning.

Sullivan (2001) identified that *J. communis* ssp *nana* was restricted to a particular oceanic climatic region in north-west Scotland, on thin soil over metamorphosed, sedimentary and igneous rocks, and that it is vulnerable to burning and browsing. As well as occurring in a range of other plant communities, this sub-species is a dominant or co-dominant component of Prostrate Juniper Heath (NVC H15, Rodwell 1991b) which Sullivan (2001) demonstrated occupies a smaller geographical area than its potential. Although Sullivan (2001) argued that current land use was not having a damaging impact on existing examples of H15, the populations of *J. communis* ssp *nana* he surveyed in 2002-2003 (Sullivan 2003), which were largely in plant communities other than H15, were assessed as predominantly over mature and heavily browsed.

5. DISCUSSION

The purpose of this survey was to characterise a representative sample of the current treeline ecotone sites occupied by *Betula nana, Salix myrsinites* and *Juniperus communis* populations. Through Principal Component Analysis of existing field and remote environmental data the known records for each species were categorised. This allowed the identification of the main site types from which the populations were selected for more detailed field survey. Thus the data gathered should provide good indication of the range of tolerance of each species to different site factors.

Overall across the three species the soil chemical characteristics tend to suggest that generally they occupy different soil types, although there is considerable overlap across some chemicals. When these soil characteristics are coupled with other site characteristics, such as aspect, slope, altitude and soil moisture regimes, *B. nana* and *S. myrsinites* are clearly different with *J. communis* somewhere in between, but perhaps showing greater overlap with *S. myrsinites* than *B. nana*. The amount of plant-available nutrient cations (Ca, P, K and Mg) in soil is known to vary throughout the growing season (William Towers pers. comm.), and so does the associated pH. The sites for all three species were surveyed, inter-mixed over several months and as a result it is reasonable to conclude that differences between the three species soil site types are real, but the exact values need to be treated with caution in relation to the individual species site types.

All three study species tend to exhibit, through their current site types and growth habits, some traits common to stress-tolerant species (Grime 2001). Resources tend to be allocated to survival and longevity rather than sexual reproduction (K – selection, Grime 2001). However, this may be simplistic if low levels of seed production are the result of long-term herbivory. All three species are comparatively slow growing and, from the data presented here, all are tolerant of some browsing, although *J. communis* less so than the two deciduous species (Bryant and Kuropat 1980, Herder *et al.* 2008, Gilbert 2011). The two deciduous species have some traits which are contrary to stress-tolerance, and some more generally associated with colonisers (Grime 2001), such as having un-protected buds in winter, and large numbers of small, wind-dispersed seed. Bélisle and Maillette (1988) demonstrated that the retention of dead leaves over winter by *Salix uva-ursi* in the high arctic mimicked the protection afforded to evergreen buds by their leaves, and this is a feature shared with *S. myrsinites* (Meikle 1984). A new category was proposed for Grime's triangular growth strategy model to include plants adapted to relatively unproductive systems with high frequency, low intensity biomass loss and disturbance (e.g. through herbivory and/or trampling) (Oksanen and Ranta 1992). This modification appears to explain better the circumstances of these three species in the UK, although *B. nana* was categorised as a stress-tolerant species (K-strategist) from its Scandinavian habitats. Tall-shrub montane willows were not included in the study by Oksanen and Ranta (1992) and further work to clarify better the important factors for of all three species in relation to their growth strategies in the treeline ecotone would be very useful in guiding their future requirements in the UK.

5.1 Site Characteristics

5.1.1 Betula nana

The main outcome of this survey is the demonstration of overriding differences between the tall, relatively dense population of *B. nana* growing at Glen Muick and the populations at all the other sites. That the RDA also suggested that *B. nana* grows larger on sites with lower percentages of wet soils raises questions about the perception of this shrub as a plant primarily of deep peats in the UK (Ashton 1984, De Groot *et al.* 1997).

Not only were the *B. nana* plants at Glen Muick taller with a larger mean maximum crown diameter but the mean stem diameter was more than twice that for any other site. In addition to size, the stems of plants at Glen Muick seem to be older and more mature than at other sites on the basis of the appearance of the bark. The site characteristics were also very different: a relatively steep, drained slope, wet heath compared to blanket bog vegetation, and soils with relatively low carbon content. The recent past land management history at Glen Muick does not include burning or use for grazing domestic stock and although there was evidence that red deer do use the area the impact on *B nana* was low. Glen Muick was the only site with patches of bare mineral soil where seedling plants were seen.

At every site, with the particular exception of Glen Muick and less emphatically Loch na Beinne Baine, the *B. nana* plants were below the height of the surrounding vegetation and well below their potential height. One of the consequences of this is that the flowers of this self-sterile, wind pollinated plant are within the surrounding vegetation and sheltered from air currents, a situation that is exacerbated because the male flowers arise below the female flowers on shoots, rather than at the shoot tips. The low stature of plants may be maintained by herbivory, which was a feature of every site, and/or it may be related to regular burning, or a response to growing on deep peat with poor anchorage.

There are a number of factors about the biology of *Betula nana* which suggest it would be more successful on better drained sites away from blanket bogs. It is a plant that across its range readily develops ectomycorrhizal associates (Kallio and Mäkinen 1974). Ectomycorrhiza, which are known to benefit their vascular plant partners, particularly during the establishment phase, are obligate aerobes (Harley and Harley 1987, Andrew Taylor *pers comm*.) which suggests that they would be more likely to be present in well drained soils. *B. nana* seedlings are very small and slender, and highly prone to desiccation. The relatively deep moss layer at most sites, most commonly of *Sphagnum* species, is potentially a barrier to recruitment due to its tendency to dry out over the summer when seedlings tend to be vulnerable.

Another, more speculative, outcome from the survey relates to the impacts of land management practices on mires and the survival of *B. nana* populations. As previously reported, no *B. nana* was found in 2008 at two sites that had been selected for field survey. One was close to the Lochaber – Argyll border, the other was in Sutherland, the first had been surveyed in 1988 (Coupar 1989, Highland Birchwoods 2000) and the *B. nana* was described as "extensive", the second was surveyed in 1987 and described as "fine stands with *Arctostaphylos uva-ursi.*." (Ferreira in Highland Birchwoods 2000 dataset). In 2008 neither location had a moss layer and the surface of the peat soil was visible between the surrounding vegetation. It appeared that both sites had been burned and the Sutherland location had also been drained. A recognised characteristic of *B. nana* found at many sites surveyed is the occurrence of horizontal stems running along the surface of the soil below the moss layer (Whittaker 1993). On the sites with deep peat and actively growing *Sphagnum* the stems were within the *Sphagnum* layer (Loch na Meur, Loch a'Chairein, Ben Loyal, Cnoc Maol Malpelly, Port Clair). It is possible that where the horizontal stems are associated with a damp moss layer they may be more able to withstand burning, possibly losing their aerial shoots but readily replacing them with new shoots, and possibly roots, from these stems.

5.1.2 Salix myrsinites

The most notable feature of the *S. myrsinites* sites was the wide ranging but mainly acidic nature of the soil, with values from just above pH 4 to only one site up to pH 7.5, which is generally very low for a plant described as calcicolous. Despite this the values for available Ca in the soils were relatively high, compared to those of both *B. nana* and *J. communis*, although this was not the case for other soil chemicals, notably phosphorus and potassium. The four sites in the north-west (both Inchnadamph and both Sgurr a'Gharaidh sites) and at least one in the Cairngorms (Creag an Dail Beag) were on alkaline bedrock, while the remain seven sites were on either sandstone or granite bedrock of less well defined base-status, although at least one was within a geological complex known to include high base-status rocks (Coire Gabhlach). It has not been possible to consult specific site information for *S. myrsinites* in other countries but it is described as “distinctly basiphilous” by Christensen *et al.* (2000). Willows are deep rooting plants (Wilkinson 1999, Kuzovkina & Volk 2009) and this result suggests that *S. myrsinites* survives by scavenging the nutrients it requires from below the soil and that the soil pH is not helpful in determining site suitability for this species. Further detailed study is required to confirm this.

Salix myrsinites plants were taller than the surrounding vegetation at most sites. The two exceptions to this were both Inchnadamph sites. One site had been enclosed in a large mammal-proof fence for over 50 years (Scott, A 1997) and had the tallest field layer vegetation and thickest moss layer recorded; the other was un-enclosed and had been subject to the heaviest browsing of any of the sites. The canopy diameters of these populations were very similar, and the leader lengths were also similar (means were approximately 50 mm longer on the protected plants). At several sites, including enclosed Inchnadamph and Garbh Coire, a number of the plants were coincident with bryophyte hummocks (either *Sphagnum* spp, or pleurocarpous mosses) to such an extent that only the new growth was visible above the moss. This has raised concern for the health of *S. myrsinites* plants (A. Scott, pers. comm.) prompting proposals to allow herbivores some access to some exclosures in the context of reduced herbivore pressure in the wider area (G. Sullivan pers. comm.).

The majority of *S. myrsinites* populations were in areas where the surrounding vegetation was relatively sparse and low growing. This may be due to the thinness of the soils and erosion, as at Creag an Dail Beag, Slochd Beag, Garbh Coire and Beinn Bhrotain. At both Sgurr a'Gharaidh sites it may be due to the high magnesium and calcium content of the soils which may be challenging to other normally more competitive plants. At Coire Odhar, Coire Garbhlach, Creag na h'Iolaire and Druim na Bo the greater tolerance of these sub-arctic plants to extreme climate and adverse weather may also be a factor. All the higher altitude sites had a degree of inaccessibility which has discouraged what might otherwise have been heavy use by herbivores. The exception is Creag an Dail Beag which is on a heavily eroding crag, frequented by sheep. In this case the main part of each remaining plant was largely out of reach of the sheep.

As *S. myrsinites* is a dioecious and insect-pollinated plant the proximity of individuals, of both sexes, is an important factor in the condition of populations. In south west Norway Peeters and Totland (1999) found that a minimum of 2% of *S. myrsinites* flowers might be pollinated by wind, and successful pollination is affected by the spacing of plants and their level of exposure (Totland and Sottocornola 2001). Marriott (1997) reported that 50 m was a reasonable distance for pollinating invertebrates to travel, although Shaw (2006) suggested that successful pollination was dependent on male and female plants being considerably closer and that the dipteran pollinators of *S. arbuscula* were very dependent on favourable weather conditions.

Two populations surveyed supported large populations of an apical bud gall (cf *Rhobdophaga*, possibly *R. rosea* (Pekka 2004) a gall-midge which creates a roseate gall in the apical bud of a shoot). At Beinn Bhrotain many plants had the majority of shoots supporting this gall. The remains of galls present on site suggested that there had also been a reasonable population in the previous year. The effect of the gall is to kill the length of new growth on a shoot. There is little information available about the occurrence of this gall in treeline willows in the UK and further work is required to assess its impact on the populations.

5.1.3 Juniperus communis

Although Sullivan (2001) confirmed that there are particular climatic and geological restrictions on the distribution of *J. communis* ssp *nana*, there are no similar constraints on the occurrence of *J. communis* ssp. *communis*. Superficially, the 13 sites surveyed in 2008 appeared to be in reasonable condition in terms of the percentage of each site occupied by the plants and their general size, particularly when compared to the condition of *B. nana* and *S. myrsinites* populations. However, at most sites the plants appeared old, in many cases over mature, with limited signs of new recruitment. Sullivan (2003) identified damaging browsing levels at a number of sites coupled with limited or no recruitment. No recruitment was found at any *J. communis* ssp *nana* population, and a number also had evidence of high browsing levels.

Six of the 2008 sites were, or had been in the recent past, within sporting and/or agricultural holdings. The *J. communis* stands tend to be within an area of grass-dominated grazing land bounding, uphill, *Calluna*-dominated open moorland. There have been two consequences of this situation which relate to the potential for population expansion. Firstly, at three sites the upper boundary of the population, adjacent to the moorland had been (and is being, Estate staff, *pers comm.*) constrained by burning. The charred stems from the previous season's burn were still present at one site. Secondly, the boundaries of each population across the slope have generally been constrained by stock grazing of the grass sward. Not only does the grazing constrain the successful establishment of any seedlings, the resulting dense sward reduces the number of bare-ground niches suitable for seedling germination (Thomas *et al*. 2007). Sullivan (2001) cites the catastrophic loss of a relatively large stand of mature *J. communis* ssp *communis* in Strathdearn in 1983/84, in this case thought to be caused by deep snow over winter and there is more recent evidence of the total loss of old *J. communis* stands in northern England. Strathdearn is particularly rich in extensive *J. communis* stands, and those that were surveyed, and others known to the author, are composed of old plants which are generally tending toward moribund. The sudden demise of a whole stand may result from a complex combination of weather, browsing, bark stripping and / or disease. Without further research it would be difficult to dis-entangle the exact cause but large, mature stands without recruitment must be considered potentially vulnerable to a similar fate.

From the 2008 survey it would appear that land management is a major constraint on the expansion and self-perpetuation of *J. communis*. In addition it is possible that when combined with exceptional weather events such as heavy winter snow cover, it can be catastrophic for individual populations. Because the plant is long-lived there is a perception by land management staff, that it will always be there and there has been little consideration of the actual state and condition of many populations, particularly in the treeline zone.

5.2 Management Considerations that can be drawn from these results

5.2.1 Betula nana

The main site characteristics which were common across all the sites surveyed and are relevant to management or site selection for the creation of new populations, were the acid nature of the soils and an ericaceous shrub-dominant sward.

The contrast between the low-statured and relatively young aerial-stemmed plants growing on the blanket bog sites and the tall, large, mature aerial stems on the wet heath site at Glen Muick, suggests that this plant may have been more widespread on a greater range of heathland habitats in the past. It is not known whether the stature of the plants at Glen Muick relates to the substrate or the lack of grazing and/or burning. However it does suggest that past drainage of moors supporting wet heath vegetation leading to a reduction or loss of the moss layer would have removed the protection from burning for *B. nana,* resulting in a loss of populations.

The absence of young plants at many populations suggests that seed production may be a limiting factor to the long-term survival and expansion of populations. In turn this may be due to only limited volumes of pollen successfully dispersing from male flowers close to ground level. Recent management by Trees for Life (M. Drury, *pers. com.*) suggests that protection from browsing by fencing can improve the frequency of flowering. However, further work would be required to determine whether the height of the plants relative to the surrounding vegetation is a critical factor in achieving successful pollination and seed dispersal. There is growing, but un-quantified, evidence that hybrid seed (*B. nana* x *B. pubescens*) is a constant feature in catkins collected from wild *B. nana* populations. The frequency of this may be another unforeseen consequence of the low stature of the *B. nana* plants if pollen from neighbouring *B. pubescens* woodland is more numerous than the pollen that is able to get into the air currents from the *B. nana* male flowers.

The evidence of the levels of browsing on *B. nana* at many sites suggests that it is preferentially browsed to *Calluna vulgaris*. Consequently control of herbivores is likely to have a positive effect on the size of plants (Scott 2001). It is possible that the potential for some existing populations to respond to reduced herbivore numbers has been compromised, as demonstrated on *B. glandulosa* browsed in summer by Crête & Doucet (1998). At several sites surveyed, for example Carn Dubh, this did not appear to be the case because despite very small plants and evidence of heavy browsing the leader lengths measured during the survey included some of the longest, and the mean for the site was in the middle for the survey, strongly suggesting that a period or reduced or no browsing would allow year on year growth. This would also improve the volumes of *B. nana* pollen available in spring.

In summary, there is good evidence to suggest that wet heath vegetation is a suitable substrate for *B. nana* populations, and it is possible that it may provide better growing conditions than blanket bog. *B. nana* does appears to able to survive burning providing there is a good moss carpet protecting horizontal stems, but that the regular loss of aerial stems does compromise its regenerative ability. A reduction, or cessation, of browsing (coupled with a cessation of burning) would facilitate plant growth at the majority of populations and improve the potential for production of pure species seed. An investigation of whether substrate (blanket bog or wet heath) has an effect on growth performance and habit would provide significantly improved management advice.

5.2.2 Salix myrsinites

Two site factors appear to be common across all the *S. myrsinites* sites: the relatively high level of plant-available Ca in site soils and the relatively restricted range of, predominantly northerly, aspect. *S. myrsinites* is a relatively short montane willow which means that it is perhaps more vulnerable to competition from other species than some others, and a feature of many sites was the level of exposure and/or erosion resulting in a relatively open surrounding sward. Another factor observed during the survey was the relatively low levels of browsing, due in part to inaccessibility resulting from steepness.

It is possible that the combined effects of competition and browsing may explain the relatively restricted area of *S. myrsinites* populations at each locality. Neither was directly tested in this survey, but a field experiment investigating the interaction between browsing and exposure on young plants suggested that increased shelter adversely affects survival, potentially due to increased competition (Gilbert 2011*)*. At Inchnadamph long term exclusion of herbivores initially benefited *S. myrsinites* but after 20 years the growth of other species, from bryophytes to small trees, was excluding seedling establishment and over-shading the

S. myrsinites plants (Scott, A 1997). Steepness, potentially controlling browsing and competition, was a feature of many sites, particularly in the Cairngorms. Tolerance of the generally adverse conditions such as northerly aspect, exposure, eroding ground and nutrient poor soils are ways of avoiding competition (Crawley 1997, Grime 2001). The ability to scavenge nutrients from base-rich bedrock using long roots may be a strategy for coping and may be an important issue when considering management of this species. The potential role of a plant that is able to bring nutrients such as Ca to the surface in areas with acidic soils should be further investigated.

The overall size of the UK *S. myrsinites* population has reduced to the extent that it is now listed in the British Vascular Plant Red Data Book as vulnerable (Cheffings and Farrell 2005), and the nature and limited level of recruitment of many individual populations is such that the decline would seem set to continue. Large numbers of plants at individual sites do not necessarily provide a long-term safeguard if the population is broken up by cliffs and erosion and small groups of plants are effectively isolated in terms of successful pollination. Recent work propagating and re-introducing *S. lanata* to sites close to existing populations will provide valuable experience, along with that gained by the National Trust for Scotland at Ben Lawers (Mardon 2004) in the methods for establishing new and enhancing existing populations.

In summary, management of many populations will be required to ensure their long-term survival in terms of recruitment of new plants. At some sites, such as Craig an Dail Beag, this initially means reduction or removal of herbivores from the eroding slopes. At other sites enhancement of the existing population to promote increased seed production would be beneficial. However, better understanding of the relative roles of competition with other plants, browsing and the Ca content of soils would aid management of existing populations and the selection of sites for expansion or new populations.

5.2.3 Juniperus communis

From the results of the two surveys of *J. communis* ssp *communis* (2003 and 2008) it would be difficult to identify specific site factors which define their site types. All the populations surveyed are on land which is or has been managed for grazing, either by domestic stock or as deer forest. Many of these higher altitude populations bound areas managed intensively for red grouse and from which expansion of juniper is excluded, either intentionally or incidentally by burning.

All the sites were dominated by mature and over mature plants but despite this many are in relatively good condition, with a high density of plants and a reasonable ratio of male and female plants, in the short term. At many sites longevity appears to be maintaining the populations, which means that they may be vulnerable to catastrophic loss, and over the longer term the lack of good levels of recruitment is of concern. Because the main population at many sites is closely spaced the existing recruitment tends to be around the edge where it is vulnerable to browsing and particularly to fire. Castle Hill and Kirriereoch were the exceptions to the above. Both populations were sparsely spaced and at Castle Hill no recruitment was seen and the levels of browsing were relatively high because the plants tend to be small (mean height less than 50 cm). At Kirriereoch recruitment was present in very low numbers and the nature of the ground means that the mature plants are often more than 5 m apart so seed production is also likely to be low.

Although *J. communis* ssp *nana* heath H15 was restricted to a particular geology and climatic region Sullivan (2001) argued that there were suitable areas within the range where a change in land management intensity might allow its development. Some of these areas were already occupied by *J. communis* ssp *nana* plants, but they tend to be relatively small, younger and may be subject to high levels of browsing and trampling.

In summary, action to facilitate the survival of existing levels of recruitment would benefit many populations. In addition, control of herbivore damage may facilitate better seed production and so allow more recruitment (for example Castle Hill). In populations where sparsely distributed plants and poor pollination may be limiting seed production there may be an argument for enhancement planting (for example Kirriereoch, and some *J. communis* ssp *nana* populations) if other damaging impacts are reduced or removed.

5.3 Conclusions

The populations visited through the surveys undertaken were generally in reasonable short-term condition and no species is in imminent danger of extinction. These surveys and the analysis of the collected data have increased our understanding of the types of sites occupied by the three species investigated. In particular, the 2008 survey of *B. nana* populations showed that this plant could occupy wet heath sites as well as blanket bog, and that it might grow better on shallower soils. *S. myrsinites* predominantly grows on unstable, northerly facing steep slopes at high altitude, with relatively Ca-rich soils, potentially to avoid competition with other vegetation. If this were the case there will be particular management issues if recruitment cannot be successfully achieved. For *J. communis* the main conservation concerns also revolve around recruitment which at many sites might be solved by modifying land management to allow the successful establishment of young plants.

Inevitably such studies also raise many questions pertinent to management. For example: Is the prostrate nature of *B. nana* on blanket bogs a result of land management or due to a lack of stability, and so would it be wise to establish new populations on drier ground? Is it soil type, a lack of competition or browsing pressure that confines *S. myrsinites* to inaccessible and/or unstable ground and what levels of competition can it cope with? There is only limited published information about the age of *B. nana* and *S. myrsinites*, and *J. communis* at higher altitudes, but the surveys tend to suggest that many populations may be composed primarily of old plants. How old are the individual plants at existing populations and, particularly for *B. nana* and *S. myrsinites,* how many individuals exist in small populations? The quantity of bare ground at most sites suggested that there are microsites available for establishment of seedlings and that this is not the primary reason for the lack of recruitment. It was not possible to study the reproductive capacity of a population in one visit but these may be limiting factors and would warrant further attention.

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APPENDIX 1: SELECTION OF SITES FOR FIELD SURVEY

A1.1 Data collation

A dataset compiled in 2000 (MacKenzie 2000) provided the location data for all 'known' records of populations. The information associated with each record was highly variable and required modification, as follows, prior to analysis. Because *J. communis* grows across the altitudinal range from sea level to mountain summits the dataset was filtered for sites above 350 m above sea level (asl). All records with only a low resolution grid reference of 10 km square were discarded. Records at 1 km square resolution were also discarded unless the description indicated that the plant was widespread throughout the square. In order to include these latter sites in the analyses the XY co-ordinates were set at the centre of the square. The database included the following fields, although not all records had a complete set of information:

Local authority district name (pre-1995 re-organisation)	Author of the record
Grid reference	Resolution (10 m, 100 m, 1 km)
Site name	Minimum altitude
	Maximum altitude
Notes (very variable, relating to surrounding vegetation or number of plants present, or other tall-shrub species present)	Aspect Slope X coordinates Y coordinates

Gaps in physical data for each record (e.g., aspect, altitude or slope) were filled by extracting the data from the appropriate dataset in ArcGIS 9.0 layered with Ordinance Survey 100 x 100 km square Digital Terrain Model data. The resolution of this dataset is 500m x 500m. The aspect data, which was recorded as degrees east of north, was transformed to provide two sets of data relating each aspect to both the north-west or north-east in a linear format to meet the needs of analysis. This was achieved by subtracting 45° from the aspect angle and calculating the cosine and sine, respectively, of each angle. Scottish mountain ridges, and soil temperature gradients tend to be aligned from south west to north east and so this transformation provides a more useful assessment of aspect than angles related to north. In order to avoid false north readings level ground, or zero aspect and slope values were re-set to zero in both aspect transformations. Finally, the average altitude was calculated from the minimum and maximum values. The completed dataset was then separated into species.

The following additional data was added to each record using ArcGIS 9.0:

- growth degree days (GDD) (days with average temperature over 5.5°C), from accumulated temperature map overlay for Scotland at 5 km resolution (Brown *et al*. 2008)
- exposure ratings (DAMS: FCS database)
- Land Cover Scotland 1988 (LCS88, Macaulay Land Use Research Institute, 1993)
- Soils data (Macaulay Institute for Soil Research 1984)

The LCS88 and soils data were further broken down by identifying key characteristics which were relevant to this analysis. For the soils these were: peat content, wetness, mineral content and alpine, whereas for LCS88 they were: bogginess, heather cover, grass cover, tree cover, rockiness, and burning. For *J. communis* 'bracken cover' was also included as a category due to its presence in some of the LCS categories for *J. communis* records. Each soil or LCS88 category was ranked against these characters with help from MLURI soil and land cover scientist William Towers, the indices used are defined in Table A1.1. The rankings for each LCS88 and soil type for each species are provided in Tables A2.1, A2.2 and A2.3 in Appendix 2.

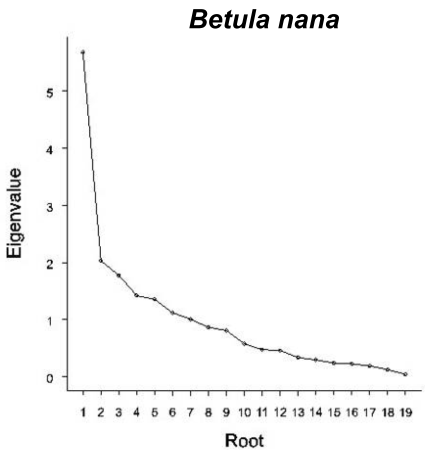
Table A1.1 *Definition of indices used to rank LCS88 and soil characteristics used in Principal Component Analysis (Appendix 2.1, Tables A2.1,A 2.2, A2.3 give the rankings for the records of each species)*

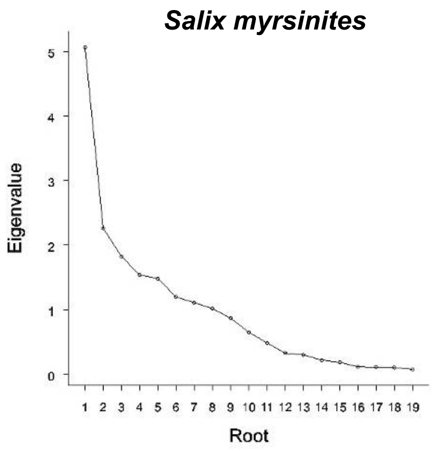
categories	Range	Definition
Soil character		
Peat content	0 - 3	0 = no peat; 3 = all component soils are peat based
Wetness	0 - 3	0 = drifts with rankers, forest or alpine soils; 2 = predominantly peat component soils; 3 = open water
Mineral content	0 - 3	0 = all peat soils; 3 = brown magnesian soils, and rock & scree
Alpine	0 - 3	0 = no alpine or sub-alpine soil component; 3 = an alpine soil component with rankers [not peat]
LCS88 character		
Bogginess	0 - 4	0 = dry heather moor, undifferentiated smooth grass, rocky montane; 3 = blanket peat; 4 = open water
Heather cover	0 - 4	0 = all forest or woodland types, grassland types, or cliffs; 4 = heather moor, undifferentiated heather, no grassland
Grass cover	0 - 3	0 = heather moor, undifferentiated heather moor, blanket bog; 3 = all grassland
Tree cover	0 - 3	0 = all non-forest/woodland types with no trees; 3 = forest & woodland types
Stability	0 - 1	0 = cliffs or any type with ‘erosion’ ; 1 = no erosion, not cliffs
Rockiness	0 - 2	0 = 'no rock' specified; 2 = cliffs
Burning	0 - 2	0 = forest types, 'no burning' specified; 2 = 'burning' specified
Bracken (Juniper only)	0 - 3	0 = bracken not specified; 2 = 'bracken' specified in dominant type

A1.2 Data Analysis

The final output of this collation of information was a dataset of records for each species which included a site identifier (site number) and 19 different environmental characteristics for analysis for *B. nana* and *S. myrsinites* and 20 for *J. communis* due to the inclusion of bracken cover (Table A1.2).

Each species dataset was examined using GenStat 10.0 Principal Component Analysis (PCA) with the environmental characters forming the dimensions of the analysis. The first two components of the PCA in each case, accounted for the majority of the variation in the data (Fig. A1.1).





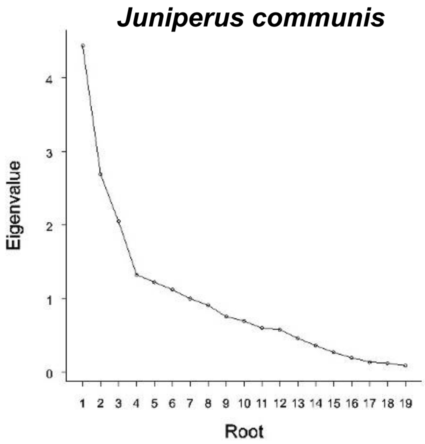


Figure A1.1 *Eigenvalues of the Principal Component Analysis of 19 dimensions for* Betula nana *and* Salix myrsinites *and 20 dimensions for* Juniperus communis.

Table A1.2 *Attributes for each species used in the PCA analysis of site information.*

Topographical data	PCA output text	Habitat data	PCA output text
Average altitude	average altitude	Soils	
Cosine aspect	cos aspect	Peat content	peat
(north-easterly)	sin aspect	Wetness	wetness
Sine aspect	slope	Mineral content	mineral
(south-easterly)	Xcoord	Alpine	alpine
Slope		LCS88	
X coordinate,	Ycoord	Bogginess	bog
(easterly-ness)		Heather cover	heather
Y coordinate,	GDD	Grass cover	grass
(northerly-ness)		Tree cover	trees
Growth Degree	DAMS	Stability	stability
Days		Rockiness	rock
DAMS (exposure)		Burning	burning
		Bracken[1]	bracken

[1] used in *Juniperus communis* analysis only

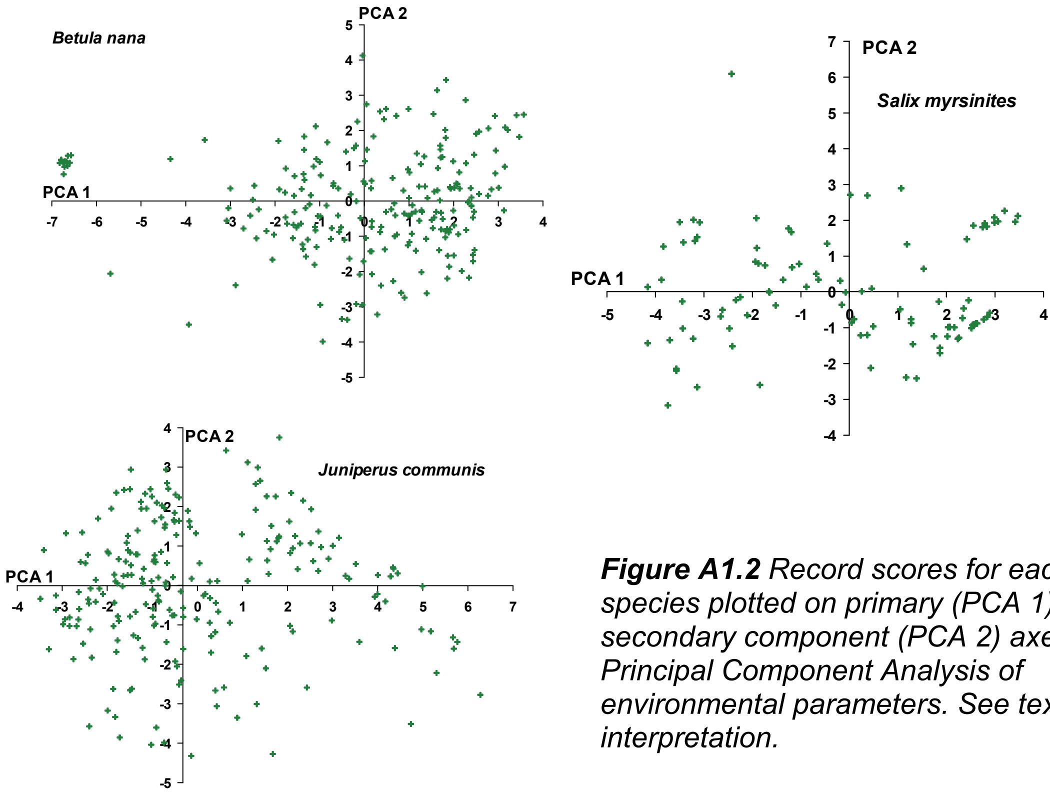


Figure A1.2 *Record scores for each species plotted on primary (PCA 1) and secondary component (PCA 2) axes from Principal Component Analysis of environmental parameters. See text for interpretation.*

A1.3 Field survey site selection

The general field survey site selection process was as follows:

i) For each species a plot of the distribution of records across the first two component axes (PCA 1 and PCA 2) was generated (Fig. A1.2). This facilitated the identification of categories with different combinations of environmental characteristics. It also allowed the identification of any clumps of different records associated with particular groupings of environmental characteristics from the PCA.

ii) Because the records for each species were generally well spread across the axes each quadrant of the component plots (Fig. A1.2) was identified as a separate category of site type (Table A1.3).

iii) Each species record was then cross-referenced to the native woodland model (NWM) classification category (Table A1.4, Towers *et al*. 2000) for that location. The NWM used a number of different datasets, including LCS88 and climate data to predict the suitability of different locations for different native woodland types.

iv) Multiple records that were within 1 km of each other and had the same PCA and NWM categories were considered the same population and reduced to one site for the next stage.

v) Several of the PCA/NWM categories for each species contained more than four sites and so represented possible optimum site characteristics (Table A1.5). At least one field survey site was selected from each of these categories. Otherwise the selection of categories was spread widely across the range, with no more than two potential sites identified from any one category. In categories with multiple sites the actual sites for survey were selected using random numbers.

vi) All the candidate field survey sites were checked according to the evidence in the dataset for population size (at least 10 individuals) and accessibility (each field survey needed to be completed in one day). Alternatives were identified where these criteria were not satisfied.

A1.4 Outcomes

The species specific features of each PCA plot and any particular aspects of the field site selection process are set out below.

A1.4.1 Betula nana

The strongest positive correlations with the first component (PCA1) were bogginess, peat cover and burning. Equally strong but negative were slope, alpine and mineral content. Y-coordinate (northerliness), wetness and a south-easterly aspect (sine aspect) also tended in a positive direction, while heather cover, rockiness and X-coordinate (easterliness) tended to the negative. Stability and growth degree days were positively correlated with PCA2 and exposure (DAMS) and altitude were negative.

The records were plotted onto the first two component axes and produced a relatively evenly scattered pattern (Fig. A1.2) except for a group of records from Glen Muick, which were clustered at the extreme negative end of PCA1, correlated with alpine and mineral-ness. From this plot four categories were identified from the four quadrants of the PCA plot (Table A1.3). Following the rationalization of multiple records from the same location 67 sites remained and ranged across the PCA and NWM category combinations as given in Table A1.5A a). The selection of the 15 field survey sites is given in Table A1.5A b), and included one site from the Glen Muick group identified on the PCA plot (Fig A1.2).

Table A1.3 *Categorisation of site types from the plot of species record scores on the primary (C1) and secondary (C2) component axes arising from Principal Component Analysis of topographic and habitat parameters associated with records for each species.*

Category name	C1 score	C2 score	Description
Betula nana			
A	0 to -7	0 to 5	Populations in the east on steeper slopes with a drier heathery sward and likely to be facing north-east
B	0 to -7	0 to -5	High, windy sites with a tendency for rocky, mineral, alpine soils
C	0 to 4	0 to 5	Northern, lower altitude sites which tend to be warm and peaty
D	0 to 4	0 to -5	Cooler, wet, boggy sites which are likely to be burned, tend to be in the west with a south-easterly aspect
Salix myrsinites			
A	0 to -5	0 to -4	Stable, northern, boggy sites
B	0 to -5	0 to 7	Wet, peaty, grassy sites which tend to be warmer
C	0 to 4	0 to -4	Alpine, mineral soil sites which tend to be eastern, stable and may be heathery
D	0 to 4	0 to 7	Rocky, steep, exposed, higher altitude sites
Juniperus communis			
A	0 to -4	0 to -5	Wet, peaty sites which tend to be warm and heathery, and maybe boggy
B	0 to -4	0 to 4	Stable, sheltered eastern sites, which are grassy with trees and may have a south-easterly aspect
C	0 to 7	0 to -5	Exposed, rocky sites, tend to be high and on steep slopes
D	0 to 7	0 to 4	Alpine sites with drier, mineral soils which may have

bracken

***Table A1.4** List of Native Woodland Model predicted habitat codes and descriptions identified at* B. nana, S. myrsinites *and* J. communis *record locations.*

NMW code	Habitat type
Sc1	Juniper
Sc2	Scattered juniper
Sc3	Birch/willow
Sc4	Scattered birch/willow
Sc5	Peatland with scattered trees/scrub
Sc6	Basin bog woodland /scrub
Sc7	Mixed montane scrub
Sc8	Scattered mixed montane scrub
Sc5/W18	Peatland with scattered trees/scrub + W18 mosaic
Sc5/W4	Peatland with scattered trees/scrub + W4 Birch with purple moor grass and open ground mosaic
Sc5/W4/W17/ W18	Peatland with scattered trees/scrub +W4 Birch with purple moor grass and open ground + W17/W18 Mosaic
W4	Birch with purple moor grass and open ground
W4a	Birch with purple moor grass
W4/Sc5	W4 birch (with open ground) + Peatland with scattered trees/scrub mosaic
W4/Sc5/W17/ W18	W4 Birch (with open ground) + Peatland with scattered trees/scrub + W17/W18 mosaic
W4/W17/W18	W4 birch (with open ground) + W17/W18 mosaic
W7	Alder-ash with yellow pimpernel
W9	Upland mixed broadleaved with dog's mercury
W11	Upland oak-birch with bluebell/wild hyacinth
W11/W7	Oak ash mosaic
W11/W9	Ash/oak or mosaic
W11/W17	Upland oak
W17/W11	Upland oak
W17/W18	Birch, pine or mosaic
W17/W18/W4	W17/W18 + W4 Birch (with open ground) mosaic
W17	Upland oak-birch with bilberry/blaeberry
W18	Scots pine with heather
W18/Sc5	W18 + peatland with scattered trees/scrub mosaic
W18/W4	W18 + W4 mosaic
W18/W4/SC5	W18+W4+Peatland with scattered trees/scrub mosaic
W18/W17	Birch, pine or mosaic
W19	Juniper woodland with wood sorrel
U	Unsuitable for tree/scrub growth
WATER	Inland water

A1.4.2 Salix myrsinites

The *S. myrsinites* first component axis (PCA 1) was very positively correlated with altitude, alpine and mineral content, and less so with exposure, slope and easterly-ness. Wetness and peat content were strongly negatively correlated to PCA 1 and grass cover, bogginess and growth degree days also tended in the negative direction. Along the second axis (PCA 2) stability, heather cover and northerly-ness were strongly negatively correlated but rockiness and slope were positive and weakly positive on PCA 1. Aspect, burning and tree cover were not particularly important on the first two components. The four PCA categories generated from this plot are given in Table A1.3.

Figure A1.1 shows the distribution of *S. myrsinites* sites on the two axes and their relationship to the different categories in Table A1.3. There were 36 sites left following the assignment of NWM categories and grouping of multiple records for the same site. Table A1.5Ba provides the spread of sites selected for survey across the different PCA and NWM categories. There was only limited information about the condition of the majority of populations in the dataset. Further discussion with SNH identified more recent information for a number of sites selected for field survey and several additional sites not in the dataset.

A1.4.3 Juniperus communis

The outcome of the PCA analysis showed that alpine, altitude and mineral content were strongly positively correlated with PCA 1, while wetness and peat cover showed negative correlation with both PCA 1 and PCA 2. X-coordinate (easterliness), stability, tree cover and grassiness were positively correlated with PCA 2 while bogginess was negatively correlated along with rockiness and exposure (DAMS). Neither aspect nor northerliness were strong contributors to the first two components. Table A1.3 shows the categories developed from the four quadrants of the PCA 1 and PCA 2 plot.

Following the addition of NWM categories and grouping of multiple records for the same site there were 154 sites. Table A1.5Ca shows how these were spread across the different PCA and NWM categories and which categories were selected for the final field survey.

Table A1.5 *Categorisation and selection of field sites for records of A* Betula nana, *B* Salix myrsinites, *C* Juniperus communis. *a). Categorisation of records by PCA type (see text for explanation) and Native Woodland Model (NWM) predicted site suitability. b). Selection of fifteen sites for field survey according to the representation across PCA and NWM categories.*

A *Betula nana*

a). PCA type	Native woodland model predictions[1] Sc1	Sc3	Sc5	Sc5/ W18	Sc5/ W4	Sc5/ W4/ W17/ W18	Sc7	U	W17/ W11	W17/ W18	W18	W18/ Sc5	W18/ W4	W4	W4/ Sc5	W4/S c5/W 17/W 18	W4/ W17/ W18	WAT ER	Total
A	1						6			1	1	2		1			2		14
B		3				1	6	1			2	1	1				3		18
C			4	4	3				2			1		1	2	1		2	20
D			5	4	4										1			1	15
Total	1	3	9	8	7	1	12	1	2	1	3	4	1	2	3	1	5	3	67
b). Site selection																			
A	1						1					1							3
B							1	1			1						1		4
C			1	1	1				1						1				5
D			1	1	1														3
Total	1	0	2	2	2	0	2	1	1	0	1	1	0	0	1	0	1	0	15

B *Salix myrsinites*

a). PCA type	Native Woodland Model predictions[1] Sc 1	Sc2	Sc3	Sc4	Sc5/ W4	Sc7	Sc8	U	W9	W17/ W18/ W4	W18/ W17	W4	W4/S c5/W 17/W 18	Total
A	1		3	1	1						2	1	1	10
B							1	1	2	2				6
C	5	1				2		3					1	12
D	2			1				5						8
Total	8	1	3	2	1	2	1	9	2	2	2	1	2	36
b). Site selection														
A			1		1						1	1		4
B							1		1	1				3
C	1	1				1		1					1	5
D	1			1				1						3
Total	2	1	1	1	1	1	1	2	1	1	1	1	1	15

Table A1.5 *contd. a). The breakdown of* Juniperus communis *sites by PCA type (see text for explanation) and NWM predicted site suitability. b). The selection of fifteen sites for field survey according to the representation across PCA and NWM categories.*

C *Juniperus communis*																	
	Native Woodland Model predictions[1]																
a). PCA type	Sc 1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc5/W4/W17/W18	Sc5/W4	Sc7	Sc8	U	W9	W11	W11/W17	W11/W7	W11/W9	Sub- total
A	1			3	1	1	1	1	1		1			1			11
B			1		1								3	5	2	4	16
C	2	2		1			1		2	1	8						17
D	12	1	8						5	1	4	2		1			34
Total	15	3	9	4	2	1	2	1	8	2	13	2	3	7	2	4	78
b). Site selection																	
A				1													1
B														1			1
C	1										1						2
D	1		1						1		1						4

a). contd. PCA type	W17	W17/W18	W17/W11	W17/W18/W4	W4	W4a	W4/Sc5/W17/W18	W4/W17/W18	W4/Sc5	W7	W18	W18/W4	W18/W17	W18/W4/Sc5	W18/Sc5	W19	Total
A			1	2	1		1	4	1		13		4	1	3		42
B	1	4	5		2	1				3	5	5	12			1	55
C												1	2				20
D	1		1								1						37
Total	2	4	7	2	3	1	1	4	1	3	19	6	18	1	3	1	154
b). contd. Site selection																	
A								1			1		1				4
B			1								1	1	1				5
C																	2
D																	4
Total	0	0	1	0	0	0	0	1	0	0	2	1	2	0	0	0	15

[1] See Table 3

APPENDIX 2: LAND COVER SCOTLAND VEGETATION AND SOIL TYPES IDENTIFIED FROM MONTANE SCRUB SPECIES RECORD LOCATIONS

Table A2.1 *Land Cover Scotland vegetation type (LCS88, MLURI 1993) and soil type (MISR 1984) codes identified at* Betula nana *records and the rankings for the different characteristics used in the Principal Component Analysis.*

LCS88 units and indices for sites characteristics								Soil type code and indices for site characteristics				
Vegetation code no.	Bogginess	Heather cover	Grass cover	Tree cover	Stability	Rockiness	Burning	Soil type code no.	Peat content	Wetness	Mineral content	Alpine
18	4	0	0	0	1	0	1	1	0	2	2	0
70	0	0	0	3	1	0	0	4	3	1	0	0
85	0	1	1	2	1	0	0	23	3	1	0	0
110	0	4	0	0	1	0	0	26	2	2	0	0
112	0	4	0	0	1	0	2	28	1	1	0	0
114	0	4	0	0	1	1	0	29	2	2	1	0
120	2	3	0	0	1	0	0	30	1	1	2	0
130	1	4	0	0	1	0	0	32	2	2	1	0
131	1	4	0	1	1	0	0	33	1	1	1	1
134	1	4	0	0	1	1	0	34	2	2	1	1
160	0	0	3	0	1	0	1	35	0	0	2	2
180	3	1	0	0	0	0	1	61	2	2	1	0
182	3	1	0	0	1	0	1	74	1	1	1	0
184	3	1	0	0	1	0	1	101	1	1	1	0
222	0	1	1	0	1	1	1	117	1	1	1	0
223	0	1	1	0	1	0	1	119	2	2	1	0
312	2.5	2	0	0	1	1	0	123	2	2	1	0
358	2.5	2	0	0	1	0	1	134	1	1	1	1
360	2.5	2.5	0	0	1	1	0	135	2	2	1	1
361	2.5	2	0	0	1	0	0	136	0	0	2	2
374	2.5	2.5	0	0	1	0	0	504	2	2	1	0
382	2.5	2	0	0	1	0	1	513	2	2	1	1
384	2.5	2	0	0	1	1	1	557	2	2	1	0
442	1	2	2	0	1	0	0	601	0	3	0	0
444	1	0	3	0	1	0	1	604	3	1	0	0
476	2	3	0	0	1	0	0	606	3	1	0	0
477	2	2.5	0	0	0	0	0					
556	2.5	2	0	0	0	0	0					
580	2	2.5	0	0	0	1	0					
599	2.5	1	1	0	0	1	1					
602	2.5	1	1	0	0	0	1					
603	1.5	1	1	0	0	0	1					
607	1.5	1	1	0	0	1	1					
634	2.5	2	0	0	0	1	1					
736	2.5	2	0	0	0	0	1					
890	0	2	1	0	1	0	0					
948	0	3	0	0	0	1	0					

***Table A2.2** Land Cover Scotland vegetation type (LCS88, MLURI 1993) and soil type (MISR 1984) codes identified at* Salix myrsinites *records and the rankings for the different characteristics used in the Principal Component Analysis.*

LCS88 units and indices for sites characteristics								Soil type code and indices for site characteristics				
Vegetation code no.	Bogginess	Heather cover	Grass cover	Tree cover	Stability	Rockiness	Burning	Soil type code no.	Peat cover	Wetness	Mineral cover	Alpine
10	0	0	0	0	0	2	0	1	0	2	2	0
26	*	*	*	*	*	*	*	4	3	1	0	0
27	*	*	*	*	*	*	*	23	3	1	0	0
70	0	0	0	3	1	0	0	26	2	2	0	0
111	0	4	0	1	1	0	0	28	1	1	0	0
114	0	4	0	0	1	1	0	29	2	2	1	0
130	1	4	0	0	1	0	0	30	1	1	2	0
134	1	4	0	0	1	1	0	32	2	2	1	0
140	1	0	3	0	1	0	1	33	1	1	1	1
162	0	0	3	0	1	1	0	34	2	2	1	1
182	3	1	0	0	1	0	0	35	0	0	2	2
222	0	1	1	0	1	1	0	61	2	2	1	0
223	0	1	1	0	1	0	0	74	1	1	1	0
317	1	2	2	0	1	1	0	101	1	1	1	0
360	2.5	2.5	0	0	1	1	0	117	1	1	1	0
374	2.5	2.5	0	0	1	0	0	119	2	2	1	0
382	2.5	2	0	0	1	0	0	123	2	2	1	0
414	2	1	3	0	1	0	0	134	1	1	1	1
494	1	2	3	0	1	1	0	135	2	2	1	1
564	1	2	3	0	1	0	0	136	0	0	2	2
568	0	3	1	0	1	1	0	504	2	2	1	0
571	2	1	3	0	1	1	0	513	2	2	1	1
580	2	2.5	0	0	0	1	0	557	2	2	1	0
603	1.5	1	1	0	0	0	0	601	0	3	0	0
607	1.5	1	1	0	0	1	0	604	3	1	0	0
608	1.5	1	1	0	1	1	0	606	3	1	0	0
620	1.5	1	1	0	1	0	0					
755	0	2	3	0	1	1	0					
912	1	3	1	0	1	1	0					
939	2	1	3	0	1	1	0					
942	0	0	2	0	0	2	0					
950	0	3	2	1	1	0	0					
1448	0	2	3	1	1	1	0					

Table A2.3 *Land Cover Scotland vegetation type (LCS88, MLURI 1993) and soil type (MISR 1984) codes identified at* Juniperus communis *records and the rankings for the different characteristics used in the Principal Component Analysis.*

LCS88 units and indices for sites characteristics									Soil type code and indices for site characteristics				
Vegetation code no.	Bogginess	Heather cover	Grass cover	Tree cover	Stability	Rockiness	Burning	Bracken		Peat cover	Wetness	Mineral cover	Alpine
10	0	0	0	0	0	2	0	0	1	0	2	2	0
18	4	0	0	0	1	0	0	0	3	3	2	0	0
26	*	*	*	*	*	*	*	*	4	3	2	0	0
27	*	*	*	*	*	*	*	*	5	1	2	2	0
70	0	0	0	3	1	0	0	0	15	0	0	2	3
73	0	1	1	3	1	0	0	0	20	1	1.5	1	0
76	0	0	2	3	1	0	0	0	21	2	1.5	0	0
79	0	1	1	3	1	0	0	0	22	2	1.5	0	0
82	0	0	1	2	1	1	0	0	23	3	2	0	0
83	0	0	0	0	0	0	0	0	26	2	2	0	0
84	0	1	1	0	1	0	0	0	27	0	1	1	0
85	0	1	1	2	1	0	0	0	28	1	1.5	0	0
90	0	0	3	0	1	0	0	0	29	2	2	1	0
110	0	4	0	0	1	0	0	0	30	1	1	1	0
111	0	4	0	1	1	0	0	0	31	2	1.5	1	0
112	0	4	0	0	1	0	2	0	32	2	2	1	0
114	0	4	0	0	1	1	0	0	33	1	1	1	1
115	0	4	0	1	1	1	0	0	34	2	2	1	1
116	0	4	0	0	1	1	2	0	35	0	1	2	2
117	0	4	0	1	1	1	1	0	36	0	0	2	3
130	1	4	0	0	1	0	0	0	53	0	1	1	0
131	1	4	0	1	1	0	0	0	101	1	1.5	1	0
132	1	4	0	0	1	0	2	0	112	0	0	2	0
134	1	4	0	0	1	1	0	0	117	1	1	1	0
136	1	4	0	0	1	1	2	0	126	2	1.5	1	0
140	1	0	3	0	1	0	1	0	127	3	2	1	0
142	1	0	3	0	1	1	0	0	129	2	1.5	1	0
150	0	0	3	0	1	0	0	0	132	3	2	0	0
155	0	0	3	1	1	0	0	0	134	1	1	1	2
156	0	0	3	2	1	0	0	0	135	2	2	1	1
160	0	0	3	0	1	0	0	0	136	0	0	2	3
161	0	0	3	1	1	0	0	0	137	0	0	2	3
162	0	0	3	0	1	1	0	0	160	3	2	0	0
163	0	0	3	1	1	1	0	0	165	0	1	1	0
171	0	0	1	1	1	0	0	0	182	3	1.5	0	0
180	3	1	0	0	0	0	0	0	188	3	2	0	0

Table A2.3 *contd. Land Cover Scotland vegetation type (LCS88, MLURI 1993) and soil type (MISR 1984) at* Juniperus communis *record sites.*

LCS88 units and indices for sites characteristics									Soil type code and indices for site characteristics				
Vegetation code no.	Bogginess	Heather cover	Grass cover	Tree cover	Stability	Rockiness	Burning	Bracken	Soil type code	Peat cover	Wetness	Mineral cover	Alpine
182	3	1	0	0	1	0	0	0	191	3	2	0	0
222	0	1	1	0	1	1	0	0	192	2	1	1	2
301	0	2	3	0	1	1	0	0	218	3	2	0	0
312	2.5	2	1	0	1	1	0	0	221	0	0	1	0
326	0	3	2	0	1	1	0	0	225	0	1	1	0
360	2.5	2.5	0	0	1	1	0	0	226	1	1	1	0
374	2.5	2.5	0	0	1	0	0	0	227	0	1	1	0
382	2.5	2	0	0	1	0	0	0	228	2	1.5	1	0
389	0	3	1	0	1	0	0	0	229	3	1.5	0	0
396	1	3	2	0	1	1	0	0	230	3	2	0	0
412	1	3	2	1	1	0	0	0	235	0	0	2	0
416	1	0	3	0	1	0	0	0	240	0	1	1	0
434	0	0	3	1	1	0	0	1	241	1	2	2	0
438	2.5	2.5	1	0	1	0	2	0	243	1	1	1	0
440	0	0	2	1	0	0	0	1	245	3	1.5	0	0
442	1	2	2	0	1	0	0	0	258	0	0	2	3
443	1	2	2	0	1	0	2	0	281	2	2	1	0
444	1	0	3	0	1	0	1	0	316	0	1	2	0
448	1	2	2	0	1	1	0	0	317	1	1.5	1	0
457	0	0	3	1	1	1	0	1	318	0	1	2	0
460	0	3	0	0	1	0	0	1	358	3	1.5	0	0
467	0	3	2	0	1	0	0	0	364	0	1	1	0
477	2	2.5	0	0	0	0	0	0	369	0	1	3	0
486	1	3	1	0	1	0	0	0	371	0	1	3	0
533	0	0	3	1	1	0	0	1	395	3	2	0	0
568	0	3	1	0	1	1	0	0	475	1	1	1	0
580	2	2.5	0	0	0	1	0	0	498	0	1	1	0
602	2.5	1	1	0	0	0	0	0	499	2	1	1	0
603	1.5	1	1	0	0	0	0	0	500	3	2	0	0
607	1.5	1	1	0	0	1	0	0	505	0	1	1	0
608	1.5	1	1	0	1	1	0	0	508	0	0.5	2	0
620	1.5	1	1	0	1	0	0	0	509	2	1	1	0
634	2.5	2	0	0	0	1	0	0	510	2	2	1	0
695	0	3	2	0	1	0	2	0	511	3	2	0	0
844	0	4	1	0	1	0	2	1	513	2	2	1	2
861	0	0	1	1	1	0	0	2	517	3	2	0	0
873	0	2	1	0	1	1	0	0	520	0	1	1	0

***Table A2.3** contd. Land Cover Scotland vegetation type (LCS88, MLURI 1993) and soil type (MISR 1984) at* Juniperus communis *record sites*.

LCS88 units and indices for sites characteristics									Soil type code and indices for site characteristics				
Vegetation code no.	Bogginess	Heather cover	Grass cover	Tree cover	Stability	Rockiness	Burning	Bracken	Soil type code	Peat cover	Wetness	Mineral cover	Alpine
890	0	2	1	0	1	0	0	0	521	2	1.5	1	0
912	1	3	1	0	1	1	0	0	522	2	1.5	1	0
928	0	1	1	3	1	0	0	0	532	2	2	2	2
933	1	3	2	0	1	1	0	0	533	2	1.5	1	3
948	0	3	0	0	0	1	0	0	549	2	1.5	1	0
1128	1	3	1	0	0	2	0	0	550	3	1.5	1	0
									561	0	0	2	2
									602	0	0	3	0
									606	3	1	0	0

APPENDIX 3: FIELD SURVEY SHEETS AND PROTOCOL

Site Name		Date	2008	Surveyor	Alt Max
Site no	Corner	WP	+/-		Alt Min
Grid refs (4 min) for outer limits				approx area of scrub	Weather on day:
					Time on site:

whole patch (5m rule)

Shrub distribution

Indiviual spacings	% area	ave Size	Group spacings	% area	ave Size
Sparse >3m			Sparse >4m		
Med <3>1m			Med <4>2m		
Clumped >0.5 <1m			Clumped >1<2m		
Continuous			Continuous		
Seedlings R O F A			Saplings R O F A		

Growth form
Additional info:

Stems	%		%
Single		prostrate	
Multi		Intermediate	
		Upright	
		lollipop	

Bare Ground Total % site:
Additional info:

tiny <10cm	R	O	F	A
small >10 <30 cm	R	O	F	A
Med >30cm <1m	R	O	F	A
Large >1m	R	O	F	A

Variation in moisture Must = 100%
Additional info:

	% SITE
Wet/standing water	
Moist	
Dry	

Land management		seen/fur/footprints	Fresh Dung	Old Dung
Grazing presence	sheep	R O F A	R O F A	R O F A
	deer	R O F A	R O F A	R O F A
	hares	R O F A	R O F A	R O F A
	rabbits	R O F A	R O F A	R O F A
	voles	R O F A	R O F A	R O F A
	Grouse	R O F A	R O F A	R O F A

Grazing Impact		Tall Shrubs	Dw Shr	G/S/H
		1 2 3 4 5	I II III	I II III
		1 2 3 4 5	I II III	I II III
		1 2 3 4 5	I II III	I II III
		1 2 3 4 5	I II III	I II III

Burning	YES	NO		current	recent	old
			% area			

Topographical variaion

	deg	% site	deg	% site	deg	% site	deg	% site
Aspect								
Slope								

Topex	degrees			
N				
NE				
E				
SE				
S				
SW				
W				
NW				

General desciption of site:
context, features e.g. rock outcrops, fences

for area < or = 1ha

Figure A3.1 *Field survey a) Sheet one applicable to the whole site.*

Sample points	**Date:**		**Site no**							
	1	2	3	4	5	6	7	8	9	10
Dominant species + % cover										
Sward Hgt										
Field layer										
2										
3										
4										
moss 1										
2										
3										
4										
Litter 1										
2										
3										
4										
Shrub Height										
Longest Horiz										
Perpendi horiz										
Stem no.										
Stem diam										
Leader lgth (mm)										
Growth form										
Browsing evid										
Browsing age										
flowering M/F										
Regen										
Soil Depth										
1										
2										
3										
4										
pH cores taken										

NVC 2 x 2 m square								
Species	Point no.	% cover	Species	Point no.	% cover	Species	Point no.	% cover

Figure A3.1 *contd. Field survey b) Sheet two applicable to ten sample points across the site*

Protocol: Site survey form: Tall shrub site characterisation

The first page of the form refers to the site, the rest to the patch if it is < I ha or to a 1ha area within a patch

Site is an area of scrub where the individual plants, or groups of plants are 5m or less apart. Within the patch the distribution may vary but doesn't exceed 5m spacing between an individuals and at least one neighbour.

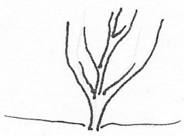
Grid ref of outer limits record the GR at points where there is a direction change as you walk round the site. This will references the outer limits of the patch in order to subsequently work out the centre point. Mark area on map. Include WayPoint no. from GPS & accuracy of each reading.

Shrub distribution if there are a range of distribtion types and groupings which are geographically separate indicate the main area on the map. Include an indication of seedling (< 3 years old) & sapling (>3 < 15 years old)

Growth form

prostrate

Upright



Intermediate

lollipop

Bare ground record large areas on map

Moisture variation record areas larger than 5% of site on map

Herbivore presence rare* occasional* frequent* abundant* Record for each species, for dung record whether Fresh or Old * See Table below for definitions

Grazing impacts: Give the animal responsidble for the main browsing damage and percentage of shrubs and ground vegetation showing evidence of grazing

	1	2	3	4	5
Shrubs	1 - 20%	20 - 40%	40 - 60%	60 - 80%	80 - 100%
Ground veg	1-30%	30 - 70%	70 - 100%		

Burning Current: aut 07 - sprin 08 **R**ecent: 1- 3 yr **O**ld: > 3yr

Topographical variation record % area where more than one type and show on the map

Protocol: Sample point & NVC survey form: Tall shrub site characterisation

An individual bush for sampling is the closest bush to the bottom left hand corner (from direction quadrat set out) (see overleaf). The individual is identified as a unit of stems which are all radiating from the same place when the stems are traced back along the ground from the aerial section. The non-bush measurements are made within each quadrant of a 2 x 2 m square at the sample point.

Shrub: height, horiz to accuracy of +/- 2cm. is OK

Stem no.: give no. of stems for the individual. Indicate the order of number of stems for multi-stemmed plants (>5 = 6 - 10; >10 = 11-20; >20=20 - ∞). In fact many plants are single stemmed or have a few stems but the branches join below the level of surrounding vegetation.

Stem diam.: measure the diameter of the main stems within 20cm of ground, avoiding irregularities, and old bud scars etc. For multi-stemmed plants measure all or the 5 largest, accessible.

Leader length Measaure the length of new growth on the leader, or average 5 of upper terminal shoots

Browsing evidence see grazing impacts system above, but estimate the percentage of shoots browsed

Browsing age record whether browsing is **N**ew (this season), **R**ecent (last 3 years), **C**ontinuous (>10years)

Flowering M/F if flowers/fruit are present record whether they are **M**ale &/or **F**emale, or **C**atkins or **B**erries

Regen: Record **Sa**plings or **Se**edling no. within plot

Sward heights measure field, moss and litter layer actual heights (to nearest 1 cm) in each quadrant of 2 x 2 quadrat. Do not include inflourescences if taller than surrounding veg.

Soil depth Measure soil depth in each quadrant of 2x2 m quadrat, up to 1m depth.

Figure A3.2. *Field survey protocol for completion of survey forms*

Dominant species for each sample point record the initials of dominant plants (up to 4) and a % cover figure for the whole 2x2 m square					
NVC 2x2 m square 1 Square per site - number 7 unless on an edge, in which case 6. Record all higher plants and known lower plants and their percentage cover (can be >100%)					
MAIN EQUIPMENT : **1:50,000 map** **GPS** **A4 MAP/Aerial photo if available**	**1 large bags** **4 med soil bags** **6 Bamboos**	**Caliper** **Clinometer** **Compass** **Camera** **Corer**		**2 x 2 m quadrat** **1.5m steel rod** **Steel ruler (30cm)** **Survey forms**	**trowel** **5m tape**
Sample point selection: 10 sample points will be selected for each site. Their location is dependent on the size of the sample patch. Once known and marked out the area will be divided systematically into transects and the points located at regular intervals, ie for a roughly triangular area 80 m by 40 m, 3 parallel transects can be drawn through the area 80, 50 and 35 m long which allow for 5, 3 and 2 sample points at 15 m spacings (see below). When identifying the layout of the grid for sample points care will be taken to account for any features which might be over represented in any transect (i.e. if a transect runs along a ridge). This can be avoided by offsetting some sample points by several metres from the transect to one side.					
Individual plant definition: An individual is a single or group of stems arising from the ground which is separate from another single or group of stems by 50 cm.					

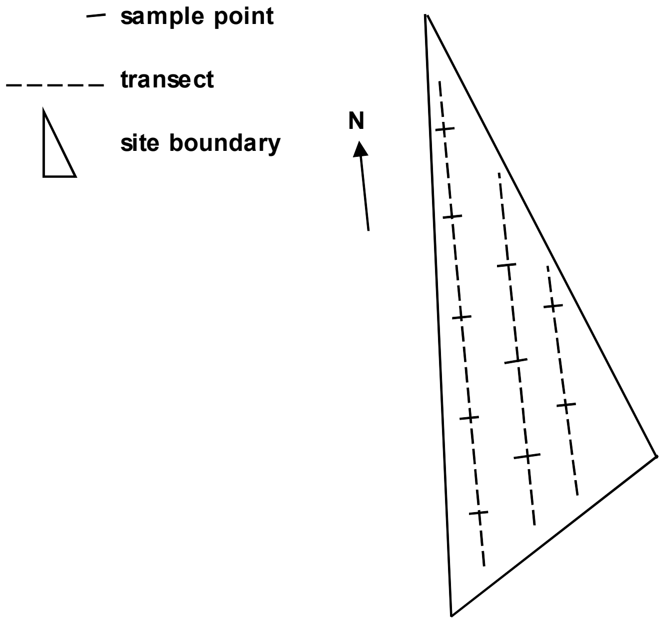


Figure A3.2 *contd. Field survey Protocol*

Table A3.1 *Guideline figures for estimating level of herbivore presence on sites.*

Herbivore / evidence	Rare (R)	Occasional (O)	Frequent (F)	Abundant (A)
Red deer, sheep / dung groups	< 3	3 – 8	9 – 15	> 15
Grouse / dung groups	< 3	3 - 5	6 – 10	> 10
Hares / dung	< 1 per 10 strides	1 per 5 – 10 strides	1 per stride	>1 per stride
Vole / holes	< 5	5 -10	11 - 20	> 20

APPENDIX 4: FIELD SURVEY DATA SHEETS

The data sheets listed below (4.1 to 4.10) refer to Excel (2000) worksheets available to download as a separate file. These contain the data collected during the relevant survey. Site and sample codes can be related to site names and locations in the sheet "2008SurveyRemoteSitedata" or in Table 2 of this report. The methodology for the collection and use of data in 2008 is contained in the body of the report. The methodology and protocols for collection of data in 2002-2003 is given in the pages which follow the list below.

4.1. 2008 Survey Site level data
4.2. 2008 Survey Soil data
4.3. 2008 Survey Sample data
4.4. 2008 Survey sub-sample data
4.5. 2008 Survey stem diameter data
4.6. 2008 Survey dominant species data
4.7. 2008 Survey Remote survey data
4.8. 2003 SNH Juniper survey data.
4.9. 2001 *Juniperus communis* ssp *nana* sites used in results
4.10. All species collated site characteristic table

A4.8 2002-2003 *Juniperus communis* Scotland wide sample survey protocols

A4.8.1 Selection of $1km^2$ for survey

All $1km^2$ in the $100km^2$ in which juniper of each type (woodland, open ground, prostrate) occurred were identified using the information obtained in the previous phase of survey. For each type (where more than one type occurred) one $1km^2$ was selected by means of pairs of random numbers, and this square was surveyed to ascertain the condition of the juniper therein.

A4.8.2 Recording of attributes

The attributes of sites and plants recorded in the field, and the method of recording them, are given below. The field recording sheets used for this phase of the survey, and the explanatory field notes used, are appended (Appendices 3 and 4). In addition to these field-recorded attributes, information was also obtained from topographical, geological, and soil maps.

A4.8.2.1 Environment of condition survey $1km^2$

Maximum, modal, and minimum altitude, maximum, modal, and minimum slope, and aspect, were determined on relevant 1:50 000 Ordnance Survey maps. Major and subsidiary geological types were determined using the relevant Geological Survey 1:625 000 map (British Geological Survey 1979), and soil class and major soil sub-group were determined on 1:250 000 soil maps (Macaulay Institute for Soil Research 1981). Major and subsidiary land uses were assessed in the field.

A4.8.2.2 Juniper presence

Total number of bushes was counted. In areas of dense juniper where individual bushes could not be easily discerned, the number of bushes was estimated based on the size of those examples of discrete bushes which could be observed.
The area of occurrence of juniper was estimated in the field where possible, or notes and grid references were recorded in order to allow the area to be estimated by subsequent reference to maps.
Juniper density was subsequently calculated by dividing total number of bushes by area of occurrence, omitting those sites in which area of occurrence was less than 0.1 km.
The area of dense juniper (more than 75% juniper canopy cover) was determined by means of the following procedure -

(a) Pick out any patches of continuous juniper involving more than one bush.
(b) By eye, imagine a tight boundary around each continuous patch and its nearest bushes or patches and estimate the juniper cover within this boundary.
(c) If the juniper cover falls below 75% then reject these additional nearest neighbours.
(d) If the juniper cover is greater than 75% repeat the process for the next nearest neighbouring bushes and/or patches.
(e) Continue in this way until all the “dense” patches have been determined and then estimate, by eye, their total area.

A4.8.2.3 Characteristics of ground where juniper is growing

Maximum, modal, and minimum altitude at which juniper was growing in the $1km^2$ square was determined by reference to the 1:50 000 topographical map on which juniper occurrences were recorded in the 100 000 km^2 phase of the survey. The percentage of the area on which juniper was found which was either:

- cliff or crag;
- broken rock or outcrop;
- block scree;
- fine scree;
- gravel, sand, and/or bare soil;
- not bare or rocky;

was estimated in the field. Percentage of the area which was convex slope, concave slope, and flat, was also estimated. Slope was recorded by estimating the percentage of the area which fell into the following classes:

- less than 1 in 3 (<18°);
- 1 in 3 to 1 in 2 (18°-26°);
- 1 in 2 to 1 in 1 (26°-45°):
- steeper than 1 in 1 (>45°)

A4.8.2.4 Attributes of the juniper population

Where there were less than 100 bushes in the 1 km^2 all plants were assessed for the characters given below. Where there were more than 100 bushes 5 subsample sites were selected using random numbers, and located using GPS. At each of these sites 20 bushes were assessed for these characters giving a sample of 100 plants. Many of the characters were recorded on the tally sheet which forms the second page of the field recording sheet (Appendix 3) and percentage values for each class were later calculated.

Plant width
Width of live prostrate bushes, defined as the greatest diameter of an individual in vertical projection, was recorded in the following size classes: <10 cm; 11-50 cm; 51-100cm; >100 cm.

Plant height
Height of woodland and open ground bushes was recorded, as was the height of the tallest and shortest bushes in the square whether in the sample or not. On steep ground and crags, where determining how to measure height can present difficulties, height was measured as the distance perpendicularly from the plane of the ground on which the plant is growing to the most distal part of the plant. The variation in height of the population was determined according to the definitions given in Table A4.8.1.

Table A4.8.1 *Definitions of height class variation descriptions for juniper populations in 1 km^2*

Variation description	Definition
Mostly similar	More than half of the plants within +/- one height class of the mode
Evenly dissimilar	More than half of the plants within +/- two height classes of the mode
Irregular	Less than half of the plants within +/- two height classes of the mode

Plant growth stage
Growth stage of juniper plants was recorded according to the definitions given in Table A4.8.2. It must be borne in mind that these definitions refer to physiological stages rather than chronological age, and that environmental factors influence the appearance of bushes.

Table A4.8.2: Definitions of growth stage of juniper individuals

Growth Stage	Definition
Pioneer	Seedling or sapling stage. Small bushes but usually growing vigorously, often with an open structure.
Building	Moderately sized, vigorous, well-branched bushes, with a full, dense canopy.
Mature	Bushes with canopy beginning to thin, but without dead or collapsed branches. Growth rate decreasing. Branches of prostrate bushes have not lost bark cover.
Old	Fully grown bushes but canopy thin, with dead branches and slow growth. May have collapsed branches. Branches of prostrate bushes may have lost some bark.

Plant shape
Plant shape was recorded according to the definitions given in Table A4.8.3 below.

***Table A4.8.3**: Definitions of juniper plant shape*

Plant shape	Definition
Columnar	Taller than broad and of relatively even width for most of its height, may taper towards apex or base.
Pyramidal	Triangular shape, wider at the base than the apex, which may not be distinctly pointed
Inverted Pyramidal	Triangular shape, narrower at the base than the top, which may not be completely flat. Equivalent to the shapes variously described as umbrella, vase, and fountain.
Low spreading	Broader than tall, with most visible branches growing at an angle of less than 20^0 to the ground but not prostrately.
Low upright	Broader than tall, of relatively even width for most of its height, with most visible branches growing at an angle of 20^0 or greater to the ground. May be some layering, or stems buried in litter.

While plant shape varies almost continuously, and therefore there will always be plants which are difficult to categorise, the descriptions below allow the variation to be reduced to a manageable number of categories. In a reasonably-sized sample, any effect of plants which are difficult to categorise is minimised.
Examples of these plant shape categories are illustrated in Plates 13-21 on the CD-ROM which accompanies this report.
Reproductive status
Reproductive status was recorded according to the definitions given in Table A4.8.4.

Table A4.8.4 *Definitions of reproductive status for juniper plants*

Reproductive status	Definition
Male	Male stroboli present. These may persist on the plant for considerable periods following pollen dispersal, particularly in sheltered situations such as in woodland.
Female	Female stroboli present. On mature females producing seed annually, stroboli at some stage of development will be found at all times of year.
Apparently sterile	Plant at a more advanced growth stage than pioneer, but without male or female stroboli at a time of year when male stroboli could be reasonably expected to be present as indicated by their presence on nearby bushes of comparable growth stage.
Indeterminate	Without male or female stroboli at a time of year when male stroboli could not be reasonably expected to be present.

A4.8.2.5 Impacts on plants

Damage to juniper bushes by browsing
Browsing damage to each growth stage of plants was recorded according to the categories in Table A4.8.5.

Table A4.8.5*: Browsing impact classes recorded on juniper individuals*

Impact Class	Definition
High	Bark stripping may be present. Most of most recent year's shoots removed on browsed shoots. Nearly all shoots browsed, almost immediately obvious. May have a rounded and densely branched appearance like a garden "topiary" bush.
Medium	No bark stripping (except possibly by rabbits).Only tips of most recent years shoots removed. Large proportion of shoots browsed but unbrowsed shoots can still be found.
Low	No bark stripping. Browsed shoots difficult to find.

Shoots were defined as the last complete year's growth. During the summer new shoot growth may be unbrowsed and this may obscure heavy browsing on the last full years shoot growth.
Any summer browsing is potentially serious and was recorded where present.

Presence of browsers
Evidence, in the form of sighting, dung, tracks, or burrows, of the presence of red deer, roe deer, cattle, sheep, horses, goats, sheep, hares, rabbits and voles was noted, and where the relative importance of these mammals as browsers of the juniper could be determined they were ranked.

Fire impact
Plants in each growth stage which were killed or severely scorched by fire were recorded.

Evidence of other types of damage
Damage resulting from other causes was recorded using a scheme devised by Forest Research. The scheme was designed to detect damage caused by snow break, shading, the fungal agents *Heterobasidion annosum, Gymnosporangium cornutum,*

Gymnosporangium clavariiforme, Lophodermium juniperi, Didymascella tetraspora, Phomopsis juniperovora, Seiridium cardinale, and *Kabatina juniperi,* the insects *Carulaspis juniperi*, *C. minima*, *Dichomeris marginella, Argyresthia dilectella,* and *Cinara juniperi*.
In addition, the presence of galls caused by *Oligotrophus* spp. was recorded.

A4.8.2.6 Habitat

Area of relevant broad habitat
The area of relevant broad habitat within the 1 km^2 was assessed. This was defined as the area which was similar in vegetation composition and in topography (where relevant) to the area in which juniper was growing. Thus where prostrate juniper was found growing only in short, wind-clipped vegetation on exposed spurs, ridges and summits in a square, then the total area of this type of vegetation was defined as relevant. For woodland juniper the area of woodland was defined as the relevant area, although where for example juniper was found in birch woodland in a square but not in conifer plantation in the same square only the area of birch woodland was defined as relevant. In cases where juniper was growing in heath only on crags and burnsides inaccessible to browsers, although the area of heath may be much greater than the area of crags and burnsides, only the latter area was defined as relevant. The area was assessed in the field or by making observations in the field and later determining it by the use of maps.

The characteristics of the associated vegetation
The composition of the vegetation associated with the juniper was assessed by determining the percentage of that vegetation which was dominated by a smooth sward of grasses and/or sedges, tussock grasses or sedges, dwarf-shrubs, ferns, mosses, lichens, and trees and shrubs taller than the juniper. Dominant or co-dominant species, and species which formed significant components of the vegetation or were of special interest, were also recorded.

A4.8.2.7 Management attributes

The proportion of juniper in the square which was fenced against rabbits or hares, sheep, cattle or ponies, and deer or goats, was estimated. The effectiveness of the fence was assessed from evidence of fence breaks, evidence of access into the juniper by herbivores such as droppings, recently used tracks, and evidence of browsing on the juniper bushes. Where fences were present in order to manage grazing in the area in which juniper was present rather than to prevent access to juniper this was also recorded.

Evidence of burning, at any time or recently, was recorded for each juniper growth stage and for the area of relevant broad habitat. This was expressed as the percentage of each category exhibiting such evidence. Recent burning was indicated by the presence of powdery charcoal still present in incompletely burned sticks of heather and juniper, with some bare ground or bare plant litter still present, and an incomplete cover of regenerating vegetation. Burning at any time was indicated by vegetation structure. It should be borne in mind that the impact of burning in the past can be difficult to distinguish from the impact of chronic grazing, and indeed these two impacts have often co-occurred.

A4.3 SCOTTISH JUNIPER SURVEY 2002

RECORDING FORM 2: FIELD CARD 1km² Surveyor: Graham Sullivan

Sample information

100 km² Name		100 km² Gridref			Date						
1 km² Name		1 km² Gridref					1 km² Type	P	U	W

General location description

	Maximum	Mode	Minimum
Altitude			
Slope			
Aspect			
Geology			
Soils			

Description of current land use **Reference sketch**

Juniper presence

No. of bushes	Area (ha) of occurrence	Dense area (ha)	Dense patch >1000 bushes?	Other dense patch within 200m of ≥ 50% of patches?

Characteristics of ground where juniper is growing

	Highest	Mode	Lowest
Altitude			

	%		%
Cliff		Convex slope	
Broken rock		Concave slope	
Block scree		Slope less than 1 in 3 (< 18°)	
Fine scree		Slope 1 in 3 to 1 in 2 (18°– 26°)	
Gravel, sand and/or bare soil		Slope 1 in 2 to 1 in 1 (26° – 45°)	
Not bare or rocky		Slope steeper than 1 in 1(> 45°)	

Character	**Sub-sample tally**					
	1	**2**	**3**	**4**	**5**	Total
Width (P)						
<10 cm						
10-50 cm						
50-100 cm						
>100 cm						
Height						
<10 cm						
10-20 cm						
20-30 cm						
30-40 cm						
40-50 cm						
50-100 cm						
100-150 cm						
150-200 cm						
200-300 cm						
300-400 cm						
400-500 cm						
>500 cm						
Shape-						
Columnar						
Pyramidal						
Inverted pyramidal						
Low spreading						
Low upright						
Growth Stage						
Pioneer						
Building						
Mature						
Old						
Dead						
Sex						
Male						
Female						
Sterile(apparently)						
Indeterminate						
Browsing						
Pioneer H						
M						
L						
Building H						
M						
L						
Mature H						
M						
L						
Old H						
M						
L						

Width of live **prostrate** bushes (cm)	0 – 10	10 – 50	50 –100	≥100
% of bushes in each category				

	Tallest	Mode	Shortest
Estimated height of juniper bushes (cm)			

	Mostly similar	Evenly dissimilar	Irregular
Variation in height			

Growth stage	Pioneer	Building	Mature	Old	Dead
% bushes in each category					

Shape of bushes	Column	Pyramid	Inverted pyramid	Low spreading	Low upright	Prostrate
% bushes in each category						

	Cones present		**Cones not present**	
	Male	Female	Sterile	Indeterminate
% bushes in each category				

Browsing impact - % of bushes in each growth stage affected

	High	Medium	Low	Summer
Prostrate				
Pioneer				
Building				
Mature				
Old				

Field evidence for the presence of herbivores.(1,2,3 etc. to indicate decreasing importance of impact as browsers of the juniper)

Red deer	Other deer	Cattle	Horses	Goats	Sheep	Hares	Rabbits	Voles

Fire impact % of bushes in each growth stage killed or severely scorched

Prostrate	Pioneer	Building	Mature	Old

Evidence of damage by insects, fungi or disease
% of bushes showing the following symptoms

1	a		b		c		d							
2	a		b											
3	a													
4	a		b		c		d		e					
5	a i		a ii		a iii		b i		b ii		b ii		c	

If 5c describe symptoms

Area of relevant broad habitat (ha)

Area of relevant broad habitat (ha)	

	Tallest	Mode	Shortest
Vegetation height excluding juniper Field layer (cm)			

	Mostly similar	Evenly dissimilar	Irregular
Variation in height of field layer			

	Tallest	Mode	Shortest
Height of any trees and shrubs, other than juniper (m)			

	Mostly similar	Evenly dissimilar	Irregular
Variation in height of trees/shrubs			

Composition of the associated field layer, shrub and/or tree vegetation

Dominated by	%	List dominant or codominant species
Smooth sward of grasses and/or sedges		
Tussocky grasses or sedges		
Dwarf-shrubs		
Ferns		
Mosses		
Lichens		
Trees and shrubs taller than the juniper		

Management attributes of the area where the juniper is growing

What % of the juniper is fenced against any or all of these herbivores ?

	Rabbits/Hares	Sheep	Cattle/Ponies	Deer/Goats
Fences present				
Fences effective ?				

What % of the juniper, and of the total area of relevant habitat, shows evidence of having been burned ?

	Prostrate	Pioneer	Building	Mature	Old	Relevant habitat
At any time						
Recently						

A4.4 SCOTTISH JUNIPER SURVEY 2002

RECORDING FORM 2: FIELD CARD 1km^2

<u>Field Reference Note</u>
This note is intended for use as an aid to completing the Field Card.

Basic information (Sample information and General location description) can be recorded before field recording begins, from published maps and information obtained on previous visit. **Shaded boxes** must be completed in the field. Remaining boxes can be completed later by summarising information recorded in the shaded boxes.

Page 1

Sample information
P= prostrate juniper
U=upright juniper in open ground
W=upright juniper in woodland

Description of current land use
Record, for example, where stock are grazed and describe, where possible, the numbers of stock which have access to the juniper areas, what total area they have to forage over, and what times of year they are present (if the area is deer range an estimate of deer density would be valuable). In woodland indicate, where possible, if the area has been thinned, felled or restocked or if there are plans to undertake any of these operations.

Reference Sketch
Sketch square indicating approximately major features, and juniper extent, and other useful points.

Juniper presence
Total number of bushes – where possible count number of individuals. This may be difficult to assess for areas of dense juniper since individual bushes may not be easily discerned. In this case, estimate the total number based on the size of those examples of discrete bushes which can be observed.
Area of dense juniper (more than 75% juniper canopy cover) - The intention here is to record areas of continuous or almost continuous juniper canopy. You first must decide what a dense patch is and where dense patches occur as follows.
(a) Pick out any patches of continuous juniper involving more than one bush.
(b) By eye, imagine a tight boundary around each continuous patch and its nearest bushes or patches and estimate the juniper cover within this boundary.
(c) If the juniper cover falls below 75% then reject these additional nearest neighbours.
(d) If the juniper cover is greater than 75% repeat the process for the next nearest neighbouring bushes and/or patches.
(e) Continue in this way until you have defined all the “dense” patches and then estimate, by eye, their total area.

Page 2

Sub-sample Tally
Where there are less than 100 bushes all should be assessed for the characters on the Tally sheet and the columns can be ignored. Where there are more than 100 bushes 5 random subsamples each of 20 bushes should be assessed for these characters.

Width of prostrate bushes
Greatest diameter in vertical projection. Record size class of individuals

Height of bushes
Record size class of individuals. Record also the tallest and shortest bushes whether in sub-sample or not (on Page 3).

Shape

Columnar	Pyramidal	Inverted Pyramidal	Low spreading	Low upright
Taller than broad and of relatively even width for most of its height, may taper towards apex or base.	Of triangular shape, wider at the base than the apex, which may not be distinctly pointed	Of triangular shape, narrower at the base than the top, which may not be completely flat. Equivalent to the shapes variously described as umbrella, vase, and fountain.	Broader than tall, with most visible branches growing at an angle of less than 20^0 to the ground but not prostrately.	Broader than tall, of relatively even width for most of its height, with most visible branches growing at an angle of 20^0 or greater to the ground. May be some layering, or stems buried in litter.

Growth stage

Pioneer	Building	Mature	Old
Seedling/sapling stage. Small bushes but growing vigorously	Moderate sized, vigorous, well branched bushes, with a full, dense canopy	Full grown bushes, canopy beginning to thin, growth rate decreasing.	Full grown bushes but canopy thin, dead branches, slow growth

Growth stages will not be easy to assess for prostrate juniper although an assessment of the proportion of live to dead bushes should at least be made.

Sex
Indeterminate – without male or female stroboli at a time of year when male stroboli could not be reasonably expected to be present.
Apparently sterile – bush at a more advanced growth stage than pioneer, but without male or female stroboli at a time of year when male stroboli could be reasonably expected to be present as indicated by their presence on nearby bushes of comparable growth stage.

Damage to juniper bushes by browsing

High	Medium	Low
Bark stripping may be present Most of most recent year's shoots removed on browsed shoots. Nearly all shoots browsed, almost immediately obvious.	No bark stripping (except possibly by rabbits). Only tips of most recent year's shoots removed Large proportion of shoots browsed but and can still find unbrowsed shoots.	No bark stripping Browsed shoots difficult to find.

Shoots here refer to the last complete year's growth. The most heavy browsing is likely to occur over the winter when more palatable browse is least available. If this happens repeatedly the bush will have a rounded and densely branched appearance like a garden "topiary" bush. During the summer new shoot growth may be unbrowsed and this may obscure how heavily browsed a bush really is. You should take care to avoid being misled. Any browsing of juniper during the summer is potentially serious and should be recorded.

Page 3

Evidence of damage by insects, fungi or disease symptoms

1 Whole bush dead (bush is evenly brown colour overall) and possibly breaking up
  - a At base of bush there is herbivore damage causing girdling of the main trunk
  - b Fungal fruit bodies present at the base of the bush
  - c Bush shaded out
  - d None of the above

2 Section of the bush dead (section evenly brown colour overall)
  - a Evidence that the brown section is broken off
  - b None of the above

3 a Section(s) of the stem(s) swollen (up to 2 times thicker than the rest of the stem); foliage green above and below the swelling, but side branches from the swollen part of the stem are dead; orange-yellow out growths may be present on the swollen part of the stem (most evident in May/June).

4 Shoot die-back present, causing evenly brown colour of some of the terminal shoots.
  - a Lesions (areas of discoloured tissue) present on shoot at the point where browning starts
  - b Evidence of insect damage (chewed bark) causing girdling of the shoot at the point where browning starts
  - c Obvious small white scales, 1.0 - 1.5 mm diameter, pale with a yellowish spot off centre, present on the foliage
  - d Mined holes in the needles (September); dense silk web present (May/June)
  - e None of the above

5 Individual needles have blotched or mottled appearance; discoloration distributed evenly throughout bush and is not limited to one branch
  - a Needles damaged with one or more of the following: holes, notches, hollow needle (disintegrates on touch)
    - i Needles and shoot tips mined/hollow and /or silk cocoons on undersides of the needles
    - ii Mined holes in needles (September); dense silk web present (May/June)
    - iii Neither (i) nor (ii)
  - b No evidence of holes, notches or hollowed-out needles
    - i Aphids present
    - ii Obvious small white scales, 1.0 - 1.5 mm diameter, pale with a yellowish spot off centre, present on the foliage
    - iii Neither (i) nor (ii)
  - c None of the above

For the purposes of these symptoms, shoots are arbitrarily defined as stems less than 5 mm in diameter.

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The area of relevant broad habitat

The area assessed should be relevant to the type of juniper present and being recorded. For prostrate juniper only the area of short, wind-clipped vegetation on exposed spurs, ridges and summits will be relevant. This may be quite a small proportion of the total 1 km^2 sample square. Similarly, for woodland juniper the area of woodland may be quite limited. The total relevant area should be recorded.

The characteristics of the associated vegetation

Mostly similar	Evenly dissimilar	Irregular
More than half of the vegetation within +/- one height class of the mode	More than than half of the vegetation within +/- two height classes of the mode	Less than half of the vegetation within +/- two height classes of the mode

Composition of associated vegetation
In addition to dominant or co-dominant species, record in parentheses species which form significant components of the vegetation or are of special interest.

Management attributes of the area where the juniper is growing
Not all the juniper may be fenced so assess what proportion falls within the fenced area. Also, assess the effectiveness of the fence from any evidence of fence breaks, access into the juniper by herbivores .e.g. recently used tracks, droppings), evidence of browsing on the juniper bushes. Record also if fences are present in order to manage grazing in the area in which juniper is present rather than prevent access to juniper.

Recent burning is defined by the presence of powdery charcoal still present in incompletely burned sticks of heather and juniper, some bare ground or bare plant litter still present, and an incomplete cover of regenerating vegetation. It usually takes (2) - 3 - (4) years for powdery charcoal to weather off incompletely burned sticks.

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