INTERACTIONS BETWEEN CLIMATE AND LAND USE WHICH DRIVE DYNAMICS IN TREELINE ECOTONE SCRUB IN SCOTLAND

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Supported by:

"Field biology is not like other sciences. Its' raw data is chaotic, emotional, wilful, often unrepeatable. Subject and observer alike are battered by weather and accidents and the sheer unpredictability of living things. Its progress can be profoundly influenced by what is happening in the next field, which in turn can be an expression of political and economic decisions made a continent away."

Richard Mabey, The Guardian, Saturday 14 March 2009

DECLARATION

I hereby declare that this thesis has been composed by myself and none of the work reported here has been accepted in any previous application for a degree. The work has been performed by me and all help received and sources of information have been acknowledged. All quotations have been distinguished by quotation marks.

Diana Gilbert

ABSTRACT

Treeline ecotone scrub, the suite of tall woody plant communities that bridge the boundary between tall forest and higher altitude open summit heaths, is a rare and little studied transition habitat in the UK. Individual species have recently attracted emergency measures to secure their future, but little is known about the current dynamics of the habitats. This thesis increases knowledge of treeline scrub dynamics, particularly in relation to young plants, and develops an understanding of the management required for future conservation. Climate and land use are the main drivers of treeline scrub dynamics, while land use policy will shape the future land use.

This study focussed on three species: *Betula nana, Salix myrsinites* and *Juniperus communis,* as representatives of the main scrub communities.

Firstly, the range of environmental conditions and the current land uses the species tolerate were surveyed for a large number of sites. This enabled the existing sites to be characterised to inform the selection of potential new sites for restoration.

Secondly, experiments tested the response of young plants to the interaction between wind exposure and simulated browsing, and, separately, to over-wintering under snow. No evidence was found to suggest that declining snow cover will adversely affect the species, but while the response of the species to increasing exposure and browsing was complex heavy browsing is likely to limit expansion in the absence of specific management.

Finally, a review of current land use policy identified that treeline ecotone scrub was included in existing implementation strategies. However, a survey of the understanding of and attitudes to these habitats by key individuals involved in creating, implementing and influencing policy demonstrated that restoration is unlikely to happen within the current structure, except through the interests of non-governmental organisations with a nature conservation focus.

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In memory of Paddy Dog, constant companion on the hill.

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Chapter one: INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

Natural boundaries between different vegetation types, where there is a change in plant life-form (e.g. from trees to short grassland), tend by their nature to be dynamic areas. These "ecotones" (Tansley 1939) or transition areas can be extensive and tend to be highly visible in the landscape. They have received increasing focus over the past decade (Risser 1993, Hester and Brooker 2007, Crawford 2008) because they are frequently highly diverse, more so than the two communities they straddle (Hester and Brooker 2007), and importantly they may be responsive to external changes to their environment making them useful as indicators. One such major boundary, the treeline, is the zone in which a forested landscape gives way to more open vegetation due to increasing exposure at higher altitude or latitude. In this zone trees are no longer able to grow to full stature, becoming increasingly small and scattered. Plants of a different life-form take their place and, depending on the particular geography of a site, might include tall and / or dwarf shrubs, and grasses and sedges. Historically, along with the rest of the landscape, this boundary area, particularly at high altitude, has been valued by humans and wild herbivores for grazing and has been subject to manipulation. Therefore areas which exhibit the full range of altitudinal vegetation succession are increasingly uncommon. In the UK this "treeline zone" is virtually absent as a result of many hundreds of years of heavy grazing and forest decline.

This thesis focuses on the tall woody vegetation that grows in the treeline zone in the UK. It is very scarce, fragmented and currently its dynamics are poorly understood. The factors that control the altitudinal or latitudinal position of the treeline have attracted much attention, (e.g. McConnell 1996, Grace and James 1993, Grace *et al*. 1989, Grace 1989, 1987, Barclay and Crawford 1984, 1982, Pears 1968). Climate change has drawn particular attention to the treeline zone because responses to global warming are already being reported (for example Aas and Faarlund 1996, Sturm *et al.* 2001, Kullman 2002, Lloyd 2005, Walther *et al.* 2005, Crawford 2008). In the UK this zone includes a range of tall-shrub species many of which are growing towards the southern edge of their global distributions (Myklestad & Birks 1993, Jalas and Suominen 1996). Although there is much published literature about some of these species from their arctic habitats (Bliss 1971, Bell and Bliss 1980, Chapin 1983, Jones *et al*. 1999, Wahren *et al.* 2005) there is little information about their history or the current factors controlling their growth in the UK (Tipping 2003, Thompson *et al.* 2002, Hester 1995). A better understanding of the dynamics of the existing populations and factors affecting them will enable decisions to be made about their future in the Scottish mountain landscape and other similar non-arctic environments in their natural range.

In the following sections this introduction addresses what the treeline zone is, why it is important and what information would aid its management in the UK.

1.2 THE TREELINE ECOTONE: DEFINITIONS AND TERMINOLOGY

The treeline ecotone has attracted much attention from research over a long period of time and across most of the main continental massifs. As a result a varied terminology has developed and different definitions for elements of the vegetation have arisen. A number of authors have reviewed the literature (e.g. Körner 1998, Wieser and Tausz 2007, Crawford 2008), but have not clearly identified a common terminology, and the potential for confusion between different studies remains. Most recently Holtmeier (2009) thoroughly reviewed the terminology used in the treeline zone and this section focuses on elements relevant to this thesis and identifies the terms that have been used in it.

1.2.1 High elevation, altitudinal or latitudinal treelines

Throughout the world, with an increase in altitude or latitude, a gradual change in the environment occurs reaching a critical level where the climate conditions no longer allow for normal vertical growth (Grace 1989). This boundary has attracted the attention of scientists from around the world for over a hundred years but is still not fully understood (Körner and Paulsen 2004). Terminology is also inconsistently used (Figure 1.1) and it was considered useful to review the most common definitions in the literature. In Scandinavia the "tree limit" tends to be used in research and is defined as the altitude of the uppermost tree with a minimum height of 2 m (Kullman 1991, 1993, Hofgaard 1997, Dalen and Hofgaard 2005). However, Aas and Faarlund (1996) suggested that different tree species have different minimum heights to qualify as trees (conifers 5 m and birch 2.5 m). Weiser and Tausz (2007) make the case that tree limit is usefully defined "as the upper limit of trees, *krummholz* and shrubs higher than 2 m". In North America the term "timber-line" is used (Griggs 1946, Smith *et al.* 2003), and was also adopted by Crawford (1989, and in his review "Plants at the Margins" 2008). The use of timberline in this context appears to be very similar to that of "treeline" used across much of Europe (Körner 1998, and others, Figure 1.1). '*Krummholz*' is a German word in common usage (Grace 1989) which describes the vegetation above the treeline where tree species are stunted and are increasingly scattered (Crawford 1989). This use of "*Krummholz*" was challenged by

Holtmeier (1981) who uses it precisely for the treeline scrub in Europe composed of the genetically stunted *Pinus mugo* Turra var. *prostrata* and *Alnus viridis* (Chaix.) D.C. In contrast again, Wieser and Tausz (2007) specifically use *Krummholz* to describe the environmentally stunted forms of tree species, reserving the word “scrub” for genetically dwarfed, or shrubby species.

What is a tree?

There appears to be no consensus on the definition of a tree in studies to explain the functions that control the treeline. As already noted the Scandinavians use a minimum height of 2 m to define a tree (Kullman 1991). The Global Forest Resources Assessment 2005 report (FAO UN 2006) used 5 m as the minimum height for mature trees included as forest. Körner (1998) has defined a tree as an individual with a dominant above-ground stem of at least 3 m “This height ensures that such a tree would have its crown closely coupled to the prevailing atmospheric conditions” (Körner 1998) and normally would not be completely covered by snow. Again Weiser and Tausz (2007) suggest that at 2 m a tree crown is exposed above the snow and coupled to the atmospheric climate. Wilson *et al.* (1987) contrasted the relationship between the meristem and atmospheric temperatures of trees of 15 m – 18 m height, below the forest line (Fig 1.1.) with the same relationship in open ground dwarf shrubs of less than 1 m height above the treeline in the Scottish mountains. They showed that in the trees the temperatures where generally closely correlated, whereas in the dwarf-shrubs there was little relationship on sunny days and the meristem experienced temperatures with a larger diurnal range than the atmosphere. Grace *et al*. (1989) used different data collected in the same study to show that the meristems of Krummholz *Pinus sylvestris* L. plants of between 1 and 4 m height also varied “appreciably” from the atmosphere. It is demonstrated by Wilson *et al*. (1987) and Grace *et al*. (1989) that the relationship between atmospheric temperature and that of the meristem varied with the weather. If it were possible to identify a tree height above which, for given common summer atmospheric conditions the tree meristem temperatures were coupled to atmospheric temperature this might provide a common definition of the treeline boundary.

Tree-line temperature definitions

Grace (1977) collated data on the annual cycle of temperatures from treelines in New Zealand, North America, and Europe, including Scandinavia and Britain showing rough agreement across all areas of a summer warmest month mean temperature of 10°C. This confirmed previous reports of work by Daubenmire in 1954 in the North American Rockies, and Koppen’s rule quoted by Crawford (2008). Subsequent species- or location-specific studies (e.g. *Picea marina* Bonan and Sirois 1992, *Betula pubescens* Ehrh. ssp *czerepanovii.*

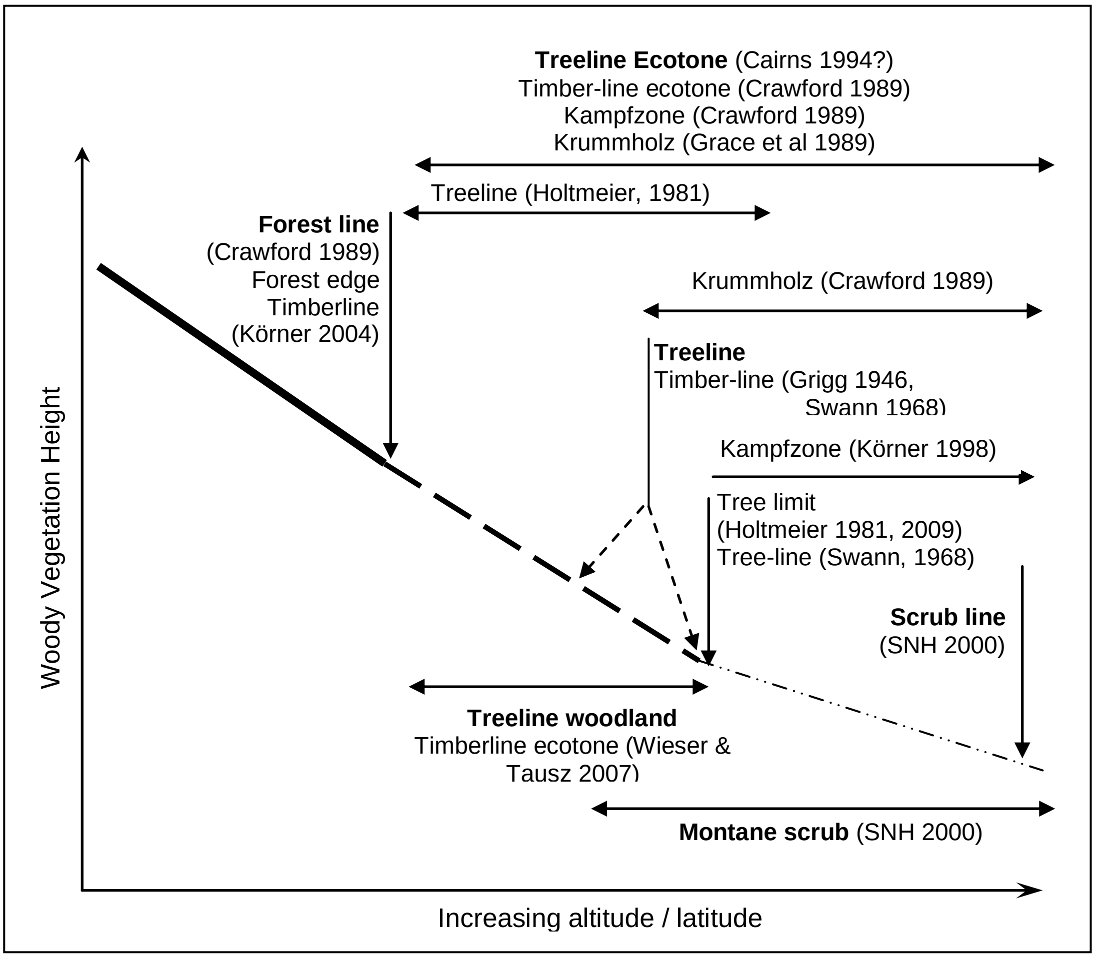


Figure 1.1 Diagrammatic illustration of the main different terms and definitions of the forest / open ground biome boundary (after Crawford 1989, Körner 1998, 2004, Holtmeier 1981, 2009, SNH 2000). Names in **bold** are those adopted in this thesis.

Kullman 1991) have also suggested the 10°C isotherm as a defining temperature. The current understanding of the functional controls of treeline position was usefully reviewed by Körner (1998), who acknowledged that the precise controls were still to be identified. More recently Körner and Paulsen (2004) re-assessed the temperature parameters common to treeline positions around the world, and made the case for an indicative mean root–zone (10 cm below ground surface) temperature of 6.7 ± 0.8° C for the "growing season" which they defined as the period between when the root-zone temperature first exceeds 3.2°C after winter, or a cooler period as in low latitudes, and when it first drops below 3.2°C following warmer weather. To make their case Körner and Paulsen (2004) used data from mainland continent areas where the treeline was climatically controlled and not anthropogenically, edaphically or artificially depressed in anyway. The data ranged from 700 metres above sea level (m asl) at 68°N above the arctic circle in Sweden, to over 4000 m asl at 19°N in Mexico, with many areas in between. The UK was excluded because it is an oceanic island and so untypical (Körner and Paulsen 2004). Sveinbjörsson (2000) also excluded oceanic sites from his review of current knowledge of factors controlling treeline position. Körner and Hoch (2006) have subsequently demonstrated that cold soil temperatures (10 cm below surface) restrict tree growth regardless of the actual mechanism involved. They postulate that temperatures around either the root or shoot meristem are the overriding determinants of tree growth (see also Grace *et al.* 1989).

Essentially, there is agreement between authors that the treeline is an important boundary separating the forest zone from the open heaths and grasslands. There also appears to be reasonable agreement that temperature can be used as an indicator of the location of the boundary. The detail of which temperature parameter gives the most accurate location has not been agreed, nor the precise mechanism that cold temperature is controlling. **In this thesis treeline is used to refer to the zone in which tree species no longer reach 2 m.**

1.2.2 Treeline woodland

This term in this thesis refers to the areas composed of stunted trees above the forest or timber line (Figure 1.1). The component tree species of treeline woodland are those present in the lower forest that can continue to grow in the adverse conditions at higher altitude and they vary around the world according to the particular flora of an area. Although there are not many species they do span a wide taxonomic range and it is interesting that they all experience limitations to growth at roughly the same atmospheric temperature. Swann (1967) points out that the taxonomic groups include *Nothofagus, Podocarpus, Philippia, Erica, Polylepis, Picea, Pinus, Betula, Abies, Rhododendron, Eucalyptus* and tree ferns. Generally these woodlands tend to coniferous, except at the high latitudinal extremes where a number of deciduous species are present (Bliss 1971, Crawford 2008). The particular types found in the UK and Europe are summarised below (section 1.4).

1.2.3 Montane scrub

Associated with treeline woodland, in some parts of the world, are a variety of tall-shrub species. These are usually more tolerant of the increasingly extreme climatic conditions and extend from beyond the treeline up to the scrubline (Figure 1.1). The plants included would be classified in Raunkiaer’s life form system as nano-phanerophytes (Tansley 1939) and normally grow between 0.25 m and 2 m. The tall-shrubs grow mixed with the tree species in a nearly continuous canopy at the lower edge, becoming increasingly broken into scattered clumps in mixture with dwarf-shrubs and graminoids (grasses and sedges) at the upper. This relatively open mosaic is called montane scrub in the UK (Scott 2000). Globally, montane scrub occurs at high altitude and high latitude and is considered a climatic climax vegetation type (Tansley 1939). Individual shrubs in Sweden have been aged at over 200 years

(Kullman, 1991). Generally, in mountain areas it forms a relatively narrow band intermixed with the upper edge of treeline woodland. There are exceptions to this and in the Colorado mountains constitutes 30% of the alpine zone (Bliss 1971). In northern latitudes this tall scrub vegetation can be extensive covering square kilometres of ground (Bliss 1971). There are a number of woody species which grow in the treeline zone, for example *Salix herbacea* L. (Least Willow), which are chamaephytes (following Raunkaier's definitions in Tansley 1939), keeping their over-wintering buds very close to ground level and prostrate (less than 0.5 m tall), enabling them to grow well beyond the scrubline. There are also a number of tall herbaceous plants, for example *Lobelia deckenii* Hemsl., which grow in tropical and sub-tropical mountains spanning the treeline ecotone and higher alpine pastures (Crawford 2008). Neither of these groups of plants is included in this definition of montane scrub because they survive in the more extreme conditions of the high alpine, and increased latitude of the arctic.

1.2.4 Treeline ecotone scrub

The term Treeline Ecotone Scrub as used in this thesis includes both treeline woodland and montane scrub as defined above and in Figure 1.1. For ease of reading treeline ecotone scrub is referred to as 'treeline scrub'. Specifically the Treeline Ecotone is the boundary zone between the forest limit (Crawford 1989), or top of the closed canopy forest, and the top of the *Krummholz* as defined by Crawford (1989), or scrubline (Scott 2000) where tall woody vegetation disappears. Tall woody vegetation is that which, in this zone, normally grows between 0.5 and 2 m tall.

1.2.5 The Treeline ecotone in the UK: Summary

The altitude at which the treeline ecotone occurs in the UK is included in the area of land generally referred to as the uplands. The uplands are defined as the hills, moors and mountains above the limits of enclosed farmland (Ratcliffe and Thompson 1989). They encompass the majority of the agricultural area defined in European agriculture policy terms as of Less Favoured Area Status, attracting many different levels of subsidy (EU Agriculture and Rural Development, 2009).

1.3 TREELINE ECOTONE SCRUB

The treeline ecotone spans the boundary between the forest zone and the higher open vegetation, and as the transition between them includes characteristics from both. The predominant characteristics at a given point in the transition relate to the proximity of either major zone. This transition is also between the relatively benign conditions of the forest zone and the more extreme climate of the true arctic or alpine zone. Generally the plants that inhabit such areas are either tolerant of the conditions (Grime 2001) or adapted to grow well and would normally do less well in different conditions (Bliss 1971, Crawford 2008). This section briefly appraises the conditions found in this zone, followed by a review of the plant strategies for overcoming them. Most of the available literature has focused on tree species at the treeline, tall-shrub growth at high latitudes or other plants growing in the higher alpine zone. The focus here is those factors which are particularly relevant to the treeline zone in Europe and the UK.

1.3.1 Treeline ecotone: Biogeographic characteristics

Treeline ecotone scrub exists in both the arctic and alpine regions and, although factors controlling growth may be similar, there are broad differences between the conditions and the vegetation in each area that are worth noting. This is relevant because in some respects the UK exhibits aspects of both. There are no vegetated areas in the Antarctic which compare with the extensive arctic vegetation (Bliss 1971) and so it is not considered here. The arctic treeline ecotone occurs on circumpolar land masses up to 72° north (Swann 1967) above which the conditions become unsuitable for forest. The characteristics of this ecotone have been summarised by Holtmeier and Broll (2005) as a mix of both the forest and open tundra, strongly influenced by the mosaic of vegetation of different statures. This mosaic, itself influenced by the climate conditions, creates small-scale variation in the distribution of different climatic effects such as humidity, snow cover and insolation (**in**cident **sol**ar radi**ation**), as well as variations in soil cover and soil moisture. A highly textured micro-topography increases the overall variability. The vegetation of the ecotone is increasingly fragmented with increasing latitude. The canopy of the scattered and stunted tree species forms a mosaic with an increasingly dominant and extensive tall-scrub composed of species from *Salicaceae*, *Betulaceae* and *Cupressaceae* (Crawford 1989, Holtmeier and Broll 2005). Despite this micro-scale variation the landscape is characterised by expanses of uniform landscape facilitating free migration of plants across it (Wright and Osburn 1967) and a relatively young, and species- poor, vegetation as a result of the last ice age in the Pleistocene (7 to 15 thousand years ago). By contrast alpine areas are highly variable. These high altitude treeline ecotone habitats are present on all the major mountain ranges across the globe and are characterised by a highly diverse regional level topography, creating small-scale local soil and climate variations, including local strong wind effects and nocturnal temperature inversions (James, 1967, Sveinbjörnsson 2000). An interesting extreme example in the Jura mountains in Switzerland was described by Körner and Hoch (2006). The screening from winter sun and a large diurnal temperature range permits the maintenance of permafrost at the bottom of an escarpment (at 1200 m asl) which is well below the altitude of the natural treeline (1800 m a s l) in the locality. There is a regional scale of variation between the relative shelter of internal mountains and those on the edge of a range (Swann 1967), reducing snow fall and lengthening the growing season. The vegetation of these areas is similar in structure to that of the arctic, although the tall-shrub component is less consistent and may be absent (Bliss 1971). Due to the older age of the flora of most alpine areas there is a far higher number of species (Wright and Osburn 1967, Bliss 1971) including a higher number of endemics which have developed as a result of the genetic isolation of some areas due to the extreme topography.

The UK is an island on the western fringe of Europe with an Atlantic coast. It does not readily fit the general biogeographic descriptions of more continental treeline ecotone areas, being highly oceanic (Crawford 2000) and somewhat in between arctic and alpine characteristics. The principal upland areas are located between 52 and 59° N and 3 and 6° W, and many tend to have a generally south west to north east orientation. Although not particularly high, many of these mountains individually range from near sea level up c. 1000 m asl resulting in a highly varied topography.

1.3.2 Treeline ecotone: Climate characteristics

Around the world the climate is highly variable within the treeline ecotone, and either at high altitude or latitude cannot easily be summarised with any precision (Tranquillini 1964). This thesis is primarily concerned with treeline scrub in the UK and the very different climatic conditions of tropical and sub-tropical treelines are not considered. This review focuses on three main cold-climate elements, cold temperatures, snow and wind, but also considers the summer conditions and growing season lengths that feature in the treeline ecotone and their impact on the scrub plants growing there. It is difficult to completely isolate the different elements from each other because they are inherently interlinked. For example, snow cover can shelter plants from cold temperatures or strong winds, but if the snow cover is erratic and the insulation provided to the plants is lost too early, they may be exposed to damage from freezing without the chance to become acclimatised (Bannister *et al*. 2005). This section reviews the compounding effects where necessary with particular reference to impacts that are relevant to the interpretation of UK treeline scrub. Chapters three and four review the effects of wind and snow, respectively, in more detail.

Low temperatures

It has been shown that the factors controlling the position of treeline ecotones at high altitude and latitude are similar and can be related to temperature (Grace 1977, 1989, Chapin 1983, Kullman 1991, Bonan and Sirois 1992, Körner 1998, Körner *et al*. 2003, Körner and

Hoch 2006, section 1.1 above). Low temperature is of primary importance, as are wind and precipitation in the form of snow; the climatic factors that can affect it. Two key elements to survival in a cold climate are tolerance of extreme temperatures during the dormant season, and the ability to grow in the prevailing growing season temperatures. In winter, or the cold season, temperatures below freezing can physically damage unprotected or non-adapted plants directly by freezing intracellular material causing cell rupture (Grime 2001, Crawford 2008). In addition, temperatures below the minimum for tolerance or adaptation by plants at the start of or during the growing season, may inhibit functions such as photosynthesis, respiration and growth (Körner et *al* 2003, Grace and James 1993), although as yet there does not seem to be close agreement on the exact mechanisms involved (Sveinbjörnsson 2000, Smith *et al*. 2003, Holtmeier 2005). Freezing conditions can be mitigated by snow (Scott *et al.* 1993, Canaday and Fonda 1974, and see below) but in the absence of snow and with time to acclimatise, plants can develop extraordinary degrees of frost resistance (Bannister *et al.* 2005). For example, at Hokaido, Japan, Sakai and Ōtsuka (1970) demonstrated frost resistance in aerial parts of *Salix pauciflora* Koidz. at – 70°C. Frost resistance develops in the latter part of the growing season and persists through the winter (Sakai and Ōtsuka 1970, Bannister *et al*. 2005). Bannister and colleagues (2005) showed that if plants escape the developing cold in autumn for any reason (for example an unusually warm autumn), frost resistance may not develop and the plants can become susceptible to damage if subsequently exposed to freezing conditions. Prostrate and short plants can become encased in ice if snow is absent or thaws prematurely, a phenomenon called ice capping (Crawford 2000). Mature treeline ecotone scrub plants are less likely to be affected in this way due to their taller stature.

In winter indirect damage can occur when transpiration in aerial plant tissues, exposed to warm daytime temperatures, causes drought and subsequent desiccation because ground water is frozen (Tranquillini 1964, Barclay and Crawford 1982, Crawford 1989). This frost drought is well documented (Tranquillini 1964, Mayr 2007) and a common occurrence, normally evident from browning of aerial plant parts in spring, in evergreens (Grace 1990), and dead foliar buds in deciduous plants (Barclay and Crawford 1982).

Wind

Generally treeline ecotones are windy locations (e.g. Mount Washington, Griggs 1946; the White Mountains, Griggs 1946; Scotland, Pears 1968). Air currents and the incidence of storms can be very site specific and some alpine areas, particularly those internal to mountain massifs can be relatively sheltered (Griggs 1946, Swann 1967). The most direct effect of strong winds is mechanical damage (Grace 1977). Plants may be blown out of the ground, or suffer from the thrashing of aerial branches and stems which can cause damage to bark and cuticles. Desiccation can then occur from water loss through the damaged tissues (Kullman 1991, Grace and James 1993).

Snow

One of the most conspicuous features associated with high altitudes and latitudes is snow. For plants growing in such areas snow can provide vital protection from low temperatures and strong winds. If cover is incomplete or inconsistent however, there may be negative effects. For example, if an unusual early snow fall buries plants in autumn before they have developed adequate frost hardiness they may be more vulnerable if subsequently exposed to freezing temperatures, as described above (Bannister *et al.* 2005). The surface of snow tends to have reduced friction, compared to the vegetation it has buried, and the wind tends to accelerate over a snow covered landscape increasing the stress on exposed plant parts (Grace and Norton 1990). Snow surfaces reflect higher levels of solar radiation (than vegetation) subjecting exposed plant parts to additional radiation and heat during a clear winter day, whilst at night the snow surface becomes colder than ambient temperatures (Geiger 1966). Conversely, the nature of the ground topography and height of the vegetation cover affects where snow falls and how it collects when blown by the wind. Generally the mosaic nature of treeline scrub tends to create a variable depth of snow cover and this in turn can affect the growth of the plants (Canaday and Fonda 1974, Myers-Smith 2007).

The length of time snow covers the ground can also have a major impact on the development of vegetation (Kudo *et al.* 1996, Wahren *et al.* 2005, Wipf and Rixen 2010). Early snowmelt can promote early de-hardening and expose plants, particularly deciduous, to damage from late frosts (Bliss 1971), a risk which, for some plants (e.g. *Vaccinium myrtillus* and *V. uliginosum*) outweighed the potential benefit of an extended growing season (Wipf *et al.* 2009). Late snow cover rarely occurs in the UK, but can impair the development of plants (Kudo *et al.* 1996).

Growing season length

Generally the treeline ecotone experiences a shorter growing season than the forest zone. Primarily this is due to lower temperatures, particularly in the dormant season, resulting in an earlier cessation of growth in autumn and later initiation in spring. In their study of global treeline controls Körner and Paulsen (2004) did not find any correlation between treeline position and the length of the growing season. In some alpine areas the start of the growing season in spring is controlled by the snowmelt date rather than day length or atmospheric temperatures (Wipf *et al.* 2006, Odland and Munkejord 2007). "Growing season" has various definitions. Körner and Paulsen (2004) used "the first crossing of 3.2°C in the root zone", in either direction, as the start and end of the growing season, and quote the growing season in numbers of days. Others quote growth degree days (or accumulated temperature, Brown *et al.* 2008) and these are calculated as the total number of degrees for the days when the minimum temperature is 0°C, 5°C or 5.5°C. Crawford (2008) quotes *Betula pendula* L. minimum day degree requirement as 1100, while for *B. pubescens* Ehrh. 700 day degrees were sufficient for survival. He defined day degrees as "frost-free days or thermal time".

1.3.3 Treeline scrub: Strategies for coping

The growth strategy of a plant in relation to the biological and physical conditions in its habitat determines how fit it will be to survive and reproduce (Grime 2001). Across the wide range of plants growing in arctic and alpine environments, including tree species, tall and dwarf shrubs, grasses and herbs, Grime (2001) has proposed a number of different characteristics that they tend to have in common, regardless of continent or plant family, and which increase the plant's fitness for its geographic location. These characteristics may be less consistent across the treeline ecotone scrub zone because it is a transition from a more benign environment towards these more extreme conditions. This section discusses those arctic / alpine characteristics which are particularly relevant to, or prevalent in, tall-shrub plants in the treeline ecotone.

Cold temperature adaptation

A number of authors identify that cold climate plants, including treeline trees and tall-shrubs, dwarf shrubs and graminoids (grasses and sedges) tend to be evergreen (Bliss 1971, Grime 2001,Crawford 2008). One of the most prevalent groups of tall-shrub plants, not just in the arctic, across northern Canada, Russia and Siberia, but also in many alpine areas ranging from the Scandes Mountains in Scandinavia to the San Juan Mountains, Colorado (Bliss 1971), are the deciduous willows (*Salicaceae*) (Bélisle and Maillette, 1988, Crawford 2008). The extensive presence of willows, and, in the north northern hemisphere treeline ecotone areas, birches (*Betulaceae*) is not discussed in relation to the characteristics of cold climate plant growth strategies by any of the quoted authors. Crawford (2008) discusses the evolution in growth strategy models to accommodate stress tolerant plants in low productive systems that are subject to predation by herbivores, but also to ground disturbance as a result of herbivore movement. Although Crawford does not explicitly include them, both the willows and *Betula nana* would appear to be candidates to this group of "*g*-strategists", which are characterised by large root to aerial shoot ratios, and large reserves of nutrients to accommodate browsing. Bélisle and Maillette (1988) showed how *Salix uva-ursi* Pursh.

mimics one evergreen characteristic through the retention of the previous year's desiccated leaves until the start of the following growing season, a characteristic it shares with the more southern *Salix myrsinites* L. (Meikle 1984). The leaves provide protection for over-wintering buds. Grime (2001) makes the case that being evergreen reduces the resource demand early in a new growing season and reduces the need for plants to respond quickly to early spring warmth and risk potential damage from late frosts. This may be the case, but evergreen conifers, particularly *Pinus sylvestris* L., store important nutrients in exposed aerial material which means they are vulnerable to loss either from weather events or browsing (Millard *et al.* 2001). Willows do not flower under the snow (Bliss 1971), but have been observed to respond quickly to unusually early favourable conditions in spring in the UK by initiating growth (*pers obs.*), although it is not known if this subsequently led to damage by later frosts.

Longevity

Arctic / alpine plants tend to be long-lived, or perennial (Bliss 1971), obviating the need to generate high levels of resources to produce reproductive material and set seed (Grime 2001). Crawford (2008) reports polar willow mats in Spitsbergen of over 200 years old.

Dioeciousness

This characteristic increases the vulnerability of isolated populations if dimorphism between the sexes (Dawson and Bliss 1989, Crawford and Balfour 1983, Jones *et al.* 1999, Sakai *et al.* 2006) affects their survival and populations become dominated by one sex, or in some cases composed entirely of single-sex plants. This is the case for a number of populations of the rarer mountain willows in the UK (Marriott 1997) and may be the case for many more, but few data area available. Elmqvist *et al.* (1988) reported male dominated sex ratios in 56 species from across a wide range of genera, including *Populus* and *Juniperus.* Species of *Salix* are among only a few where female dominant sex ratios have been reported (Crawford and Balfour 1983). Elmqvist *et al.* (1988) demonstrated that in northern Sweden voles may play a role in exaggerating the bias through higher predation of male plants.

Reproductive strategies

Grime (2001) and others (Bliss 1971, Crawford 2008) suggested that cold climate plants generally have good capacity for vegetative spread, and that it takes precedence over seed production. Grime (2001) associates willows with colonising plants of disturbed ground in relation to their annual production of large amounts of, largely wind dispersed, small seed. Generally, for arctic / alpine species he suggests that normally erratic seed production is complemented by the presence of a seedling-bank. This allows a species to react very quickly to exploit a resource niche suitable for a mature plant, when it arises, by having seedlings, or saplings ready waiting in the sward. Neither *Salicaceae* nor *Betulaceae* exhibit this feature and Bélisle and Maillette (1988) demonstrated that *Salix uva-ursi*, in common with tree *Betulaceae* (Harding 1981) tend to produce seed annually and to invest more in reproductive organs than is characteristic for cold climate plants (Grime 2001). Treeline ecotone *Salicaceae* species do spread vegetatively, both through layering and suckering (Meikle 1984, Christensen *et al.* 2000). Shrub birches (both *Betula nana* L., and *Betula glandulosa* Michx.) in arctic situations also primarily spread vegetatively and both layering and suckering are prevalent (De Groot *et al.* 1997). Further south, and so potentially in the UK treeline ecotone, De Groot *et al.* (1997) reports that seed production is more common.

Both birches and willows have very small buoyant seeds, both of which are adaptations for anemonochory (Fenner 1985). Both groups also have short-lived seeds (willow: Nicholson and Clapham 1979, Raven, 1992, Sullivan 1997, birch: De Groot *et al.* 1997), and so have no significant seed bank. Willow seeds generally only survive a matter of days following dispersal in late summer or at most over winter (Sullivan 1997, Shaw 2006). Birches disperse seed in late summer and autumn and germinate either the same autumn or following spring (De Groot *et al.* 1997). These features imply that it is necessary for seeds to land in suitably moist patches of bare ground, and / or reduced competition fairly quickly after dispersal for successful recruitment to occur (Stewart 1996, Sullivan 1997, Shaw, 2006).

1.3.4 Treeline ecotone tall-shrub characteristics: Summary

In summary, the treeline ecotone exhibits intermediate conditions between the forest zone and the true arctic or alpine zones. Many of the tall-shrubs in this zone also occur in the more extreme conditions at higher latitudes and tend to exhibit growth characteristics which are intermediate between adaptations to cold climates and true colonisers. Many are dioecious, deciduous, tolerate browsing and disturbance and readily spread vegetatively. They can regularly produce many small, wind-dispersed, short-lived seeds that require light to germinate. The seedlings are also very small, require light and are vulnerable to drought, but do not tend to remain in a juvenile state indefinitely (so do not form a seedling bank).

1.4 TREELINE SCRUB IN THE UK

Treeline scrub in the UK is uncommon, fragmented and in the majority of cases sites are small and isolated (Gilbert and di Cosmo 2004, Anon 2007a, JNCC 2009a, 2009b), and generally treeline woodlands are geographically quite separate from montane scrub sites. In policy terms treeline woodland has tended to be incorporated within the native woodland resource and is within the remit of government forestry authorities. Montane scrub is within the remit of the Government's nature conservation authorities. In the UK the main public land use bodies (agricultural, forestry and heritage) have been devolved to country level. For example: Forestry Commission Scotland (FCS) and Scottish Natural Heritage (SNH). Within the UK Scotland holds the greatest extent of treeline ecotone. Consequently this thesis focuses on this habitat in Scotland.

Horsfield and Thompson (1997) described three main montane scrub habitat types: Dwarf birch scrub; Alpine willow scrub and Alpine juniper scrub, and this terminology is used here. The main vegetation communities, as defined by the UK National Vegetation Classification (NVC, Rodwell 2006) are briefly described with reference to the related European communities. Finally, the over-arching European context according to the manual of collated European habitats (EC 2007) is given, along with information about the status of either habitat or species. This provides an indication of the significance of these vegetation communities in Europe and the UK.

1.4.1 Habitats

In this section the main UK plant communities for each treeline scrub type are briefly described. The main tall-shrub or tree components associated with each scrub type are given, as are the other NVC communities in which they occur. Table 1.1 summarises the dominant species associated with each scrub type. The relationship between either the scrub type or the associated tall-shrub species and European vegetation is mentioned.

Treeline woodland

The natural altitudinal boundaries to woodland are almost non-existent in the UK due to many hundreds of years of decline and fragmentation (Hester 1995, Gilbert 2001). In 2000 MacKenzie completed a collation of existing records for treeline woodland, i.e. climatically stunted areas of woodland (MacKenzie 2000) and demonstrated that the number of records for woodland spanning the forest line is limited to a few hundred over the UK as a whole. Apart from this report, these areas had not been specifically recorded until the initiation of the Native Woodland Survey of Scotland (NWSS, first report FCS 2009). There is no database of such sites for the UK as a whole. Essentially, most of the upland woodland types (Averis *et al.* 2004) in the UK could extend as high as the treeline ecotone, but in reality the cover of semi-natural native woodland in the UK is so low that very few examples exist close to the forest line. The oldest and most extensive area of treeline woodland is of Caledonian pine woodland ("*Pinus sylvestris – Hylocomium splendens* woodland", NVC W18, Rodwell 1991a) at Creag Fhaiclach, in the Cairngorms of Scotland (Pears 1967, McConnell 1996). Another well-documented fragment is of upland oak woodland ("*Quercus petraea – Betula pubescens – Dicranum majus* woodland" NVC W17, Rodwell 1991a) at Birk Rigg, the highest example in the Lake District of England. This type of woodland is primarily present in the north and west of the UK, but now rarely reaches the altitude of the treeline ecotone. Upland birch woodlands (Habitat Action Plan, Maddock 2008), composed mainly of *Betula pubescens, Sorbus aucuparia,* and *Corylus avellana* also occur in the west, although this type of woodland is an amalgam of NVC W17 or W11 oak woodlands depending on the associated flora and conditions (Hall *et al.* 2004). Birch woodlands tend to be more common than other types and there are a number, particularly in Scotland, which extend into the treeline ecotone (Hale *et al.* 1998). A particular example is the ancient Morrone Birkwood (Huntley and Birks 1979, MacKenzie 2000). Recent woodland expansion uphill in Scotland has been documented at a number of sites, including *Pinus sylvestris* in the Cairngorms (Bayfield *et al.* 1996, French 2001, MacKenzie 2001), and *Betula pubescens* in the west (Barclay & Crawford 1982, MacKenzie 2000).

Montane Scrub

There are three main types of montane scrub in the UK chiefly defined by the dominant tall-shrub species present (Horsfield and Thompson 1997, MacKenzie 2000, Gilbert 2001), and at the present time they tend to occupy separate locations. Table 1.1 summarises the information on the key montane scrub vegetation communities in the UK, their European Commission (EC) equivalent community, and the other NVC communities in which the component tall-shrubs occur. Information is also provided in the text on the current distribution and main site requirements, as far as these are known.

Dwarf Birch scrub

In the UK dwarf birch (*Betula nana* L.) scrub is primarily found on ombrogenous, or rain-fed blanket mires and within the National Vegetation Classification (NVC) system a specific *Betula nana* variant of *Calluna vulgaris – Eriophorum vaginatum* blanket mire *Vaccinium vitis-idaea – Hylocomium splendens* sub-community (NVC M19ci, Rodwell 1991b) has been described. This blanket mire scrub is relatively widely spread throughout the upland areas of the north, east and central Highlands of Scotland (MacKenzie 2000), primarily at 450 – 500 m asl, although in the north west it occurs at half that altitude and in eastern areas *Betula nana* is present at over 800 m asl. (Scott, R 1997). The sites are characterised by deep peat covering gentle slopes and are generally drier than the other blanket mire communities (NVC M17 or M18, Rodwell 1991b) not having surface water, and the ground normally has a cover of pleurocarpous, prostrate, mat-forming mosses (Averis *et al.* 2004).

Table 1.1 The UK montane scrub types and their classifications in terms of the UK National Vegetation Classification (NVC) terminology (*Rodwell, 1991a, 1991b*) and EU 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 (4080)
Alpine Juniper Scrub	H15 *Calluna vulgaris – Juniperus communis* spp *alpina* heath	7 woodland, 8 heathland, 4 mire, 6 grassland communities in the uplands	Alpine & Boreal heaths (4060)
Alpine Juniper Scrub	W19 *Juniperus communis* ssp *communis – Oxalis acetosella* scrub		Caledonian Forest (91C0) *Juniperus communis* formations on heaths or calcareous grasslands (5130)[13]
Dwarf Birch Scrub	M19iiic *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 (7130)[14]

[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 octapetala-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* ssp *nigrum* sub-community; [11]*Trichophorum cespitosum-Eriophorum vaginatum* blanket mire; [12]*Trichophorum cespitosum-Erica tetralix* wet heath; [13] *Calluna vulgaris – Vaccinium myrtillus* heath [14]EC Habitat's Directive priority Annex 1 habitats (EC DG Environment 2007)

Betula nana L. ssp *nana* (Suk.) Hult. is the only tall-shrub species associated with this UK vegetation community. In this thesis it is referred to by the species only. De Groot *et al.* (1997) produced a flora for *Betula nana*, and the following key points have been taken from it. It has an essentially northern distribution that includes Europe and western Asia, but has scattered populations as far south as the northern Alps, Romania and central France. Outside the UK there is another subspecies, *B. nana* ssp *exilis* (Suk.) Hult., which occurs in North America and central and eastern Asia. In general both subspecies are associated with acid, impoverished, moist soils.

Plants of *Betula nana* can be found in the UK in wet heath (NVC M15, Rodwell 1991b) and less commonly in dry heath (NVC H12 Rodwell 1991b, Table 1.1). Although primarily described as a plant of blanket bog habitats, usually on peat more than 2 m thick (Rodwell 1991b) it also grows on better drained, steeper ground with shallower organic soils (De Groot *et al.* 1997). One of the most extensive and tallest populations grows on steep, west facing slopes in a wet heath habitat (*pers obs*). Over the rest of its European and Asian range *Betula nana* is also associated with thin soils, and is also found on rocky sites, gravels and road verges (De Groot *et al.* 1997).

Alpine Willow Scrub

Alpine willow scrub is a mountain vegetation type in the UK, primarily found in the highlands of Scotland on steep, broken and rocky ground at the back of coires, on rock outcrops or in ravines. The main vegetation community associated with this scrub in the UK is *Salix lapponum – Luzula sylvatica* scrub (W20, Rodwell 1991a). Rodwell (1991a) did not described any sub-communities but Averis and colleagues (2004) proposed three distinct sub-types in Scotland. One, on more acid soils, with a dwarf shrub (*Vaccinium myrtillus V. uliginosum*), grass (*Luzula sylvatica, Deschampsia cespitosa*) and fern (*Dryopteris dilatata, Blechnum spicant*) understorey, similar to *Luzula – Vaccinium* tall-herb communities (NVC U16, Rodwell 1992). The second sub-type is found on limestone outcrops in the west of Scotland and the only willow present is *Salix myrsinites* L. The understorey is variable and can be rich with tall herbs and ferns or open and sparse. The third and most common sub-type can include all the montane willows (see below) and is associated with very rich tall-herb vegetation which resembles the *Luzula - Geum* tall-herb community (NVC U17, Rodwell 1992) with willows. The main associates in this community are tall-herbs such as *Alchemilla glabra* Negy. (Lady's mantle), *Angelica sylvestris* L. (Angelica), *Geum rivale* L. (Water Avens), *Luzula sylvatica* (Hudson) Guadin (Great Wood-rush), *Sedum rosea* (L.) Scop. (Roseroot), *Filipendium ulmaria* (L.) Maxim. (Meadowsweet) and *Ranunculus acris* L. (Meadow Buttercup). The first and third of these sub-types are normally found above 600 m asl on ground where there is some basic influence, either from the soil or ground water and these areas also tend to be out of reach of browsing animals (Mardon 1990).

There are six bush-forming indigenous tall-shrub mountain willow species in the UK, *Salix reticulata* L. (Net-leaved Willow), *S. myrsinites* L. (Whortle-leaved Willow, *S. lanata* L. (Woolly Willow), *S. phylicifolia* L. (Tea-leaved Willow), *S. arbuscula* L. (Mountain Willow), and *S. lapponum* L. (Downy Willow), all of which are components of the Alpine Willow scrub. The Flora Europaea web-based database (Eds. Jalas & Suominen 1996) provides distribution maps for all these species in Europe and the following distribution descriptions were taken from it. All of these species have essentially northern distributions, and the UK supports the most southern, and in some cases, oceanic European populations of:

S. myrsinites, which extends from the UK north and east across Norway, north-western Sweden and north Finland across northern Russia to the Europe-Asia border and the Ural

Mountains, with scattered populations in eastern Russia, all north of the 60°N parallel, apart from the UK population;

S. lanata, which is more closely restricted to the north, and is widespread in Iceland, Norway, northern Sweden, Finland and Russia, across to the Europe-Asia border, and running south down the Ural Mountains;

S. phylicifolia, which extends from Iceland, including the UK (Scotland and England) throughout Scandinavia (excluding Denmark) and the Balkan states and Belorussia, and throughout Russia, north of 50°N;

S. arbuscula, which has the most restricted distribution, including Scotland, central and northern Norway, and the extreme north of Sweden, scattered populations in northern Finland and north-east Russia and discrete populations along the Ural Mountains on the Europe-Asia border, the main focus is in Norway.

Salix lapponum is more widespread, generally extending from the UK into central Europe with isolated populations as far south as central France, the Pyrenees, and Bulgaria, although it is absent from the Alps.

Salix reticulata extends the furthest south and appears to have a distinctly alpine and arctic distribution. It is present in the far north, including Svalbard, and west (excluding Iceland), the UK, Norway, northern Finland east to the Europe-Asia border, and south along the Ural Mountains. Further south it is absent until the Mediterranean mountains, where it is widespread across the Pyrenees and the Alps, and further east there are populations in Slovakia, Yugoslavia, Romania and Bulgaria.

Myklestad and Birks (1993) used this distribution data to classify all European *Salicaceae* into different floristic elements. *Salix myrsinites, S. lanata,* and *S. arbuscula* appear in the Northern Boreal, *S. reticulata* in the Northern element, *S. phylicifolia* in the Arctic-Alpine element and *S. lapponum* in the Northern Widespread element. On the map produced by Myklestad and Birks (1993) the central uplands of the UK are comparable to western Norway.

In the UK, apart from the main *Salix lapponum-Luzula sylvatica* scrub community, these species can be found in a number of ledge and grass communities: for example *Dryas octapetala – Silene acaulis* ledge community (NVC CG14, Averis *et al.* 2004, and Table 1.1). The presence of willows in these other vegetation types tends to be inconsistent and at a very low density and they do not normally feature in the community descriptions.

Alpine Juniper Scrub

There are two distinct forms of this scrub type. The first has a northern distribution and is primarily confined to the uplands of central Scotland and northern England (Rodwell 1991a). The primary tall-shrub present is *Juniperus communis* L. subspecies *communis*. Stunted forms of *Betula pendula* L., *B. pubescens* and *Sorbus aucuparia* L., may also be present along with *Rosa canina* L. and is described by Rodwell (1991a) as *Juniperus communis* ssp. *communis – Oxalis acetosella* woodland (NVC W19). Two sub-communities occur: W19a *Vaccinium vitis-idaea – Deschampsia flexuosa* sub-community has a generally heathy understorey and occupies acid soils, and W19b *Viola riviniana – Anemone nemorosa* sub-community is more grassy with a loose bryophyte carpet covering the ground (Averis *et al.* 2004). In the Cairngorms this scrub type replaces *Pinus sylvestris – Hylocomium splendens* woodland (NVC W18, Rodwell 1991a) at the treeline.

The second scrub form is the oceanic *Calluna vulgaris - Juniperus communis* ssp. *nana* heath (NVC H15, Rodwell 1991b) which occupies quite a precise edaphic niche in the north-west of Scotland (Sullivan 2001), the Lake District and Wales (Averis *et al.* 2004) in the UK. This community exists in relatively exposed, windswept locations and has a low and prostrate habit on sparsely vegetated rocky plateaux, cliff ledges, or amongst boulders or rock debris. *Juniperus communis* L. ssp. *nana* (Hook.) Syme is the only tall-shrub present, and *Calluna vulgaris* the main constant associate, although *Arctostaphylos uva-ursi* (L.) Spreng. and *A. alpinus* (L.) Spreng. may also be present. Mats of oceanic liverworts, such as *Herbertus aduncus* ssp *hutchinsiae* Schiffn. and *Plagiochila carringtonii*, may occur along with other more common species (Averis *et al.* 2004).

There has been some debate in the literature regarding the status of the two subspecies of *Juniperus communis*, *J. c.* ssp. *communis* and *J. c.* ssp. *nana*, which has been well reviewed by Thomas *et al.* (2007). This thesis follows that paper in recognising the status of the subspecies. In the UK there appears to be quite a clear distinction between the habitat niches of each subspecies. Sullivan (2001) proposed that the prostrate *J. c.*ssp. *nana* was restricted to a western oceanic heathland habitat, although this would appear to conflict with the distribution given by Jalas and Suominen (1996) which shows a widespread occurrence across upland Europe, including the length of the eastern Europe-Asia border in the Ural Mountains. *J. communis* ssp. *communis* is more ubiquitous, ranging from sea level to over 950 m asl in the central highlands of Scotland (MacKenzie 2000), and from the northern islands to the south coast of England (Preston *et al.* 2002). Of interest to this thesis are those populations which persist in the uplands at or above the treeline.

1.4.2 European vegetation classification context

The European Commission, in response to obligations under the Convention of Biological Diversity (CBD 2009) has developed an ongoing process of collation and interpretation of member state habitat classifications into an over-arching classification that allows Europe to conserve and monitor floral biodiversity (EC DG Environment 2007). This classification provides the framework within which each EU member state conserves important habitats and plant species. This section sets out how treeline scrub features in this overall classification and how the UK scrub communities are encompassed within it.

Within the Interpretation of European Habitats (EC DG Environment 2007) treeline scrub is primarily found within the “Temperate Heath and Scrub” group of habitats. There are three habitat types described which are essentially ‘scrubby’. Firstly, the “Alpine and Boreal Heaths” [reference 4060, JNCC 2009a], a group of five heaths generally divided by geographic area across Europe, and which include UK Alpine juniper scrub. The group encompasses vegetation communities on a wide range of soil types, for example “Alphide bearberry heaths” (reference 31.47) which occur from the Pyrenees east across the Alps to the Greek and Macedonian mountains primarily on calcareous soils. The “Mountain dwarf juniper scrub” (reference 31.43) occurs in the southern Palaearctic mountains, while to the north, a more acidic “Boreo – Alpine Heaths” group (reference 31.45) which includes some Scandinavian scrub types with *Betula nana* and either subspecies of juniper. Some of the best European examples of these heaths occur in Scotland (JNCC 2009a, see the Alpine Juniper scrub above). Otherwise the “Boreo-Alpine Heaths” range east to Siberia and in most cases the taller woody shrubs characteristic of this group, *Rhododendron* spp., and *Daphne* spp., are not native to the UK.

Secondly, “Bushes with *Pinus mugo* and *Rhododendron hirsutum*” (reference 4070, EC 2007), is a dry habitat of eastern mountains, from the Alps through to the Pelagonidaes, but including the Pirin, Rila and Balkan ranges further north. It does not occur in the UK, nor are any of the main species included in UK treeline scrub.

The third type “Sub-Arctic *Salix* spp. Scrub” (reference 4080, JNCC 2009b) is a relatively widespread habitat which has four main sub-types. The first three are divided geographically across from the Pyrenees to the Hercynian mountains and are essentially Alpine communities. The last, “Boreo-Alpine Willow Brush” (reference 31.622), has a more northern distribution from Iceland, across Scotland to Scandinavia, and encompasses the UK *Salix lapponum – Luzula sylvatica* Scrub (NVC 20, Rodwell 1991a).

In addition, and of particular relevance to the UK, is the "Blanket bogs (*[1] if Active)" habitat (reference 7130, EC DG Environment 2007) in the "Raised Bogs and Mires and Fens" group. Although generally lower than the treeline over much of Europe, in the UK it is within the treeline ecotone and it is in this habitat that Dwarf Birch scrub is primarily found in the UK. In wider European terms the UK supports a large proportion of this habitat. Elsewhere in Europe *Betula nana* is also found in "Active raised bogs" in the Boreal region, and more commonly in the Boreo-Alpine Heaths (reference 31.45 of 4060, EC 2007) along with other scrub species.

Included in the list of treeline scrub, although not explicitly listed in the European habitat classification system above, are the natural extensions of forest habitats above the forest zone and into the treeline ecotone. This list would include any mountain forest type that would naturally extend into this zone. In particular these encompass many of the "Boreal Forests of Northern Europe", including "*Western Taïga" (reference 9010), "Nordic subalpine/subarctic forests with *Betula pubescens* ssp. *czerepanovii*" (reference 9040). In the "Forests of Temperate Europe" there are many examples, including "Medio-European subalpine beech woods with *Acer* and *Rumex arifolius*" (reference 9140), "Old sessile oakwoods with *Ilex* and *Blechnum* in the British Isles" (reference 91A0) particularly the sub-type "British sessile oak woods" (reference 41.532) and "*Caledonian Forest" (reference 91C0) in the north and in the UK in particular (EC DG Environment 2007).

1.4.3 The status of treeline scrub in the UK

Many of the tall-shrub plants and communities occurring in the treeline ecotone in the UK are nationally uncommon and have attracted specific conservation status affording protection from destruction, and in some cases preference in conservation programmes. This section identifies which habitats and species these are and which are also recognised as of conservation importance at a European and/or Scotland level.

Habitats

At the European level, both "Blanket bogs (if *Active)", including Dwarf birch scrub, and "*Caledonian Forest" are priority habitats (EC DG Environment 2007). Member states are required to designate as Natura sites (Eurosite 2007, JNCC 1998) and statutorily protect specific proportions of the extent of the habitat that they control. Although Caledonian forest is primarily a forest zone habitat, this designation affords protection to those sites where it does extend up into the treeline ecotone. Although not a priority European habitat

[1] * denotes a European level priority habitat or species (JNCC 2009)

“Sub-Arctic *Salix* spp. Scrub” (EC DG Environment 2007) is listed in Annex 1 of the Habitats Directive (EC 1992) requiring the UK to similarly protect sites where the habitat occurs. This European level designation requires the UK to ensure that the sites are maintained in “favourable conservation status” (EC 2000).

Within the UK there are additional processes for identifying and designating representatives of the UK’s native vegetation (JNCC 1998). Examples of montane scrub, and key areas of treeline woodland, such as Creag Fhiaclach and Morrone Birkwoods, are included in the suite of Sites of Special Scientific Interest (SSSIs). This designation may protect the habitats from deliberate destruction, but it does not provide for their positive management. More recently the UK Biodiversity Action Plan process (Anon 2007b) has been developed in response to European Habitats Directive, a mechanism for highlighting the importance of semi-natural habitats. The process has identified habitats and species which warrant specific action plans to attract funding and conservation activity (Anon 2007b). All the semi-natural upland woodland habitat types have had action plans developed (including Upland Oakwoods: both NVC W17 & W11, Upland Birchwoods: NVC W11, W17 & W4, and Upland mixed Ashwoods, NVC W9, Hall *et al.* 2004). In addition a broad habitat plan has recently been developed for “Upland Heath and Willow Scrub” (Anon 2007b), encompassing Alpine Willow Scrub, while “Blanket Bog “, including bogs with Dwarf Birch Scrub, and Upland Heaths, including areas with *Juniperus communis*, (Maddock 2008) have been in place since the inception of the process.

Species

Concerns have been raised about the future of the tall-shrubs occurring in Alpine Willow Scrub and Alpine Juniper Scrub (Cheffings and Farrell 2005, Table 1.1). Of the willows, all, with the exception of *Salix phylicifolia*, are uncommon or rare in the UK (Averis *et al.* 2004), but not in a European context (EC DG Environment 2007). *Salix lanata* and *S. lapponum* are listed in the UK Red Data Book (Cheffings and Farrell 2005) as “vulnerable” (Vu), or “have a high risk of extinction”. The former because the overall population size is small and there is little evidence of an adequate subpopulation. *Salix lapponum* is listed as vulnerable because Preston and colleagues (2002) mapped a rate of decline that meets appropriate IUCN thresholds (Cheffings and Farrell 2005). According to the same thresholds, *S. myrsinites* is listed as “endangered” (En), or “has an extremely high risk of extinction” (Cheffings and Farrell 2005). *Salix lanata* has the most restricted range of all mountain willows in the UK and is cited in a number of targeted conservation plans, for example the *S. lanata* Species Action Plan (SAP, Anon 2007b), and the Species Action Framework (Anon 2007a). *Salix reticulata, S. arbuscula* and *S. phylicifolia* are listed as of "least concern" (LC) by Cheffings and Farrell (2005). Both *S. reticulata* and *S. arbuscula* qualify as scarce plants (JNCC 1998), because they are present in less than 50 10 x 10 kilometre grid squares (25 and 48 respectively, Preston *et al.* 2002).

Juniperus communis including both subspecies is listed as of "least concern" (LC) in A Vascular Plant Red Data Book for the British Isles (Cheffings and Farrell 2005). Despite this, and due to recent declines in the UK as a whole, but particularly in England (Clifton *et al.* 1997), juniper has a species action plan (SAP, UK BAG 2007) which includes targeted actions for both subspecies.

Associated with dwarf birch, willows and juniper plants are a number of rare or uncommon plants and animals. As a consequence these tall-shrubs attract additional conservation interest. For example, there is a SAP for *Swammerdamia passarella*, a micro-moth which lives specifically on *Betula nana* which is included on the Scottish Biodiversity List (Scottish Biodiversity Forum 2004) due to its rarity.

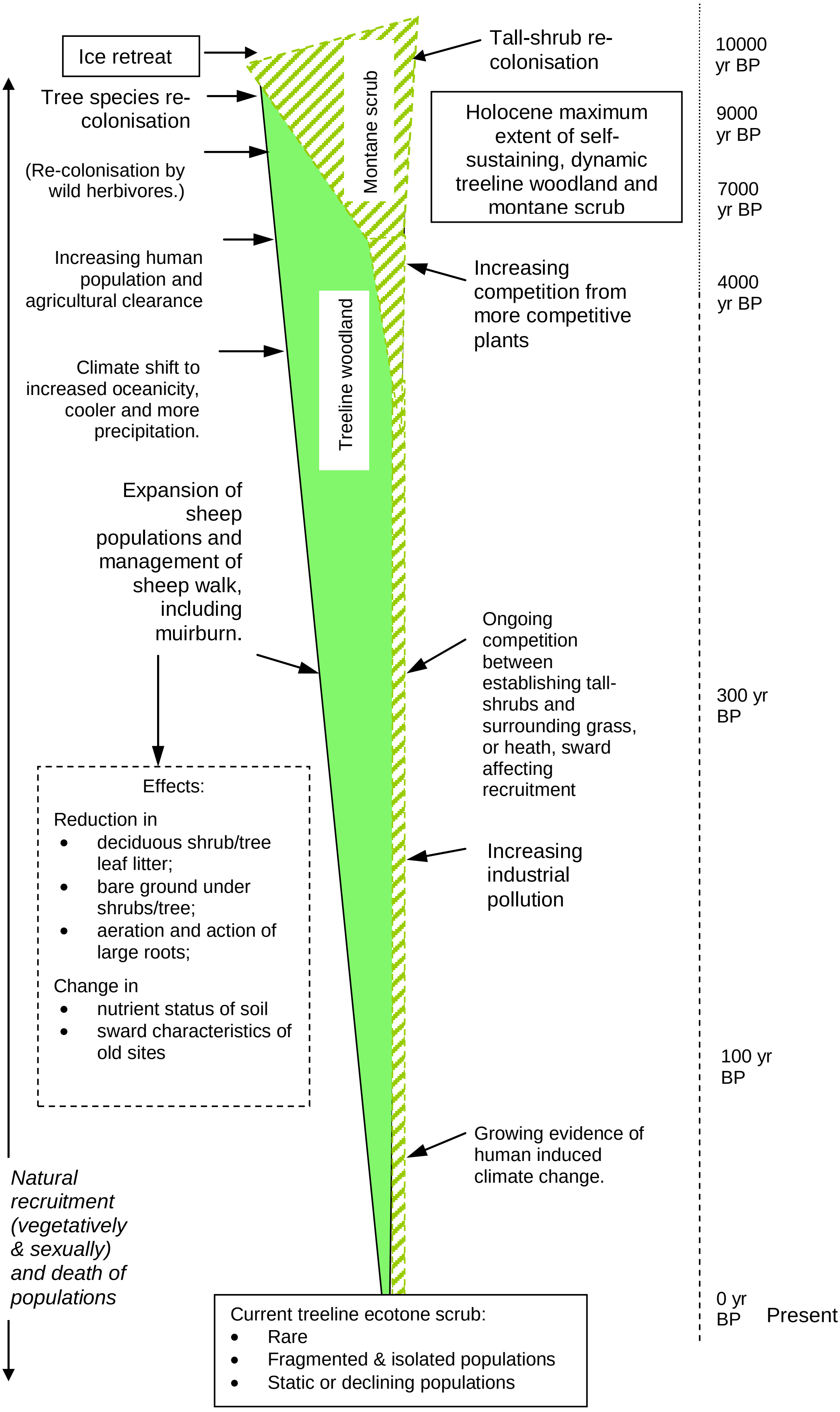
1.4.4 Treeline scrub in the UK: Summary

The UK supports a diverse range of treeline scrub communities which tend to be intermediate in character between the northern sub-arctic and more southern alpine vegetation types. Many are at the edge of their European ranges and are distinct from the wider European types. The UK supports large proportions of a number of priority European vegetation types. The key species associated with treeline scrub are rare or uncommon in the UK and continue to decline despite having attracted a range of conservation designations through the national conservation site designation system and the biodiversity action planning processes.

1.5 FACTORS AFFECTING TREELINE SCRUB IN THE UK

The current distribution and condition of treeline ecotone scrub in the UK, along with all other vegetation communities, is the result of an array of historical climate and land use factors, as well as the biology of the plants themselves, as summarised in Figure 1.2. This section briefly tracks the history of the re-colonisation of the UK by tall-woody vegetation at the end of the last ice-age, 15 – 11 thousand years ago, and the subsequent redistribution of treeline scrub in response to climatic and human activities. At the end of the section the history is interpreted in terms of the current and future options for this vegetation.

Figure 1.2 (next page). A Diagrammatic interpretation of the assumed reduction in treeline scrub since the last glaciation, >10,000 yr before present (BP). For full explanation see text. (Birks 1988, MacKenzie, 2003, Hester 1995, Tipping, 1997, Edwards & Whittington 2003.)


Ice retreat
Tree species re-colonisation
(Re-colonisation by wild herbivores.)
Increasing human population and agricultural clearance
Climate shift to increased oceanicity, cooler and more precipitation.
Expansion of sheep populations and management of sheep walk, including muirburn.
Effects:
Reduction in
• deciduous shrub/tree leaf litter;
• bare ground under shrubs/tree;
• aeration and action of large roots;
Change in
• nutrient status of soil
• sward characteristics of old sites
Natural recruitment (vegetatively & sexually) and death of populations
Montane scrub
Treeline woodland
Tall-shrub re-colonisation
Holocene maximum extent of self-sustaining, dynamic treeline woodland and montane scrub
Increasing competition from more competitive plants
Ongoing competition between establishing tall-shrubs and surrounding grass, or heath, sward affecting recruitment
Increasing industrial pollution
Growing evidence of human induced climate change.
Current treeline ecotone scrub:
• Rare
• Fragmented & isolated populations
• Static or declining populations
10000 yr BP
9000 yr BP
7000 yr BP
4000 yr BP
300 yr BP
100 yr BP
0 yr BP
Present

1.5.1 History of treeline scrub in the UK

In the 10,000 years of the current interglacial period the UK has been re-vegetated and colonised by a changing suite of plants and animals that have exploited the different phases of climate and soil evolution. Humans have been present almost from the beginning and have colonised and adapted from their hunter-gather ancestors with limited capacity to affect the overall distribution of plants and animals, to highly technical societies with the means to modify the landscape and control the fate of other life-forms. This section briefly explores the aspects of this history that are likely to have significantly impacted on treeline scrub.

Post Glacial Re-colonisation

Tipping (2003) reports that, in a brief interglacial period 14,500 to 12,000 yr BP, *Juniperus communis, Salicaceae, Sorbus aucuparia* and tree birches invaded an essentially grassy sward as far north as the south and east Scotland. Ice subsequently, although briefly, re-advanced but Tipping (2003) argues that it is possible juniper, along with arctic willows and other tall-shrubs, survived this period facilitating re-colonisation across much of the UK, including Scotland. Edwards and Whittington (2003) reported that the spread of tree species was into an existing vegetation of grasses and shrubs, including *Juniperus communis, Betula nana* and *Salix herbaceae*. De Groot *et al.* (1997) noted that *Betula nana* did not readily colonise ground recently exposed by glacier retreat in Norway, preferring greater soil development. A number of authors have documented the re-colonisation of tree species and there is close agreement that birch and hazel were among the first (Birks 1989, Edwards and Whittington 2003, Tipping 2003) and that they spread into an existing scrub cover. Tipping (2003) suggested that the tall-shrub plants were replaced within the forest zone and that during the warmest period, before 7000 yr BP (Birks 1988), trees would have extended across most of the land surface leaving only very limited areas where tall-shrubs could survive (Tipping 1997). Birks (1988) suggested that the maximum extent of forest would have been considerably less. Birks (1988) provides "crude" estimates for maximum altitudinal treelines for the UK, suggesting 100% of the altitude range across southern and north eastern England, and over 81% of the altitude in Wales decreasing to 65% in central Scotland and only 45% in the west. Above this forest Birks (1988) speculated that there would have been a fringe of *Betula*, *Sorbus aucuparia* and *Populus tremula* in the west and north of Scotland, with *Juniperus communis* and *Salix* scrub, rather than *P. tremula* in the east. In the central Highlands he suggested *Pinus sylvestris* would have been dominant with *Juniperus communis* and some *Betula*. In England and Wales Birks (1988) reported that the upper woodlands were better known and were composed of *Betula* and *Corylus* with *Ulmus* on better, and *Pinus*, on poorer soils, while *Quercus* was present and more frequent towards the south. The prominence of the larger forest trees depended on the topography and soil conditions of a location. The evidence from all authors is based on fossil pollen records and so are subject to the uncertainties and caveats outlined by Whittington (1993).

In summary, all authors acknowledged that it was not possible to be precise about the detailed species distribution or altitudinal extent of past UK forests, based on fossil pollen records (Birks 1988, Whittington 1993, Tipping 2003). It seems reasonable to suggest that the forest had extended to a maximum altitude within the limitations of climate and soil conditions by 7 - 6000 yr BP. At that time, the tall-shrub scrub that was widely present before the expansion of the forest would have continued to persist above the maximum altitude of the forest, where climate and soils allowed (Birks 1988). The strongest evidence for this in Scotland is the persistence of populations today. Otherwise there is virtually no evidence of their history at higher altitudes (Tipping 2003).

Forest Retreat

The reduction in forest area in the UK and the reasons for it have been debated and contested over much of the twentieth century. However few authors mention the fate of the ecotones bounding the main forest zone. Nonetheless there is reasonable agreement that by the turn of the twentieth century there was little more than 2% of the Scottish land mass supporting native forest (MacKenzie 1999). Humans, herbivores and climate have been the primary vectors of change (Birks 1988). Humans appeared at about the same time as the trees began to expand (Edwards 1993), and even at that time potentially influenced the quality of tree cover by transporting useful species with them (Edwards and Whittington 2003). Edwards (1993) suggested, from fossil pollen evidence that on the west there was also small scale forest management to facilitate alder, hazel and willow coppice as early as 6500 yr BP. In England there is evidence from charcoal remains of a depression of the treeline as a result of fire from 7500 yr BP. Birks (1988) speculated that this may result from the persistent use of fire at higher levels as a hunting tool. If this was the case it is likely that the fire would not only have depressed the treeline but also would have eradicated any tall-shrub present.

Agriculture, particularly the clearance of woodland for the development of pasture and planting of cereals, is thought to have appeared in Scotland between 6000 yr BP (Halliday, 1993) and 4000 yr BP (Edwards 1993). Many authors, including Birks (1988), reported that at about 4000 yr BP there was an increase in oceanicity with more precipitation and stronger winds and this, in combination with increasing human activity, has been proposed as the main reason for the long-term retreat of trees, particularly *Pinus* from the north and west, and expansion of blanket bog. These changes have been cited as possible explanations for the abandonment of human settlements from marginal areas of north west Scotland. Lowe (1993) suggested that this climate shift may have resulted from volcanic activity in Iceland. The ash clouds would have caused cooling and acidified the rain. The subsequent acidification of soils may have impacted negatively on those tall-shrub species, primarily *Salicaceae* and *Juniperus*, which prefer a degree of base richness in soils. From this time onward there is a fairly clear record of a growing human population and increasing clearance of ground for agriculture. In the uplands clearance was primarily of forest with subsequent management, including burning, to encourage the grass sward for grazing (Birks 1988, Lowe 1993). Halliday (1993) argued that land adjacent to access routes on ridges and hilltops were cultivated both for crops and seasonal pasture early in the Neolithic (5 to 4000yr BP) because it was easier than penetrating less accessible, forested valleys. Barclay (2003) argued that this and the frequency and complexity of human artefacts found at "higher locations" (no altitudes were given) provided circumstantial evidence for a transhumance system. This would suggest that treeline scrub may have been more vulnerable to clearance than some areas of forest, particularly before tools were sufficiently advanced to allow for the felling of large trees. This view supports the proposal by Birks (1988) that clearance of areas dominated by birch and hazel occurred pre-Roman and pre-dated the clearance of mixed deciduous forests which, in Scotland were generally lower and were thought to have been cleared post-Roman occupation.

Treeline scrub is rarely specifically mentioned in accounts of historical forest clearance but given that treeline woodland would normally have been contiguous with the forest zone at higher altitudes it is reasonable to suggest that it would have shared a similar history. This would particularly have been the case in more recent times as more extensive forest clearance continued and larger areas of hill ground were used for grazing so that by the time Roy made his maps in 1750 AD very little woodland is shown to be present (Spencer *et al.* 1989). This is the case put forward by Mather (2003), and that further clearance in order to facilitate the development of commercial sheep ranching in the hills was not necessary. Smout (2003) quotes the reports of shortages of timber as evidence of extensive deforestation by 1600. At this time the value of the remaining woods increased and forest clearance seems to have stalled. However, the value almost certainly related primarily to lower forests where tree growth was good and timber accessible, as evidenced by the location of most remaining native forests (Spencer *et al.* 1989) in the twentieth century.

The history of montane scrub tall-shrubs above the treeline is unclear (Spencer *et al.* 1989). Across England and most of Wales, forest covered much of the high ground leaving little space for the survival of montane scrub. In Scotland it was a different story and it is here where most of the remaining montane scrub tall-shrub species currently persist (Preston *et al.* 2002). Thomas *et al.* (2007) reported that much of "the natural distribution of juniper in Britain has undoubtedly been reduced by burning and excessive grazing", although they do not differentiate between low and high altitude populations. Some of the difficulties identifying past presence of the tall-shrubs have been highlighted by Bennett (1995) who reported that it is not possible to separate tree willow pollen from shrub willows. Tree willows were unlikely to be present at higher altitudes, but it does suggest that it would not be possible to separate the different shrub willows either. The tall-shrub species present all spread very effectively vegetatively (Meikle 1984, De Groot *et al.* 1997, Thomas *et al.* 2007) with the result that there is no data on the age of treeline tall-shrub plants, further emphasising the general lack of information on these plant populations.

Herbivory

A key feature of treeline scrub is its low stature and in the UK the tall-shrub species rarely reach two metres in height. As a result these plants have evolved in the presence of herbivores throughout their life cycle and the condition of populations is likely to relate to the presence and distribution of herbivores, both wild and domestic. The impacts of herbivores on plants and the subsequent changes in plant growth have been reviewed in general by Danell *et al.* (2006), and Gordon *et al.* (2008) and specifically in the UK by Milne *et al.* (1998) and are discussed in more detail in chapter 3.

Wild herbivores

Wild herbivores currently present in the treeline ecotone in Scotland, which are either browsers or mixed feeders are the native red (*Cervus elaphus* L.) and roe deer (*Capraeolus capraeolus* L.), mountain (*Lepus timidus* L.) and brown hares (*L. capensis* L.), field voles (*Microtus agrestis* L.) and bank voles (*Myodes glaveolus* Schreber), and feral sika deer (*Cervus Nippon* Temminck), fallow deer (*Cervus dama* L.) and goat (*Capra hircus* L.) and in eastern Scotland rabbit (*Oryctolagus cuniculus* L.) is present up to 600 m asl in a few areas (*pers obs*). There are no carnivores that prey substantially on deer, although Sea Eagle (*Haliaeetus albicilla* L.) and Golden Eagle (*Aquila chrysaetos* L.) do hunt hares, small mammals or the young of larger animals, and will scavenge on larger carcasses (Watson *et al.* 1992a, Watson *et al.* 1992b). Foxes (*Vulpes vulpes* L.), pine marten (*Martes martes*), wild cat (*Felix sylvestris*), pole cat (*Martelus putorius*) and a number of other raptors, including hawks and owls, prey on the smaller herbivores, although in many moorland areas they are themselves uncommon and/or controlled as part of sporting estate management.

Approximately 20% of land in upland Scotland is managed for sport hunting. The primary quarry species are either red deer or red grouse (*Lagopus lagopus scoticus* (Latham)). In both cases the management is focussed on maintaining a multi-aged heather (*Calluna vulgaris*) sward, generally within the altitudinal range of the treeline zone. The management has tended to exclude taller woody vegetation.

Domestic herbivores and their forage.

In upland Scotland, 70 - 80 % of land is registered as agricultural holdings. Although this land is no longer exclusively agricultural, much of it is grazed by domestic sheep (*Orvis aries* L.). Increases in sheep numbers to hill ground in the Scottish Highlands in the mid eighteenth century have been well documented (Mather 2003) and numbers remained high well into the second half of the twentieth century (Sydes and Miller 1988). Over the same period domestic cattle numbers fluctuated by eventually steadily declined. More recently, towards the end of the twentieth and into the beginning of the twenty-first century, stock numbers, both sheep and cattle, have significantly decreased over many upland areas, particularly in the north west of Scotland (SAC no date).

Burning

Evidence of charcoal has been found in fossil remains dating from relatively soon after the appearance of humans in the UK. Some undoubtedly relate to wild fires but there is speculation that some also relate to the use of fire to flush quarry species initially, and subsequently as a tool to manage swards with the advent of more organised agriculture (Finlayson and Edwards 2003). Burning has continued as a tool to the present day, being used to encourage grasses and heather on sheep and deer ground and in particular to maintain a diversity of ages in a heather sward for grouse moor (Anon 2008).

1.5.2 Land use policy

Land use policy is reviewed in more detail in Chapter 5. Treeline scrub popoulations on land subject to conservation designations are largely protected and their condition is monitored. The condition of populations that are on un-designated land is largely dependent on land use policy or the interest and intentions of the land manager. Treeline scrub has recently achieved a higher profile and has been included in a number of sectoral plans (e.g. Forest Enterprise Strategic Plan 2009 to 2013 includes mention of montane scrub, FCS 2009b). More importantly all the treeline scrub vegetation types feature in the current agri-environment provision through the Scottish Rural Development Plan (Scottish Government, SG, 2010) and a number of Local Biodiversity Actions Plans (LBAPs, Appendix 5.1) also include targeted actions for montane scrub.

1.5.3 UK treeline scrub condition

Treeline scrub habitat

Given the complex history of factors affecting upland vegetation in the UK it is not possible to be clear how extensive tall-shrub populations might have been once the forest zone had spread to its furthest extent (Tipping 2003). Given the changing climate and increasing soil acidification (1.5.1 above) it can be speculated that it is unlikely that alpine willow scrub would have expanded far as forest areas retreated. It is possible that dwarf birch scrub may have expanded under these conditions, taking advantage of the spread of peat, although no fossil evidence to support this view has been reported. Similarly it is possible that alpine juniper scrub may have expanded into any areas where the forest retreated downhill, although the evidence for substantial movements of the treeline is not strong (McConnell 1996). Any such expansions are likely to have subsequently suffered from expansion of agricultural management in the uplands, and/or high numbers of wild herbivores.

At the current time all types of upland scrub are rare. **Dwarf birch scrub** is perhaps the most widespread but the majority of populations show evidence of chronic browsing at levels which appear to be inhibiting growth and seed production. In many cases the *Betula nana* plants are below the height of the surrounding *Calluna vulgaris* (De Groot *et al.* 1997, *pers obs*). Many populations tend to be semi-prostrate and grow on deep peat (De Groot *et al.* 1997) which has a good ground cover of mosses, while one of the most extensive and productive populations, with tall upright plants, grows on better drained steep slopes (*pers obs*). It is questionable whether the current UK prevalence of *B. nana* on deep peat results from the detrimental impacts of burning and browsing on drier areas, or whether it really provides optimal conditions for its growth. Kirkpatrick and Heal (2001) demonstrated that at one Scottish blanket bog site higher productivity was recorded from lower water table areas, and De Groot *et al.* (1997) reported that it avoids the most oceanic locations. Rodwell *et al.* (1991b) reported it as present in one of the drier blanket bog vegetation types, and Kallio and Mäkinen (1978) report it from a range of sites include exposed mountain summits in Fennoscandia.

Alpine willow scrub is the least common habitat primarily growing in high mountain areas on at least moderately base-rich steep rocks or scree normally out of reach of herbivores (Horsfield and Thompson 1997). There is evidence that any growth in reach of herbivores is browsed (Mardon 1997, *pers obs*). Many populations have few, widely spaced plants, and some are single sex populations, ruling out any possibility of seed production (Marriott, 1997). Individual populations tend to be isolated on different mountain crags. This scrub type is often found associated with neutral to base-rich grassland with or without tall-herbs

(Cooper 1997, Averis *et al.* 2004), which may inhibit the potential for willow seedling establishment, due to dense swards. Most of the alpine willow scrub willow species in the UK are on the southern or western (oceanic) boundary of their global distribution (Jalas and Suominen 1996, Myklestad and Birks 2007), suggesting that they are on the edge of their tolerance of the climatic conditions (Crawford 2008). Forrest and colleagues, as part of The Willow Project (Scottish Montane Willows Research Group 2005), investigated the prevalence of hybridisation in Scottish willow populations and found that it was not a common occurrence for the majority of sub-arctic species in Scotland. Stamati *et al.* (2007), as part of the same project, showed that clonal growth levels for *Salix lanata* and *S. lapponum* were low, at one site and that there were still high levels of genotypic variation in the two populations. This suggested that seed production had been the dominant mode of reproduction. This work focussed on the rarest willow species and this outcome suggests it is reasonable to argue that the genetic integrity of the more widespread species may be equably robust.

The two alpine juniper scrub types occupy distinct habitats. The **prostrate juniper scrub** (NVC H15, Averis *et al.* 2004) occurs in western, high rainfall, wind swept exposed areas of broken ground on schist, where the individual shrubs tend to be associated with exposed rock or scree and relatively open vegetation. Individual sites are small, scattered and uncommon and the distribution of the habitat appears to have been restricted by land use, particularly burning and browsing (Sullivan 2001). The north west of Scotland, in the very recent past, has tended to support large populations of red deer (Sydes and Miller 1988), and many areas are regularly burned to maintain sheep pasture.

Upright alpine juniper scrub generally occurs in the more eastern upland areas, with large stands in the central to eastern highlands. Stands can vary from closed-canopy dense areas of several hectares growing up to 1 ½ to 2 m in height in relatively sheltered areas, to scattered low growing, spreading individuals of limited stature in more exposed locations (MacKenzie 2000). Many stands border heathlands where the sward is managed for red grouse. Many stands of juniper, including prostrate, show evidence of continuous browsing.

Tall-shrub growth characteristics

Treeline scrub willows and dwarf birch all have essentially sub-arctic or arctic / alpine distributions, with the UK being towards the south and oceanic extreme of their range. Generally, in the UK they may not need to depend on the cold climate adaptations identified in 1.3.3 due to the less extreme climatic conditions present here. This would support the reports of De Groot *et al.* (1997) for increased seed production in dwarf birch outside the arctic, and Stamati *et al.* (2007) for a predominance of sexual spread in two sub-arctic willows in Scotland. Both willow and juniper species are dioecious, requiring male and female plants to be close enough that they can be pollinated by insects or wind, respectively. There is now evidence for morphological differences between male and female plants, predisposing one or the other to heavier browsing (Elmqvist 1988, Danell et *al* 1991, Hjältén 1992). Danell and colleagues (1991) reported a suggestion that in large, frequently flowering populations there is a bias towards female flower production. Juniper, although less palatable (Thomas *et al.* 2007) may also suffer similarly, as is evidenced by the presence of single sex populations at a number of localities across the UK (for example, Ben Lawers, Mardon 1997).

1.5.4 Climate dynamics

Current and projected

Geographically, Scotland sits on the north-western sea board of Europe with a prevailing west north-westerly air flow (Harrison 1997). Although the complex topography creates a highly variable climate across the country as a whole, the dominant and strong westerlies are the primary climatic characteristic. Superimposed on this theme are increased exposure and cloudiness with altitude (Grace and Unsworth 1988), resulting in a decrease in solar radiation and hours of sunshine over the first 1000 m asl, which is often the top of the cloud. Oceanicity and cloudiness also tend to increase with latitude and westerly longitude (Miller *et al.* 1987, Crawford 2000). Generally, winter weather is characterised by erratic snow cover and storms (Harrison 1997), although anti-cyclonic periods are generally more common than in summer. Overall, compared with other sub-arctic and alpine areas the temperature amplitude across the year is significantly less (Körner *et al.* 2003).

On the basis of the contemporary climate conditions in 1968 Pears proposed that treelines in the Cairngorms (Scotland) should be at 760 m asl, compared to the current 640 m asl, and suggested that wind and grazing were inhibiting establishment above existing trees (Pear 1968). McConnell (1996) thought that climate could not be the only determinant of treeline altitude and she demonstrated that at one treeline site in the Cairngorms *Pinus sylvestris* had not fluctuated as previously suggested. She agreed it was depressed, but proposed a range of factors including the invasibility of the surrounding vegetation and grazing pressure, as well as climatic effects. Between 1915 and 2007, Kullman and Osberg (2009) documented rises in altitude of c. 200 m by *Pinus sylvestris, Picea abies* and *Betula pubescens* ssp *czerepanovii* at the treeline in the Swedish Scandes. The rise was primarily explained as a response to temperature rises over that time, with no link to herbivores or agricultural management.

Compared with continental treeline ecotone areas upland UK is cooler, cloudier and wetter in summer, warmer with less snow cover in winter, and generally windier. Projections of climate change in Scotland show more erratic and decreasing snow cover, higher winter and lower summer precipitation, increased windiness and incidence of storms, against a background increase in temperatures (Murphy *et al.* 2009).

1.5.5 Main factors affecting UK treeline scrub: Summary

There has been a general reduction in forest cover in the UK since the early Holocene and treeline scrub is thought to have largely shared that history. Forest reduction initially resulted from changes in climate, physical and chemical properties of soil, and increasing intensity of land use. The open landscape has subsequently been maintained for relatively long periods by high numbers of domestic and / or wild herbivores, particularly in the latter half of the twentieth century (Sydes and Miller 1988). Sheep and deer have often been present on the same ground but they tend not to mix (Smith 2003) suggesting that number-based estimates of pressure may be conservative in areas where deer are moved to more marginal, less accessible ground by the presence of sheep. This pressure has largely inhibited any expansion of tall woody vegetation (Mitchell et *al* 1977, Milne et *al* 1989, Callander and MacKenzie 1991, Clutton-Brock *et al.* 2004) except through intervention to exclude herbivores, for example by fencing (Mardon 2004, 1997, Ashmole and Ashmole 2009). There are no large carnivores in Britain and large wild herbivores populations are primarily controlled by food availability and hunting by humans.

The condition of current treeline scrub habitats is considered poor and the tall-shrub plants are uncommon with limited or no evidence of self-perpetuation. Current land use policy provides incentives for treeline scrub management, but such options are not widely taken up.

The climate in the UK is less extreme than many sub-arctic and alpine areas, and the treeline ecotone tall-shrub species, which are primarily arctic, sub-arctic / alpine in global distribution terms, are on the edge of their range. Although primarily found in colder areas than the UK, these plants do not have the full range of cold adaptation characteristics exhibited by other arctic plants and it is difficult to predict how they may respond to the predicted changes. However, all the species are uncommon and exist in small fragmented populations with very limited recruitment; factors that may handicap their potential for adaptation to any changes that occur in the climate.

1.6 RESEARCH NEEDS

In recent times the lack of treeline scrub has been identified as an apparent gap in our suite of natural upland vegetation zones and there has been ongoing discussion about its restoration (MSAG 1996, Gilbert 2002, Cosgrove 2000), and a recognition that effort should be made to safeguard the remaining sites. Habitat networks (Ratcliffe *et al.* 1998) have been recognised as providing linkages between areas of semi-natural vegetation, creating valuable corridors for animal movements and dispersal through otherwise less hospitable landscapes. It has now been suggested (B Dunsmore *pers com*.) that areas of treeline scrub have a role to play in the forest habitat, with the potential to strengthen networks by connecting areas of forest over more exposed ridges and small hills. Conservation activity to restore woody vegetation at the altitude of treeline scrub is costly (Mardon 1997, Ashmole and Ashmole 2009) and to date has only been attempted by Government Organisations (e.g. SNH) or land owning conservation charities (e.g. The National Trust for Scotland (NTS), Borders Forest Trust (BFT), Trees for Life (TfL)). Far greater confidence in predicting success and improved technical specification are required before wider restoration activity is likely to be undertaken. This section identifies the key aspects of UK treeline scrub which are important for its long term survival and reviews whether there is adequate understanding and knowledge to ensure appropriate protection.

The vegetation types of UK treeline scrub are scarce and many tall-shrub species are uncommon or rare (sect 1.4.4.) and do not appear to be sustainable in the long term without intervention. The condition of the majority of habitats is either unknown or known to be poor; composed of old plants with limited capacity for expansion, either through regeneration or vegetatively (Marriott 1997, Mardon 1997, JNCC 2009a, b). Although the evidence of past extent is unclear for any treeline scrub, it is reasonable to suggest that land use has played a significant historical role in restricting its distribution, and continues to inhibit any potential for expansion or re-establishment (sect 1.5.). Climate and soil changes have also played a role and current knowledge is inadequate for the confident identification of potentially suitable sites for treeline scrub expansion.

Much of the research on treeline ecotone plants has been undertaken in the Arctic, or in alpine areas, but the UK plants are subject to different drivers and have been shown to exhibit modified growth strategies (sect 1.5.3). Consequently it would be inappropriate to apply the results of this research to the UK situation without modification. Better information on how the treeline tall-shrub plants respond to current conditions in the UK would improve the chances of successful population recovery or expansion.

Figure 1.3 sets out the main stages in the life-cycle of higher plants and identifies the key drivers which are particularly pertinent to treeline scrub in the UK. It is a reasonable aim for the conservation for any plant population to firstly, prevent extinction due to human intervention and secondly, to achieve self-sustaining populations. Each plant within a population would need to complete the cycle set out in Figure 1.3 once during its life in order for the population to remain static. As the diagram outlines there are many factors which influence the chance of a successful outcome. In addition there are land management factors which relate to policy drivers and human attitudes which can also have major impacts on this cycle.

There is virtually no literature on factors affecting *Betula nana* in the UK. Much of the data reviewed by de Groot *et al.* (1997) in their flora was from Scandinavia and North America. Kirkpatrick and Heal (2001) investigated growth in relation to water table levels at a blanket mire site in the central Highlands and showed that the condition of plants tended to be better on areas of the site with the lowest water table. Scott (2000) documented the positive response of plants to protection from browsing in the eastern Grampians, Scotland.

The genetic integrity of the fragmented and isolated willow populations could be considered an initial major issue but the Scottish Research Willow Group (2005) results suggested that this does not appear to be the case in populations of some rarer UK treeline willows (section 1.5.3). A number of authors have looked at factors affecting seed production, viability, germination and seedling establishment. Sullivan (1997) showed that in 1996 the level of seed viability was high in small fragmented *Salix lapponum* populations at Creag Meagaidh, Scotland. Despite this there was only very limited evidence of seedling recruitment into any population. Given that many other requirements for germination and establishment appeared to be adequate he postulated that invertebrate and small mammal predation may be limiting seedling survival. Shaw (2006) reported that seedling establishment was affected by invertebrates but by how much depended on the condition of the substrate. Shaw (2006) reviewed current knowledge of pollination in sub-arctic/alpine willows and determined that successful pollination was related to size and density of flowers and the proximity of male and female plants. In her own experiments on *S. arbsucula* Shaw (2006) showed that the important .interrelationships between these factors and site characteristics and weather were also important. Seed dispersal was adversely affected by still, wet weather. Barclay and Crawford (1984) showed that seed viability in *Sorbus aucuparia* L., at a treeline ecotone site in west Scotland, was inversely related to the altitude of the parent, but conversely the mean relative growth rates of seedlings increased with altitude of the parent, suggesting some genotypic adaptation to shorter growing seasons.

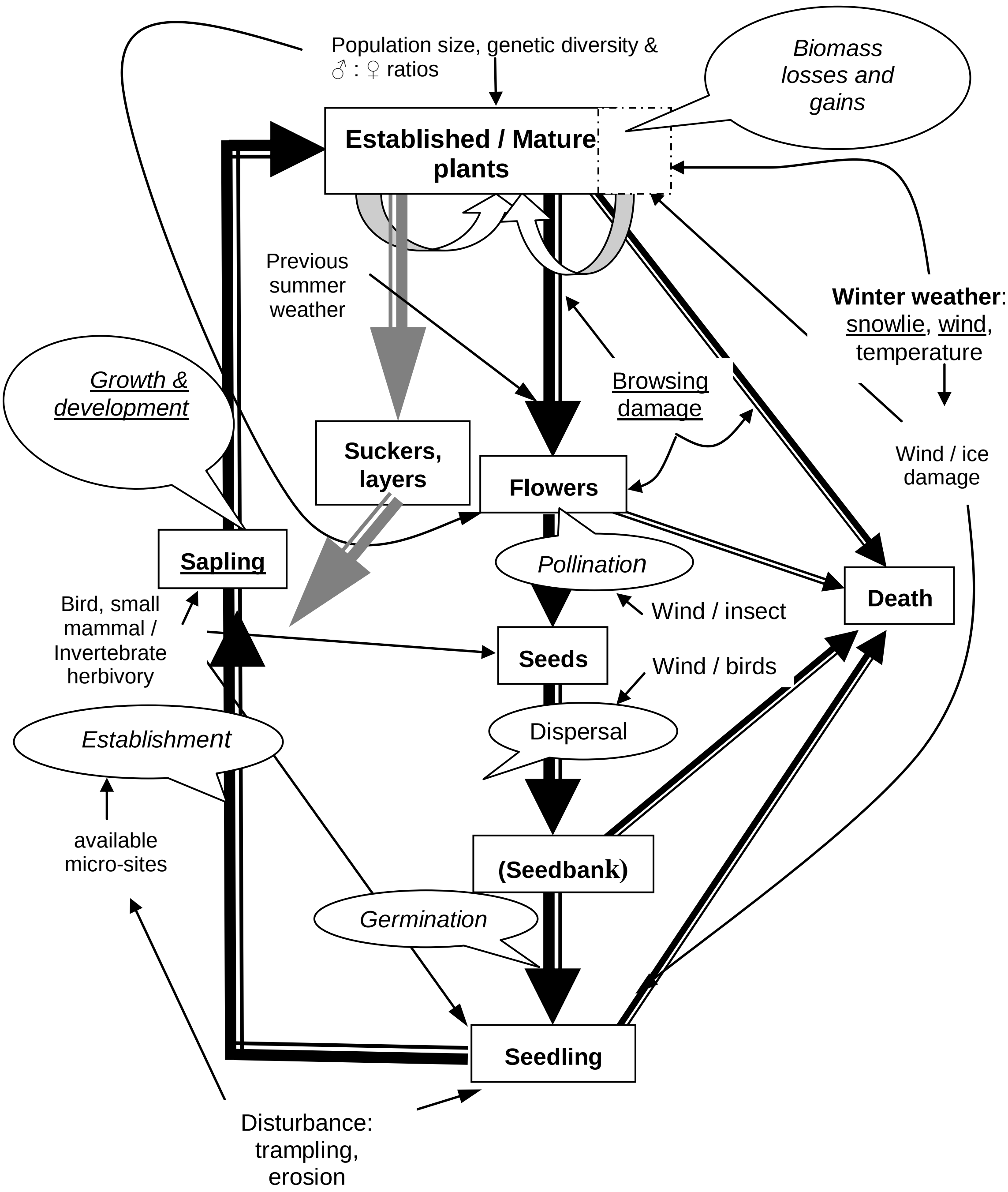


Figure 1.3. Treeline ecotone scrub growth stages (in rectangular boxes) and processes (in call-out boxes) with the current influences and factors affecting the present populations, and so potential drivers. The ongoing health of a population requires that growth equals or exceeds biomass losses. The continual survival of a population requires that establishment numbers equal or exceed the numbers of deaths of established plants. To achieve expansion the rate of vegetative spread must exceed that of biomass losses and the death of established plants. To establish new populations, dispersal, germination and establishment must exceed seed and seedling death.

This research has highlighted the inter play of factors affecting plants growing at higher altitudes in the UK, and these exist within the context of land management. Little is known about how this group of vegetation types respond to many of the key climate drivers, or current land management. There has also been no investigation of the place of treeline scrub in policy or how it is viewed by those involved in policy development and delivery.

1.7 THESIS AIMS, RESEARCH QUESTIONS AND OBJECTIVES

This thesis begins with the premise that past and ongoing land use has played a role in restricting the distribution of UK treeline scrub and that ecologically it could be more widespread (1.5.1). However changes in climate and soil characteristics have also played a role. The aim of this thesis is to provide better information on the current populations of treeline scrub and the drivers affecting their growth and management, in order to improve management guidance for existing or new populations.

The following research questions were raised:

1. a) Are there unique factors (firstly topography, altitude and aspect, secondly soil pH and chemistry, thirdly land cover) associated with the sites occupied by existing populations that suggest the current distribution of treeline scrub is at its maximum?

   b) Are land management factors (particularly herbivory) limiting treeline scrub growth and survival?

2. Do interactions between climate and land management, two major features of the Scottish upland landscape, affect the growth and development of young treeline scrub plants?

3. Is the future of treeline scrub likely to be ensured, or not, as a result of the current provisions in rural and land use policy and the current strategies for policy delivery?

If treeline scrub is a natural component of the current suite of upland climax vegetation types in the UK, then it presupposes that removal of current negative land use practices (for scrub) will stimulate the recovery and expansion of the component species to fill suitable niches. If, on the other hand, the anthropologically driven changes have had a more fundamental and longer lasting impact, natural expansion of these plants may be unlikely in the short term, without additional intervention. Any response by plants to anthropogenic factors is further compounded by variations in climate, particularly wind and snow and, linked to them, temperature. Many land managers are steered by incentives provided through implementation strategies for land use policy. Given the competitive nature of implementation projects, greater commitment to and better promotion of, the existing measures are required before land managers are likely to change their practices.

To test the above questions the following specific objectives were set:

1. establish the current condition and site characteristics of dwarf birch (*Betula nana*) scrub, alpine willow (*Salix myrsinites*) scrub and upright alpine juniper (*Juniperus communis*) scrub by gathering new data from the existing populations;
2. test, through field experiment, the interactive effects of exposure and simulated large mammal browsing on young treeline scrub plants of the above three species;
3. test, through field experiment, the effect of snow cover over winter on the growth of young plants of the above three species;
4. through a desk-based policy review, determine the extent of inclusion of treeline scrub in current rural land use policy;
5. investigate, through an interview survey, the attitude to treeline scrub of people involved in policy development, strategic delivery and influence, and the current level of uptake of existing measures.

1.8. TREELINE SCRUB TALL-SHRUBS SELECTED FOR THIS STUDY

The tall-shrub species characteristic of each treeline ecotone scrub habitat are the primary interest of this thesis because in every case they define the habitat, and in many cases they are scarce or uncommon and little is known about their dynamics in the UK. One tall-shrub species (as above) from the three montane scrub habitats (1.4.1) was chosen as the focus for the investigations. Chapter two provides detailed descriptions of the plants selected.

1.8.1 Dwarf birch scrub

Betula nana was selected as the representative tall-shrub species of Dwarf birch Scrub. It is the only constant tall-shrub component of this habitat and has shown retraction of its range from the west of Scotland (Preston *et al.* 2002) over the last forty years. This and the fact that is appears to occupy quite different sites in the UK from much of the rest of its world range suggests that it requires investigation to properly provide for its future in the UK.

1.8.2 Alpine willow scrub

There are a number of willows associated with UK alpine willow scrub (see 1.4.1). *Salix myrsinites* was selected for several reasons. *S. lanata,* the most threatened species in the

UK, is very rare, many of the existing populations are unviable and it is the subject of intense conservation effort (Anon 2007). There is also some research published from Scandinavia relating to its biology and dynamics (e.g. Walker 1987, Henry and Gunn 1991, Oullet 1994, Totland and Sottocornola 2001). *S. lapponum* has similarly attracted previous research attention (Sullivan 1997, Ross 1998) and some conservation effort (Mardon 1990, Ashmole and Ashmole 2009). It is also widely spread in Scotland and relatively catholic in its site preferences (Meikle 1984, Jonsell 2000). *S. myrsinites* is little researched, has recently attracted heightened conservation status (see 1.4.4) due to the declining populations and so requires better understanding. Although it has attracted conservation effort at one site (Scott, A 1997) little is known about its dynamics across the rest of its range in the UK. It is intermediate in its requirements between the restricted *S lanata* and widespread *S. lapponum* but has been less studied than either. Studying *S myrsinites* should not only provide useful information about the dynamics of the willow scrub habitat in general, but also valuable information to assist the conservation of *S myrsinites* in the future.

1.8.3 Alpine juniper scrub

Juniperus communis was selected as representative of alpine juniper scrub. It is the primary tall-shrub component of this scrub and it can also be considered a representative of treeline woodland. Although there has been much work undertaken on *Juniperus communis* ssp *communis* in the UK (reviewed by Thomas *et al.* 2007) there is limited literature about its behaviour in the treeline ecotone in the UK. It is also a species of some conservation concern (UKBAP no date), with particular mention of its condition at higher altitudes, and in southern England. Sullivan (2001) studied the distribution and site characteristics of *Juniperus communis* ssp *nana* and has shown that this species is very slow to propagate consequently it was decided not to use this subspecies in experimental work, see below. Sullivan (2003) has subsequently undertaken a random sample survey of *J. communis* sites from across its whole range in Scotland.

Betula nana, Salix myrsinites and *Juniperus communis* ssp *communis* were used in the following investigations to address the objectives set out above.

1.9 RESEARCH STRATEGY AND THESIS LAYOUT

The results of a field survey of site characteristics for populations of each of the three tall-shrub species were used to address Objective 1. **Chapter Two** provides a review of the known ecology and development of each selected tall-shrub species from their global distribution and particularly what is known about their dynamics in the UK. It then reports on the findings of the survey of a range of sites across Scotland, and discusses their implications for the condition of each species in Scotland.

Chapter Three gives a brief review of the separate impacts of wind and herbivory on treeline scrub; and reports on the results of a field experiment to test the response of young plants (of the same three species) to exposure and herbivory, which was set up to address objective 2. The method of propagating young plants used in this and the following experiment is also explained.

Chapter Four briefly reviews how snow cover affects plant growth, particularly in the context of predicted snow fall changes for the UK; and reports the results of a field experiment set up to compare the effect of consistent winter snow cover on young plants with erratic snow cover in order to address objective 3.

Objective 4 was addressed through a review of current policy and implementation strategies and Objective 5 through a series of semi-structured interviews with key groups of people involved in policy development and implementation. **Chapter Five** briefly reviews the history of land use and rural policy evolution in the UK; and reports the findings of both the above exercises, summarising the implications of the results for treeline scrub.

Chapter Six discusses the future of treeline scrub in Scotland from the perspective of the climate and land management factors that affect its growth and development now, and may do in the future, with particular reference to existing populations. Factors which are considered important to the identification of potential sites for new populations are discussed. The responses of the three tall-shrub species to the integrated effects of wind and browsing and to winter snow cover are discussed in terms of the sustainability of current populations and the conditions required for successful recruitment into existing populations. The implications of the results of these experiments for the management of existing populations are explored. The conclusions from the land use policy review and their potential overriding effects on the possible interest in management of treeline scrub in the future is discussed.

This research has addressed a small part of the ecology and policy issues relating to the management of marginal treeline ecotone habitats in the UK. It has highlighted ongoing gaps in our knowledge, and raised some specific questions in relation to the species investigated. These are set out at the end of chapter six.

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Chapter two: WHERE DOES TREELINE ECOTONE SCRUB CURRENTLY GROW IN SCOTLAND?

2.1 INTRODUCTION

Treeline ecotone scrub (treeline scrub) is not only uncommon in the UK but there is very little documented information about existing sites. The populations tend to be in remote inaccessible areas and, unless they coincide with protected sites, have been little visited or documented. This chapter sets out the rationale for field surveys and describes a survey that has improved knowledge of the condition of treeline scrub populations, and the characteristics of the sites they currently occupy.

There is a perception that UK treeline scrub is currently threatened and that it was once more widely spread. There is also a growing interest in taking action to protect its future. However, better information is required about the characteristics of the sites currently occupied to ensure that effort invested in the future of treeline scrub is not wasted. There has been much debate about historical changes in tree species and woodland cover in the UK (Bennett 1996, Tipping 2003, Fenton 2008, See Chapter 1.4) and the extent/causes of deforestation, particularly the differing roles of climate and land use. Where there is comprehensive historical information available about vegetation it can be valuable in providing an indication of the past distribution of species and the conditions that have affected spread or contraction. For tall-shrub treeline scrub the picture is far less clear. The generalities of the return of plant groups 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, these reports tend to focus on tree species (primarily pine and oak) with limited or no mention of treeline ecotone tall-shrubs (*Salix* spp, *Betula nana* or *Juniperus communis*). This gap is partly explained by the lack of clear evidence for these species in the pollen record (Ives 1977, Tipping 1997), although some useful data do exist for specific areas or sites (for example northern Scotland and western islands, Bennett 1995). To date data are scarce for all the treeline ecotone tall-shrub macro-fossils, perhaps because palynological work at higher altitudes in the uplands has been limited (Tipping 1997). As a result there are different views among vegetation historians about the exact altitudinal extent of the forest zone in the uplands (Tipping (1994) and Bennett (1996) gave the main extremes of opinion) and the amount of land that would have remained between the forest line and mountain summits and potentially occupied by treeline scrub. In a detailed and comprehensive study of the palynological and macrofossil evidence at a site in south west Scotland, Bos *et al.* (2004) quoted evidence from modern studies at higher latitudes for under-representation of *Salix* in pollen records and over-representation of *Betula nana*. Bos *et al*. (2004) found evidence of *Betula nana*, both macrofossil and pollen, but admits that the separation of this species from the tree *Betula pubescens* is tentative (Birks 1968, Ives 1977). This was a study of deposits laid down prior to the last glacial period and so does not contribute to the discussion of vegetation cover during the current interglacial.

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 1991). It seems likely that in combination they create different conditions at the current time from any earlier period in this interglacial. As a result it may be unreasonable to suggest that the past can provide a template for a realistic distribution of vegetation types at the present time (Tipping *et al.* 1999, Willis *et al.* 2007). A study of the function of tall-shrubs in the arctic (Bliss 1971, Bélisle & Maillette 1988) suggested that sub-arctic 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 profiles produced by paleobotanical studies simply reflect the relative levels of flowering across species rather than their frequency, so perhaps the 'over-representation' referred to by Bos *et al.* (2004) reflects the difficulty in separating *B. nana* from tree birch pollen. Rymer (1973) showed that modern pollen rain in Iceland included relatively high levels of undifferentiated *Betula* pollen in elevated areas, while *B. nana* specific pollen was reasonably consistent with the frequency in the sward.

Scottish records for treeline 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 is in the form of presence in a 1 or 10 kilometre squares with limited additional information. Conversely, there may be a ten figure Ordinance Survey grid reference with additional information about other species present and/or 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 take much longer).

This chapter reviews the current knowledge of distribution, ecology and population dynamics for three treeline tall-shrub species selected as representative of the key treeline scrub habitats (see Chapter 1.8), *Betula nana, Salix myrsinites,* and *Juniperus communis.* It reports on a field survey of each species that sampled a range of site types from all the available population records with a grid reference of 1 kilometre square resolution or more and where populations contained at least ten plants. The aim of the survey was to identify the range of site types currently occupied by each species and, where possible, to relate these to plant condition. Finally, the outcomes of the survey and their relevance for the future of the tall-shrub populations are discussed in the context of current and potential distributions.

The objectives of the field survey were to:

Select field survey sites from across Scotland that span the range of known site types and support populations with at least ten plants.

At each site to collect information about:

- the topography and physical nature of the area inhabited by the tall-shrubs;
- the distribution of the population within the site, including the spacing and size of plants;
- the sward vegetation;
- the condition of the tall-shrub plants;
- the land management of the area supporting the population, including evidence of herbivore presence (e.g. dung, fur, tracking, sight) and impact on the vegetation;
- the soils on which the tall-shrubs are growing.

These data provide a description of the condition of the tall-shrub populations at each site, the site characteristics in terms of vegetation and land use, and a range of site soil characteristics. This permitted an examination of the conditions under which these three species are currently growing in Scotland.

2.2 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. European and UK distribution maps for each species were accessed from Atlas Florae Europaea (Jalas and Suominen 1996) and the New Atlas of British and Irish Flora (Preston, Pearman and Dines 2002).

2.2.1 *Betula nana* biology, distribution and ecology

This review concentrates on information relevant to the purpose of the field survey and is largely based on information taken from a flora on *Betula nana* and its close relative B. glandulosa by De Groot et al. (1997) and supplemented by more recent literature or experience.

Biology

Betula nana belongs to the Betulaceae, a group of deciduous, monecious, generally catkin bearing trees or shrubs (*Corylus* is the nut-bearing exception). Of the three *Betula* species in the UK, *B. nana* is the only non-tree, tall-shrub member. *Betula* species are generally considered to be northern colonisers producing large amounts of wind pollinated and dispersed, small, short-lived seeds. They tend to be relatively short-lived trees, in the order of 100 years, and can spread rapidly under the right weather and site conditions (Harding 1981, Stewart 1996). *B. nana* does not appear to necessarily follow this form. There is no clear evidence of how old it grows in the UK. De Groot *et al.* (1997) quotes a figure of 147 rings from one individual stem in Greenland but acknowledges that 50 to 80 is more common. Whittaker (1993) acknowledged the clonal nature of the plants and quoted reports of minimum ages of >75 years, but suggested >50 years was more common on the glacial foreland in Norway. Ashton (1984) proposed that the UK populations had been dependent on clonal regeneration because of the low viability of seeds and the poor success of germination and establishment trials that he undertook. De Groot *et al.* (1997) suggested that flower and seed production increased towards the centre and southern edge of its range. The plant readily reproduces vegetatively in the UK and there is a lack of evidence of young plants at many sites, which suggests that this may not be the case at the oceanic edge of its range, and suggests that UK individuals may also be longer lived than the ages given above.

In the UK *B. nana* is a relatively short tall-shrub up to 1m but rarely exceeding the height of the surrounding heather or 0.5 m (De Groot *et al.* 1997). In Scandinavian populations readily reaches 1.5 m in height. Whittaker (1993) described it “as a tree growing on its side” from studies he had undertaken on glacial foreland in Norway, and suggested fragments of horizontal stems regenerate easily. Root suckers can also occur frequently (De Groot *et al.* 1997).

Distribution and status

Betula nana is a northern circumpolar plant with two subspecies primarily separated by geography. Only *B. nana* ssp *nana* occurs in the UK and although its distribution extends as far south as the Alps its habitat requirements confine it to high ground in the southern half of its range, and it is absent from Ireland. It has only been recorded in the UK as far south as Northumberland (55° N) with a few current native records south of the highland boundary fault (56° N, Preston *et al.* 2002). It is relatively widespread across upland Scotland, extending from Stirlingshire (56°9'N 3°5'W) up to Caithness (58°2'N 3°4' W), and from Wester Ross (57°3'N 5°4'W) across to Deeside (57°9'N 2°5'W) (Preston *et al.* 2002), and is now absent from the Southern Uplands. Outside the main populations in central Ross and Inverness-shires, it tends to be in relatively small groups of scattered plants and it is possible that such populations consist of only a few clonal individuals.

Preston *et al.* (2002) reported that although a few new populations are being found between national plant atlas collations, these are previously over-looked populations and generally the species is in decline. They do not present any specific evidence for this claim, but the new populations tend to be within the boundary of the known distribution whereas losses tend to be on the western and southern boundaries. For example, records from the early 20th century for populations on the small isles to the west of mainland Scotland and the extreme western seaboard have not been relocated for over fifty years (National Biodiversity Network 2010).

In the UK *B. nana* is found between 100 m asl in Sutherland (58°N 4° 33'W) and over 855 m asl in the Angus Glens (56° 7'N 3°W) (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 sites (Highland Birchwoods 2000) all the records below 400 m asl are from the western counties including Sutherland, Ross-shire 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 higher mean annual temperatures at just less than 21°C and higher rainfall (1200 – 2000 mm per annum) than across the remainder of its range, where mean winter temperatures of -25°C and summers of 3°C, with rainfall of 300 – 400 mm per annum are common. It has been suggested that it may not be tolerant of 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 showed development of frost resistance and reddened leaves in response to a seven hour day in July in West Greenland.

Ecology

Kirkpatrick & Heal (2001) measured the growth of *Betula nana* in relation to ground water and soil water nutrient content at a blanket mire site in the Monadhliath (57°1'N 4°18'W, 619 m asl) to the west of the Cairngorms. Their study, commissioned by SNH, measured 33 plants which occurred within quadrats sampled inside a large mammal-proof enclosure. 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 more 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 *Betula 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 (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 (obviously, in years when snow cover reaches sea level it will be snow-covered). 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 less 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 herbivore preferences for dwarf birch compared to *Calluna vulgaris*. Bryant and Kuropat (1980) reported that in sub-arctic forest areas of Alaska, Iceland and Fennoscandia that 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 com*). 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.

2.2.2 *Salix myrsinites* biology, distribution and ecology

There is no biological flora for this species and only very limited literature from studies which have included *S. myrsinites.* The species-specific information below comes primarily from Christensen *et al.* (2000) and Meikle (1984) descriptions, supplemented by studies on other mountain willow species.

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 room temperature 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.

Distribution and status in the UK

In European terms *Salix 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. (Meikle 1984). 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 last 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).

Ecology

Preston *et al.* (2002) reported that *S. myrsinites* is apparently not very tolerant of browsing and is primarily confined to un- 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 *Alces alces, Lepidus* spp, Tetraonids, and voles have been reported by a number of authors (Bryant and Kuropat 1980, Maschinski and Whitham 2001, Stolter 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).

2.2.3 *Juniperus communis* biology, distribution and ecology

This survey was concerned with the two sub-species, *Juniperus communis* ssp. *communis*, and *J. communis* spp *nana* as they both occur in the treeline ecotone in Scotland. Thomas *et al.* (2007) completed a comprehensive flora for *J. communis* and its subspecies in the UK and those aspects of the flora relevant to higher altitude populations has formed the basis of the review below. The information quoted on the subspecies *J. communis* ssp *nana* has largely been drawn from Sullivan (2001) who examined its history, distribution and ecology in the UK.

Biology

J. 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. c.* ssp *communis*, *J. communis* ssp *nana* and *J. communis* ssp *hemispherica*. Only the first two occur widely and in Scotland, the latter is confined to a few populations in the extreme south western tip of England and Wales at sea-level 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. c.* 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.

Distribution and status in the UK

Juniperus communis occurs from the south to the north coast of the UK, 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.

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.

2.3 METHODS

The survey was divided into two parts. An initial data collation exercise bringing together available information about the records of existing populations of *Betula nana, Salix myrsinites* and *Juniperus communis*. This exercise identified a set of sites that represent the range of geographic and environmental characteristics for the second part: a field survey.

2.3.1 Field site selection

Data collation

In 2000 a dataset of known montane scrub records was collated by MacKenzie (2000). The records were those for all tall-shrubs classified as montane scrub species by the Montane Scrub Action Group (Scott 2000) plus *Sorbus rupicola* (Rock whitebeam), as well as areas of woodland identified as being “in a wind-pruned or stunted shrub-like form on exposed coastal, cliff and treeline sites” (MacKenzie 2000). MacKenzie collated the data from existing records in the offices of public bodies and from national collections, for example, the Biological Records Centre.

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

Missing physical data for each record (e.g., aspect, altitude or slope) were filled by layering the dataset in ArcGIS 9.0 with Ordinance Survey 100 x 100 km square Digital Terrain Model data and reading the appropriate values from under the scrub location. 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 relative to either the north-west or north-east. This was achieved by subtracting 45° from the aspect angle and calculating the cosine and sine, respectively, of each angle. The purpose of this transformation was to generate linear data which could be analysed alongside other features. Aligning the data in terms of its north-westerliness or north-easterliness (by subtracting 45°) provides an indication of how important these two aspects are to the data. Given that Scottish ridges, and soil temperature gradients tend to be aligned from south west to north east, this is more useful than the north-south alignment. In order to avoid false north readings, level ground, or zero aspect and slope values were re-set to zero in both aspect transformations (0° is due north and after subtracting 45° has a cosine (0.71) and sine (-0.71) value). 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, MLURI, 1993)
- Soils data (Macaulay Institute for Soil Research, MISR, 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 *Juniperus communis* there was an additional category of 'bracken cover' due to the presence of bracken in some of the LCS categories at *J. communis* record sites. 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 2.1. The rankings for each LCS88 and soil type for each species are provided in Tables A2.1, A2.2 and A2.3 in Appendix 2.1.

Data Analysis

The final output of this collation of information was a dataset of sites for each species which included a site identifier (site number) and 20 different characteristics for analysis. Minimum and maximum altitudes were highly correlated and as a result they were averaged, reducing the list to 19 (Table 2.2). Bracken presence was included in the LCS88 characteristics for *Juniperus communis,* so the list was 20 for *J. communis* analysis.

Each species dataset was examined using GenStat 10.0 Principal Component Analysis (PCA) with the 19 characters in Table 2.2 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 (Appendix 2.2 Fig. A2.1).

The general field survey site selection process was as follows:

i) A plot of the distribution of records for each species across the first two components was generated. 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) Each quadrant of the component plots (Fig. 2.1, 2.3 and 2.5) was identified as a separate category for site characteristics. The four categories for each species are given in Tables 2.4, 2.6 and 2.8.

Table 2.1 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)

Soil character categories	**Range**	**Definition**
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 categories	**Range**	**Definition**
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

Table 2.2 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 (north-easterly)	cos aspect	• Peat content	peat
• Sine aspect (south-easterly)	sin aspect	• Wetness	wetness
• Slope	slope	• Mineral content	mineral
• X coordinate, (easterly-ness)	Xcoord	• Alpine	alpine
• Y coordinate, (northerly-ness)	Ycoord	LCS88	
• Growth Degree Days	GDD	• Bogginess	bog
• DAMS (exposure)	DAMS	• Heather cover	heather
		• Grass cover	grass
		• Tree cover	trees
		• Stability	stability
		• Rockiness	rock
		• Burning	burning
		• Bracken[1]	bracken

[1] used in *Juniperus communis* analysis only

iii) Each species record was then cross-referenced to the native woodland model (NMW) classification category (Table 2.3, 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.

Table 2.3 List of Native Woodland Model predicted habitat types cited and descriptions

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

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 for the next stage.

v) A number of PCA/NWM categories (Tables 2.5, 2.7 and 2.9, respectively) contained large numbers of sites and so represented clumps with similar characteristics. Given the limited number of sites that could be surveyed these clumps were specifically included in the final list. 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 sites were checked according to the evidence in the database 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.

The species specific aspects of this selection process and the prevalent features of each PCA plot are given later.

Betula nana

The strongest positive correlations with the first component (PCA1, Fig. 2.1) were bogginess, peat cover and burning. Equally strong but negative were slope, alpine and mineral content. Y-coordinate (northerly-ness), wetness and a south-easterly (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 (Fig. 2.1) and exposure (DAMS) and altitude were negative.

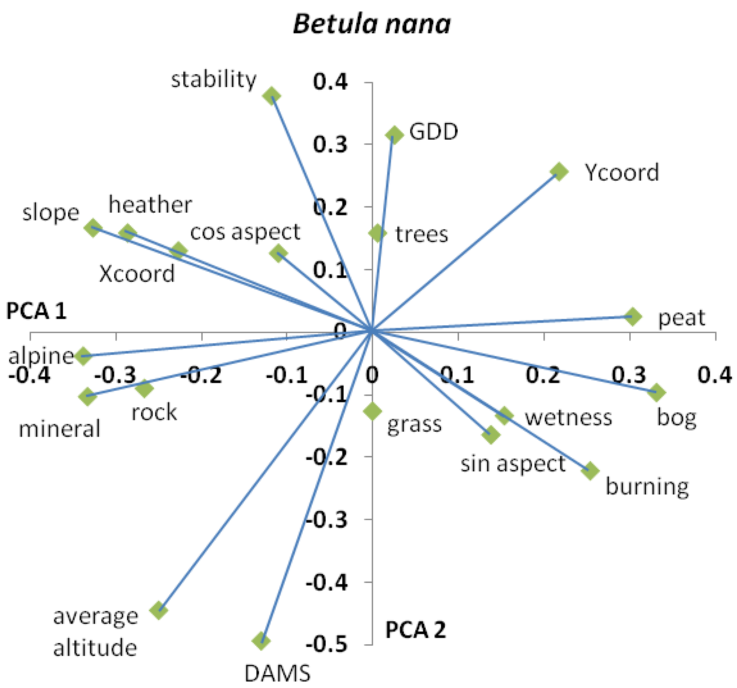


Figure 2.1 Principal Component Analysis primary and secondary component scores from *Betula nana* records. See text for interpretation.

When plotted onto the first two components axes the sites were well scattered (Fig. 2.2) with the exception of a cluster of records from the same geographical area, Glen Muick, Deeside (56° 55' N, 3° 12'W), at the extreme end of the alpine and mineral axis. The four PCA categories identified through this process as given in Table 2.4. 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 2.5 a). The allocation of the 15 field survey sites is given in Table 2.5 b).

Table 2.4 *Betula nana* site characteristics derived from PCA primary and secondary component scores

Category name	C1 score	C2 score	Description
A	0 to -7	0 to 5	Populations in the east on steeper slopes with a dryer 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

Table 2.5 a). The breakdown of *Betula nana* sites by PCA type (see text for explanation) and Native Woodland Model (NWM) predicted site suitability. **b).** The selection of fifteen sites for field survey according to the representation across PCA and NWM categories.

a). PCA type	**Native woodland model predictions[1]** Sc 1	**Sc 3**	**Sc 5**	**Sc5/ W18**	**Sc5/ W4**	**Sc5/ W4/ W17/ W18**	**Sc 7**	**U**	**W17/ W11**	**W17/ W18**	**W18**	**W18/ Sc5**	**W18/ W4**	**W4**	**W4/S c5**	**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

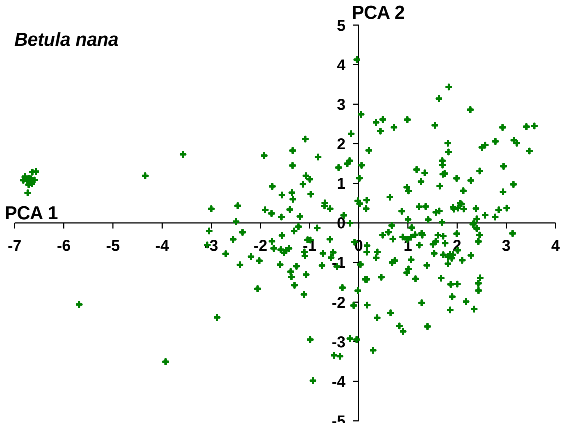


Figure 2.2 Distribution of *Betula nana* records on the Principal Component Analysis primary and secondary component axes. See text for interpretation.

Salix myrsinites

The *Salix myrsinites* first component axis (PCA 1) was very positively correlated with altitude, alpine and mineral content, and less so with exposure and easterliness. Wetness and peat content were strongly negatively correlated to PCA 1and 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 (Fig. 2.3). The four PCA categories generated from this plot are given in Table 2.6.

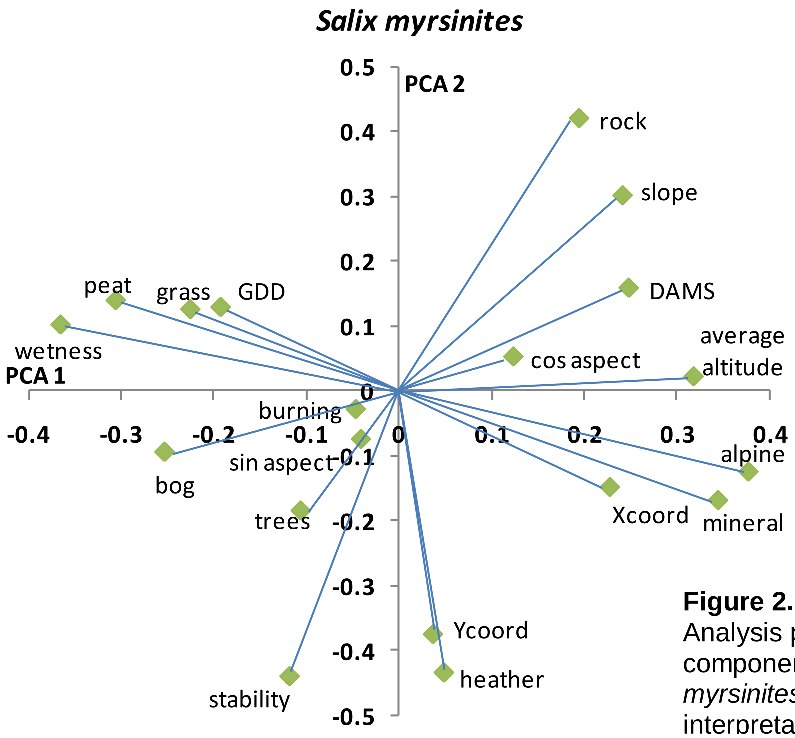


Figure 2.3 Principal Component Analysis primary and secondary component scores from *Salix myrsinites* records. See text for interpretation.

Figure 2.4 shows the distribution of *S. myrsinites* sites on the two axes and their relationship to the different categories in Table 2.6. There were 36 sites left following the assignment of NWM categories and grouping of multiple records for the same site. Table 2.7 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.

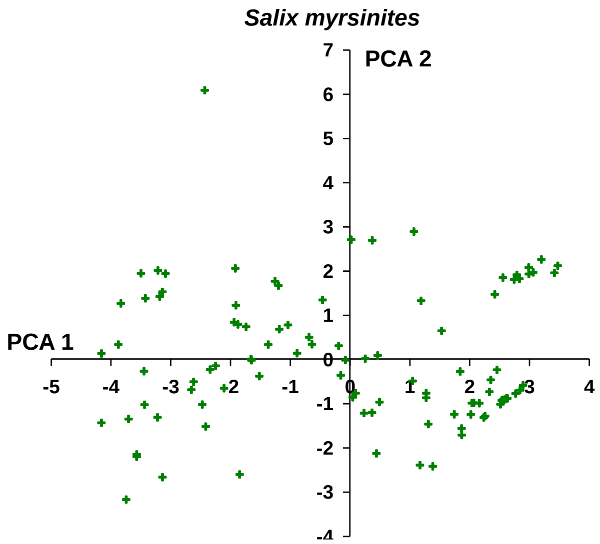


Figure 2.4 Distribution of *Salix myrsinites* records on Principal Component Analysis primary and secondary component axes. See text for interpretation.

Juniperus communis

Only *Juniperus communis* records from the original database with altitudes greater than 351 m asl were used in the analysis. Bracken was included because it can be a dominant feature in the Land Cover Scotland categories on which *J. communis* occurs. Figure 2.5 illustrates the relationship between the first two components from the PCA analysis. Alpine, altitude and mineral 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 2while bogginess was negatively correlated along with rockiness and exposure (DAMS). Neither aspect nor northerliness were strong contributors to the first two components. Table 2.8 shows the categories developed from the four quadrants of the plot in Fig. 2.5.

Table 2.6 *Salix myrsinites* site characteristics derived from PCA primary and secondary component scores

Category name	C1 score	C2 score	Description
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

Table 2.7 a). The breakdown of *Salix myrsinites* sites by PCA type (see text for explanation) and Native Woodland Model (NWM) predicted site suitability.
b). The selection of 15 sites for field survey according to the representation across PCA and NWM categories.

	Native Woodland Model predictions[1]													
a). PCA type	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 4**	**Sc5/ W4**	**Sc 7**	**Sc 8**	**U**	**W9**	**W17/ W18/ W4**	**W4**	**W4/S c5/W 17/W 18**	**W18/ W17**	**Total**
A	1		3	1	1						1	1	2	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	1	2	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

[1] see Table 2.3

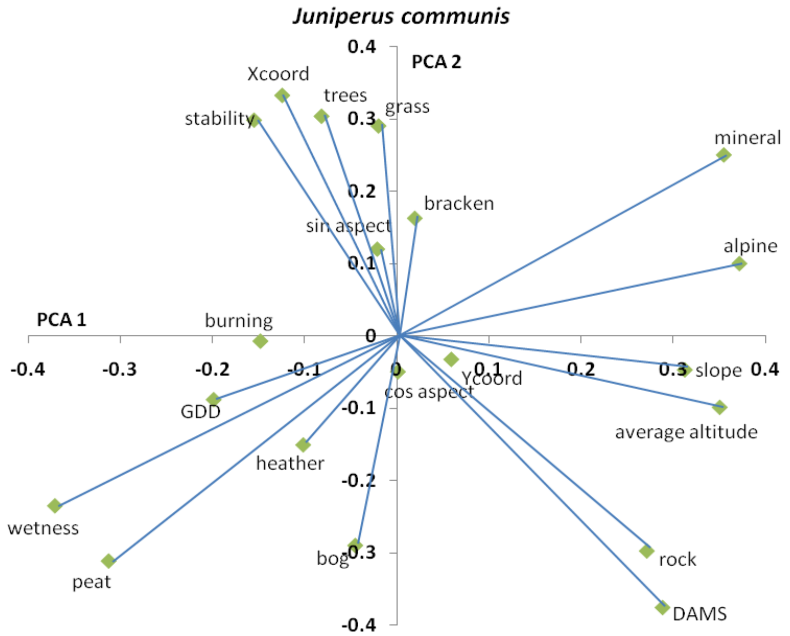


Figure 2.5 Principal Component Analysis primary and secondary component scores for *Juniperus communis* records. See text for interpretation.

Figure 2.6 shows the distribution of records across the two component axes. Following the addition of NWM categories and grouping of multiple records for the same site there were 154 sites. Table 2.9 shows how these were spread across the different PCA and NWM categories and which categories were in the final field survey.

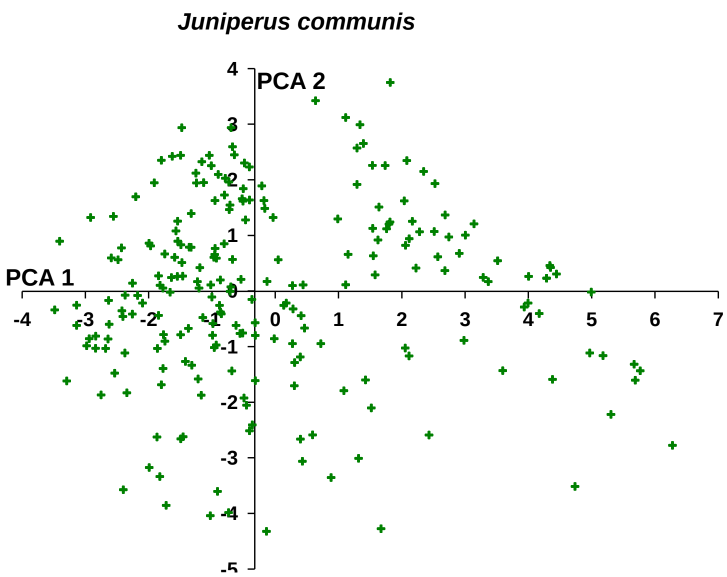


Figure 2.6 Distribution of *Juniperus communis* records on Principal Component Analysis primary and secondary component axes.

Table 2.8 *Juniperus communis* site characteristics derived from PCA primary and secondary component scores.

Category name	C1 score	C2 score	Description
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 which 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

2.3.2 Field survey

Data collection

The field survey was a single-visit-per-site survey undertaken between May and October, 2008. As far as possible trips were organised so that sites in the same general location could be visited on following days. All site owners or managers were contacted and informed about the survey in advance. In some cases where the populations were on designated land this required liaison with Scottish Natural Heritage (SNH). Permission was not directly withheld for any site but in the case of one *Juniperus communis* site an alternative was identified when SNH were unable to confirm permission due to ongoing negotiations with the owner. A total of 15 populations for each species were identified through the site selection process. A site was defined as at least 10 individuals of the target species within 1 ha or less, in either dense stands or scattered individuals, where the scattered individuals were not more than 5 m apart. Where a population exceeded 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 information collected related to aspects of the sites which were independent of the time of year. Leader lengths, which change, were also collected.

At each site field survey sheets (Appendix 2.3 Fig. A2.2a & b) were completed according to the protocol in Appendix 2.3 Figure A2.2 c & d. The survey sheet was separated into information gathered about the site as a whole from a general walk around the population, and data collected within 2 m x 2 m quadrats placed systematically within the site. Evidence of land management (grazing, drainage or burning) was gathered at the whole site level.

Whole site data

An initial walk around the site defined the boundaries, ensuring that individuals within the population were less than 5 m apart. For easily accessible sites the corners of the population were marked with canes and grid references recorded by GPS (Garmin Summit©). The general distribution of the population and variations in growth form and regeneration were

Table 2.9 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.

a). PCA type	Predicted NWM type[1] Sc 1	Sc 2	Sc 3	Sc4	Sc 5	Sc 6	Sc5/W4/W17/W18	Sc5/W4	Sc 7	Sc 8	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	W 4	W4 a	W4/Sc5/W17/W18	W4/W17/W18	W4/Sc5	W7	W 18	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

noted, as well as any evidence of burning, browsing, and presence of herbivores. Herbivore presence was based on actual sightings, droppings, browsing damage, evidence of tracks, holes in the ground (voles), foot prints, fur, or any other clearly identifiable evidence of presence. Table 2.10 provides a guide to the estimation of herbivore presence. It is only a guide because the size and nature of the sites varied. Data were collected from the centre of the site on its physical nature, including aspect, slope, altitude, TOPEX and notes were made of variations in soil moisture and bare ground. The majority of *Salix myrsinites* populations were on steep, rough, unstable slopes and it was not possible to walk around the site. The general spread of the population across the slope was identified as far as possible from above or below. Much of the site information was recorded when half way through the sample point survey by which time the centre of the site had been reached. The location and altitude was recorded by GPS at each sample point. At a number of *S. myrsinites* sites it was not possible to maintain the minimum 5 m spacing criterion because many populations were restricted to areas where soil has collected and formed between crags and cliffs. The areas of exposed near-vertical rock were often more than 5 m across.

Table 2.10 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

The time on site and the weather during the survey were recorded, as well as the names of the surveyors involved.

Sample point (quadrat) data

From the corner grid references the approximate size of the population was estimated. In most circumstances sites were on a slope. Ten 2 m x 2 m quadrats were systematically spaced evenly across the site along transects which, for ease of working and to aid with accuracy of finding quadrat positions, ran up and down the slope. For *S. myrsinites* populations, which tended to be on slopes which have greater horizontal spread than vertical, the quadrats were placed alternately, e.g. one then two per vertical pass, in order that the quadrats were well within the population boundaries. At several sites, in practice, it was a matter of locating the quadrats where it was possible to include vegetation, rather than bare rock.

A flexible 2 m x 2 m quadrat was used to sample both the ground vegetation and the target species. The quadrat positions were located by counting steps from the down slope or up slope boundary of the site and using GPS for verification. Once the location had been reached the quadrat was placed on the ground immediately in front (in relation to the direction of travel). As sample points were systematically located they did not necessarily include an individual of the target species. Where they did not, the closest individual to the quadrat was sampled. Where there was more than one individual in the quadrat the one closest to the surveyor when the position was first reached was sampled.

Within the 2 m x 2 m quadrat the percentage cover was recorded for the four most dominant plant species. Measurements of the individual target species plants were made: height, longest horizontal canopy diameter and the diameter horizontally perpendicular to it, the length of the leader and the number of stems from the base (1 to 5 counted individually, and >5 in one category). The basal diameter was measured for all the stems up to five, or the five largest where there were more than five. The growth form was categorised and any evidence of browsing was classified by intensity and age. (Fig. A2.2 c, in Appendix 2.3, provides the protocol for the sample survey). Browsing intensity was recorded on a scale of 1 to 5 (1 = 1 – 20%; 2 = 20 – 40%; 3 = 40 – 60%; 4 = 60 to 80%; & 5 = 80 to 100% of the canopy showing damage to current year's growth). The heights of the different vegetation layers and soil depths were recorded from the centre of the vegetation within each quarter of the 2 m x 2 m quadrat. A soil core, approximately 5 cm diameter by 15 cm deep, was taken from the four quarter quadrats at four different quadrat positions across the site, for later analysis. For each quadrat position the four cores were amalgamated, unless visually and texturally very different, as was the case with one core at a *S. myrsinites* site. A plant species list was generated for the whole site during the survey and at one quadrat position (usually number 6 or 7) a full list of vascular plants and most bryophytes was made with percentage cover estimated by eye.

The judgement of the condition of a population for each of the species was anticipated to be a combination of the distribution of the plants across the site, taking physical site factors into account, the size of plants, in terms of height and spread, 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 suggests plants are in reasonable health. Absence in one year does not indicate poor health. Burning, browsing impacts and surrounding vegetation also help qualify the condition in terms of an assessment of future potential.

Soil chemistry

Soil samples were chilled within 4 hours of collection and frozen within 48 hours. They were 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 M $CaCl_2$ was then added to create a 0.01 molar solution of $CaCl_2$ and mechanically mixed for a further 30 minutes before leaving to stand for 2 hr. The pH was measured in the supernatant above the soil. In order to ensure quality of procedure and performance of the electrode three test soils of known pH were included within the set of soils. The electrode was calibrated at the beginning of each day by laboratory staff and when not in use was standing in de-ionised water. Soil particles absorb hydrogen ions on drying, particularly in organic soils and re-wetting in H_2O does not tend to re-release them to the same extent as a weak $CaCl_2$ solution (Sumner 1994). Measuring pH in de-ionsied water is generally in the order of 0.5 pH points higher than in 0.01 molar solutions of $CaCl_2$ for organic soils.

Plant available calcium, phosphorus, potassium and magnesium 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). Three test soils and a blank (of 0.43 M acetic acid) were included with the set of soils to provide a measure of quality control on the procedure and equipment. The presence of the four cations is provided in parts per million (or ml/litre of solution) but is more usefully expressed as mg/kg of dry soil, for which the moisture content of the soil is required. This was determined by placing an accurately measured (to four decimal places, between 1 g and 5 g) sample of each soil in a porcelain crucible in an oven at 105°C for at least 2 hours. The hot samples were placed in a desiccator until cool before re-weighing accurately (to four decimal places). Three test soils of known moisture content were included as quality control. The concentration of cations in the soil (X measured in mg/kg) was then calculated 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.

Approximately 10 g of each sample was processed in a ball mill to a fine powder in order to achieve a uniform material. This material was used for analysis of the total elemental nitrogen (N) and carbon (C). 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) and the weights automatically recorded in a sample table. The tin cups were crushed in order that no material could be lost prior to analysis. A sample batch consisted of 40 samples which for purposes of instrument check and quality control included two bypasses (white wheat flour), two blanks of crushed empty tin cups, and six tests of incrementally increased weights of a reference material, in this case milled grass, then a low carbon test (Leco) and a standard test of upland soil. In total 12 quality control samples were included at the start of each batch and a test soil at every 11th sample. 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.

Data handling

The data from the survey forms and the soil chemistry and pH values were entered into an Access database for further collation and presentation. The quantitative measurement data from the ten quadrats per site were pooled for each population and the means, maximums and minimums were used in any further analysis or presentation. Canopy area was calculated from the longest horizontal canopy diameter (LCD) and the diameter horizontally perpendicular to it but proved to be closely correlated with the LCD and neither it nor the perpendicular diameter measure was used. For measurements of vegetation layer heights and soil depths this meant the inclusion of four separate 1 m^2 measures for each of the ten 2 m x 2 m quadrats (n = 40). The site means were generated directly from all 40 measures.

Statistical analysis

Where multiple measurements were collected for different parameters at each site they were summarised as means, with the range. The site means for total carbon and nitrogen and available cations (Ca, P, K and Mg) were each separately tested across the whole dataset in a one-way analysis of variance (ANOVA) for difference between the sites of the three target species in GenStat 10©.

2.4 RESULTS

2.4.1 Field site selection

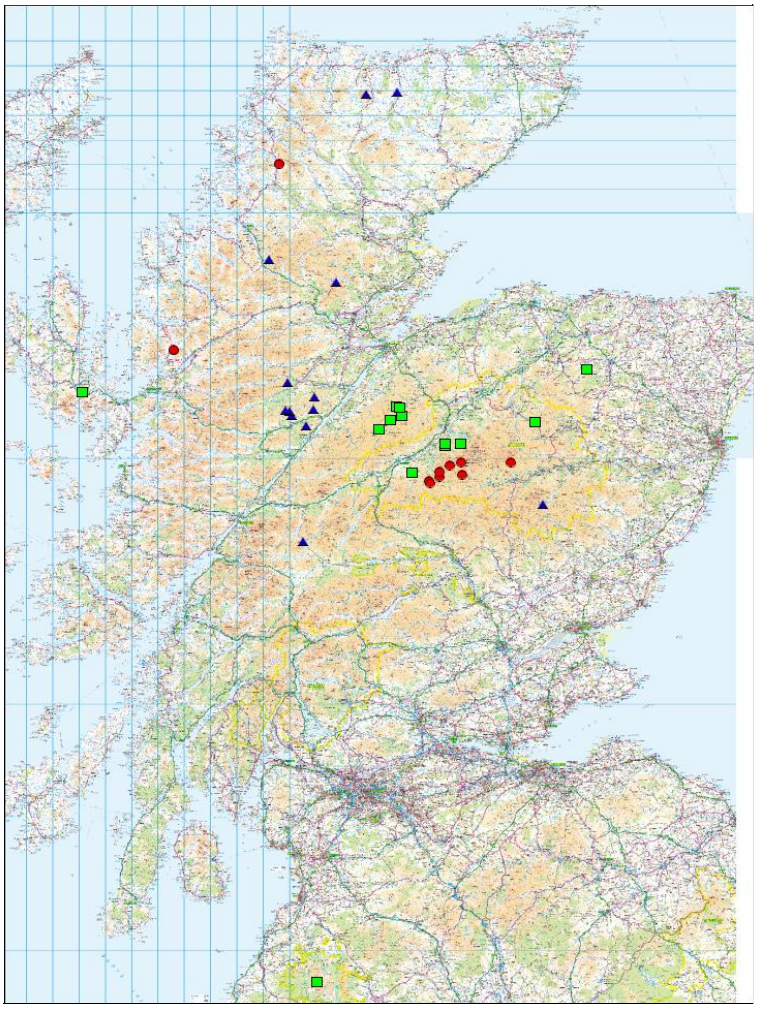


Figure 2.7 Map showing the location of *Betula nana* (blue triangles), *Salix myrsinites* (red circles) and *Juniperus communis* (green squares) sites which were surveyed over the summer of 2008.

Figure 2.7 is a map of the field survey sites selected. Thirteen sites were surveyed for *Betula nana*, 12 for *Salix myrsinites* and 13 for *Juniperus communis*. At two *B. nana* sites no plants were found with the 1 km square of the record. In one area an alternative population was found in the neighbouring 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, Castle Hill, was about 1 km north west on similar but more sheltered ground.

2.4.2 Field survey findings

Inter-species comparisons

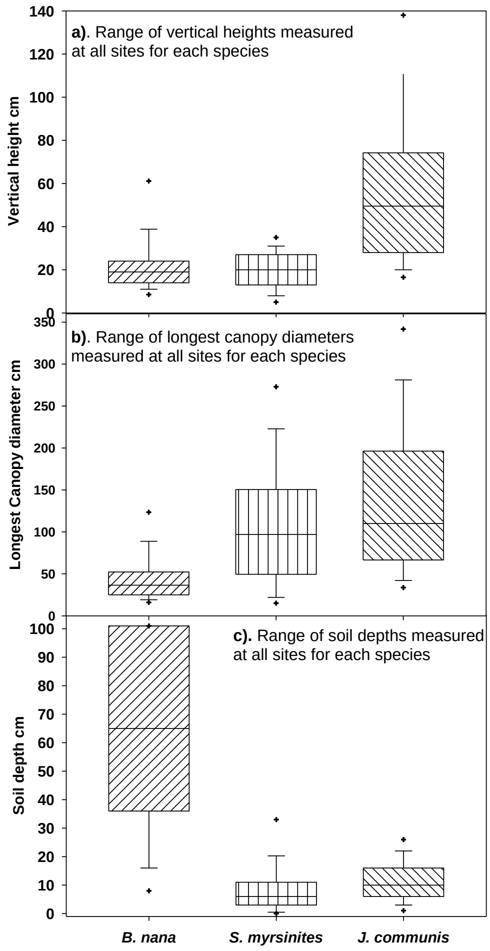


Figure 2.8. Boxplots of the range of variation in a) vertical plant height (cm) b) longest canopy diameter (cm) and c) soil depth (cm) for *B. nana, S. myrsinites* and *J. communis.* The box gives the median +/- 25 percentile and each + gives the 5th and 95th percentiles.

Although the primary interest in the survey relates to the range of variation across the sites occupied by each species, it is nonetheless interesting to compare the variation between the three species. As might be expected the species differences in plant dimensions are primarily related to vertical height (Fig. 2.8a) where *J. 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 the least variation in height and relatively short plants. *J. communis* had the largest canopy diameter values and although there was considerable overlap with *S. myrsinites* this was not the case with *B. nana* (Fig. 2.8b). *B. nana* sites had the deepest soils measured in the survey but *S. myrsinites* and *J. communis* sites showed very similar ranges of soil depths (Fig. 2.8c).

Betula nana sites had significantly higher carbon, nitrogen and phosphorus than either *S. myrsinites* or *J. communis* sites ($P < 0.05$) and significantly lower pH values ($P < 0.05$, Table 2.11). Potassium levels were significantly higher than *S. myrsinites* sites ($P < 0.05$), but not *J. communis* sites and calcium levels were significantly lower than *S. myrsinites* sites ($P < 0.05$) but not *J. communis* sites. *S. myrsinites* sites had significantly lower levels of carbon, nitrogen and potassium ($P < 0.05$) than either *B. nana* sites or *J. communis* sites, and significantly lower levels of phosphorus than *B. nana* ($P < 0.05$). Levels of calcium and pH values were significantly higher than at either of the other species' sites ($P < 0.05$). *J. communis* site values tended to be in between the other two species and for carbon, nitrogen and pH the values were significantly different ($P < 0.05$). Calcium and potassium values were similar to those for *B. nana* sites and phosphorus levels were similar to *S. myrsinites* sites.

For the other parameters there was considerable overlap between the species, and the descriptions of the between site variation for each species follows.

Betula nana

Site characteristics

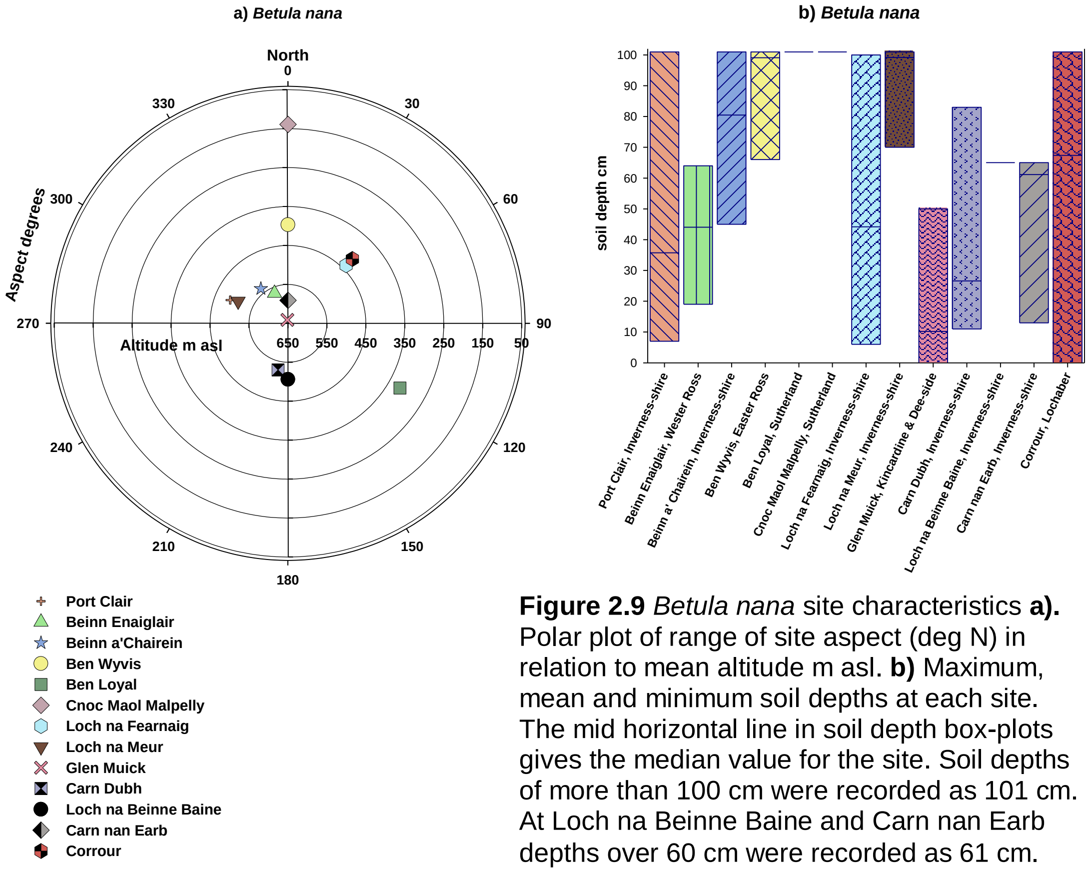


Figure 2.9 *Betula nana* site characteristics **a).** Polar plot of range of site aspect (deg N) in relation to mean altitude m asl. **b)** Maximum, mean and minimum soil depths at each site. The mid horizontal line in soil depth box-plots gives the median value for the site. Soil depths of more than 100 cm were recorded as 101 cm. At Loch na Beinne Baine and Carn nan Earb depths over 60 cm were recorded as 61 cm.

The sites surveyed extended from Sutherland in the north as far south as Lochaber and as far east as Aberdeenshire. There was no particular aspect common to the sites (Fig. 2.9) which may result from the generally very gently sloping ground of most sites. Ten out of 13 populations were on less than 10° of slope and two were on level sites. These, Cnoc Maol Malpelly and Carn nan Earb, were included in Fig. 2.9 in order to show their altitude. Their

Table 2.11 ANOVA output from one-way test of difference between chemical constituents of species site soil samples.

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	3.2008	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).

representation with an aspect of due north is a result of classifying them with zero aspect. De Groot *et al.* (1997) reported plants found at higher elevations in the west, and near to sea level in the east due to the influence of oceanicity. This differs from the database and the field survey findings where all the sites below 400 m asl are down the western side of the country from north-west Sutherland and Caithness to Lochaber and sites extend from 400 m asl to 855 m asl in the Grampian mountains in the more continental east.

Plant distribution and size

At seven of the 13 sites the majority of plants were clumped (between 0.5 and 1 m spacing) (Table 2.12b). At Carn Dubh (central), approximately 40% of the plants were single stemmed. At all other sites >90% were multi-stemmed. Glen Muick and Loch na Beinne Baine are the only sites where the mean height of the surrounding vegetation was not taller than the mean height of the plants (Fig. 2.10). At Glen Muick the mean height of the *B. nana* plants was taller than the maximum height of the surrounding vegetation while at Loch na Beinne Baine 4 out of 10 sampled plants were taller than the surrounding vegetation (not shown). The size of plants at Glen Muick was considerably greater than at any other site. However, the mean current leader length was longer at Loch na Beinne Baine and the range was larger (Fig. 2.10). Current year's leaders at Corrour were also long. These 3 sites were surveyed at the end of July and, in the case of Corrour, at the end of August, several weeks after many of the other sites, so it is crucial to consider all leader lengths in the context of their survey date, and not make direct comparisons between leaders with significantly different survey dates. However, Carn Dubh and Carn nan Earb were also surveyed at the end of August and have leader lengths which are short, and similar to those sites surveyed a month earlier (Fig. 2.10). The smallest mean plant spread was recorded at Beinn Enaiglair, Carn Dubh and Cnoc Maol Malpelly. The largest mean by 50 cm was at Glen Muick.

Surrounding vegetation

There is no clear relationship across the sites between growth and size of plants and moss layer heights and litter layer depths (Fig. 2.11).

Herbivory

All the sites showed some level of browsing. At the majority (11 out of 13) at least 50% of the plants examined showed evidence of continuous browsing, defined as evidence for annual damage over a number of years (Fig. 2. 12). Despite that 11 out of the 13 sites had plants which showed no recent (evidence from the last 3 years) damage. Ben Wyvis had 40% of plants showing no recent browsing. Carn Dubh showed the highest level of impact from browsing both at a site level and from the sample plant survey. Five plants had current year damage to at least 40% and three plants up to 80% of the canopy. Port Clair showed the

Table 2.12 a) *Betula nana* site information, including date of survey, location coordinates (grid reference eastings and northings from a GPS) and slope (from a Clinometer) and the range of soil moisture and distribution of bare ground estimated from a walk round each site.

Site no.	Site name	Date	XCOORD	YCOORD	Slope degrees	Soil moisture on site[1] % Dry	% Moist	% Wet	Bare ground[2] % area	L *f*	M *f*	S *f*	T f
1096	Port Clair, Inverness-shire	13/06/2008	236986	813615	18		100		0				
1010	Beinn Enaiglair, Wester Ross	18/06/2008	22241	88126	7		95	5	2			R	
1052	Beinn a' Chairein, Inverness-shire	19/06/2008	229876	831072	7		98	2	0				
1159	Ben Wyvis, Inverness-shire	22/06/2008	248214	872386	12		100		0.1				O
1186	Ben Loyal, Sutherland	03/07/2008	259547	948288	8		100		0.1				R
1192	Cnoc Maol Malpelly, Sutherland	04/07/2008	271481	949304	0		95	5	1			O	
1114	Loch na Fearnaig, Inverness-shire	10/07/2008	239571	820106	8		99	1	1			O	
1118	Loch na Meur, Inverness-shire	18/07/2008	239845	825285	4		100		0.5				R
1229	Glen Muick, Kincardine & Dee-side	26/07/2008	326681	731237	38	10	90		4		O	O	
1064	Carn Dubh, Inverness-shire	30/07/2008	231242	817659	8		95	5	5			O	F
1036	Loch na Beinne Baine, Inverness-shire	30/07/2008	228926	819752	9	5	95		1			R	
1066	Carn nan Earb, Inverness-shire	31/07/2008	230334	819256	0		95	5	7	O	O		F
1231	Corrour, Locharber	28/08/2008	235292	766252	2	3	87	10	2				O

[1]soil moisture was defined as follows: dry – soil was obviously dry and crumbled easily; moist – soil damp to wet but no standing water visible; wet – water visible on the surface of the soil. In making judgement account was taken of the current and previous 24 hours weather.

[2]bare ground was estimated as a percentage of the whole site and classified as follows: L – large patches >1m across; M - >30 cm to <1m across; S - >10 cm to <30 cm; T - <10 cm across. *f* is frequency: R – rare, O – occasional; F – frequent; A – abundant.

Table 2.12 b) *Betula nana* plant distribution and form across survey sites. Figures are estimates from a walk round each site. Site names are given in 2.12 a).

	Shrub distribution[1]								Shrub form[2]					Herbivores[3]				
Site no.	% shrub cover on site	% Clumped	Individual diam (m)	clump diam (m)	% Medium spacing	Individual diam (m)	% Sparse	Individual diam (m)	% multi St	% Single St	Intermediate	Up-right	Prostrate	Re Dr	Ro Dr	Har	Gro	Vol
1096	20	0			25	0.25	75	0.25	99	1	70	20	10	O	O			
1010	25	0			100	0.3	0		95	5	70	20	10	O				
1052	5	70	0.4	3	30	0.4	0		95	5	80	0	20	F				O
1159	20	75	0.5	2	25	0.5	0		95	5	80	20	0	O		O		
1186	1	100	0.25	1	0		0		100		70	10	20	F				
1192	2	100	0.25	2	0		0		90	10	60	30	10	A				
1114	2	15	0.3	1.5	84	0.25	1	0.25	99	1	50	40	10			O	R	
1118	10	100	0.5	2	0		0		100		70	20	10	F		R	O	
1229	30	90	1.5	11	10	1.5	0		98	2	80	20	0	O			O	O
1064	2	90	0.15	5	10	0.1	0		60	40	80	10	10	O				
1036	10	0			95	0.3	5	0.3	98	2	80	0	20	F			R	O
1066	1	30	0.4	3	70	0.3	0		97	3	50	40	10	O		O	O	
1231	5	15	0.35	2	20	0.35	65	0.35	100		80	20	0	O			O	

[1] Shrub distribution is given as an estimate of percentage cover across the whole site. Distribution is classified as the percentage of population that is: Clumped - >0.5 m <1m spacing; Medium spacing - >1m to <3m spacing; Sparse - >3m spacing (but <5m). Individual diam; and clump diam: – approximate diameter of individual or clump; [2] Shrub form is given as estimates of the percentage of the population that are multi-stemmed (mlt St) or single stemmed (Sing St), and that had the following growth forms: Inter – intermediate between upright and prostrate, both vertically and horizontally growing branches; Upright – a generally upright growth with no branches growing horizontally; Prost – prostrate, growing primarily horizontally either along or just above ground level.

[3]Herbivore presence based on evidence on site (see text for explanation) ReDr – red deer; Ro Dr – roe deer; Har – hares; Gro – grouse; Vol – voles. A – abundant; F – frequent; O – occasional; R – rare.

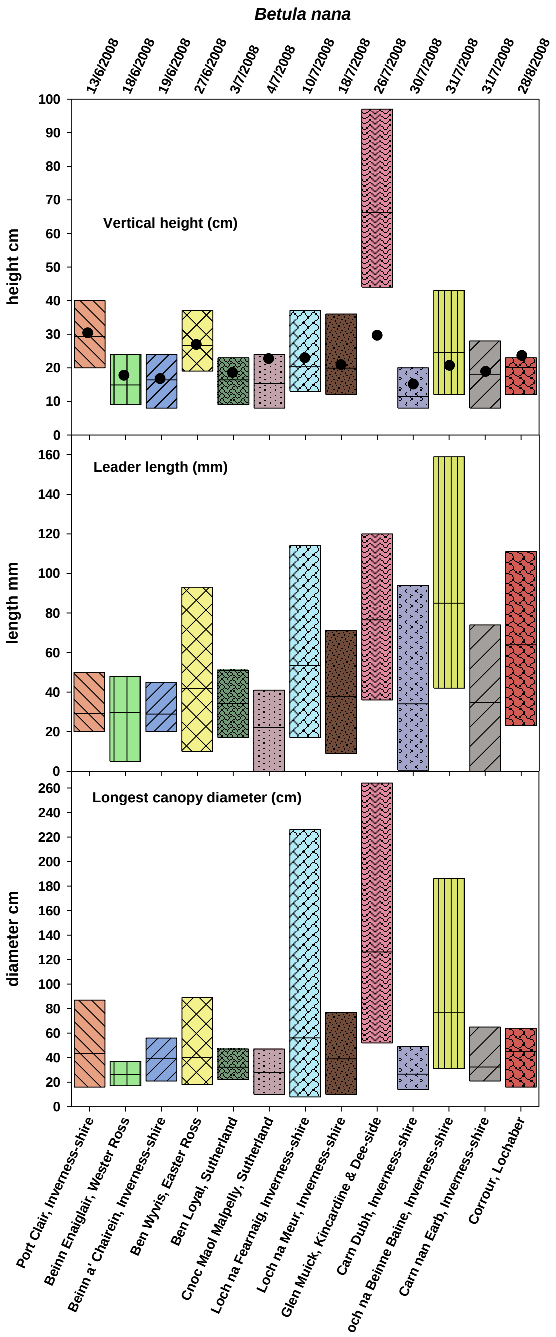


Figure 2.10 Mean, maximum and minimum site growth parameters (see titles) for *Betula nana, n*=10. Dates of surveys are given at the top of each column. ● on vertical height graph indicate heights (cm) of the field layer vegetation.

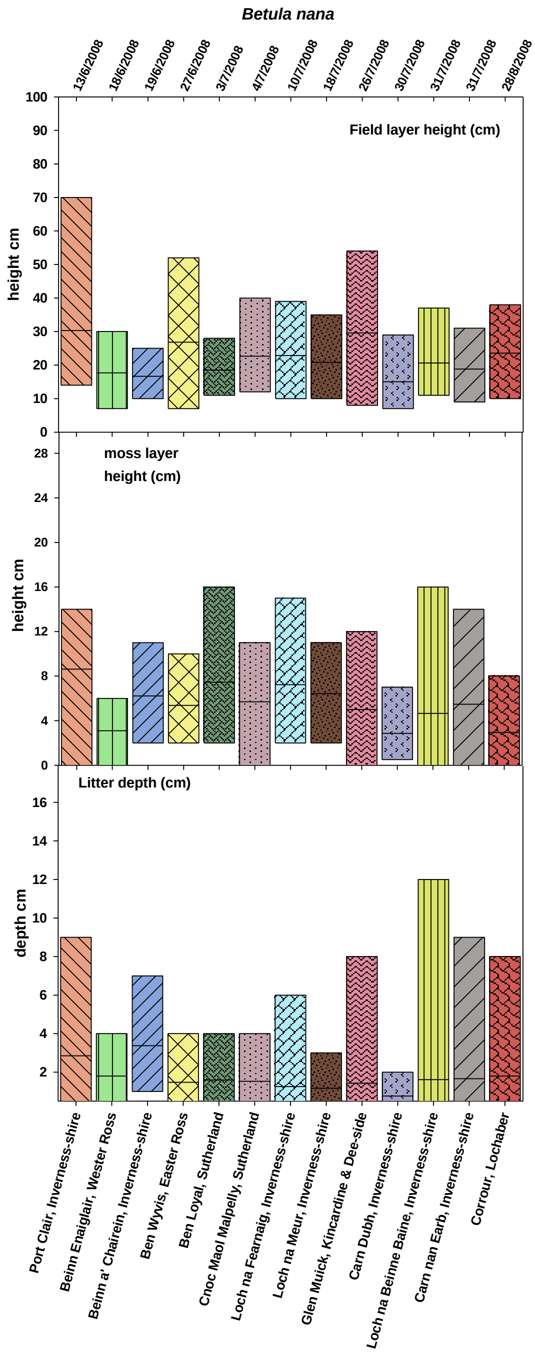


Figure 2.11 Mean, maximum and minimum sample site vegetation layer heights, *n* = 40.

lowest level of browsing with seven plants having damage to between 20 and 40% of the canopy, and one undamaged. This site showed the highest percentage of recent, as opposed to continuous, damage. There were no sheep at 12 out of 13 sites. None were seen at the 13th (Cnoc Maol Malpelly) site, but it was croft land and they may be present at other times of the year. There was evidence of red deer at all sites primarily through the presence of

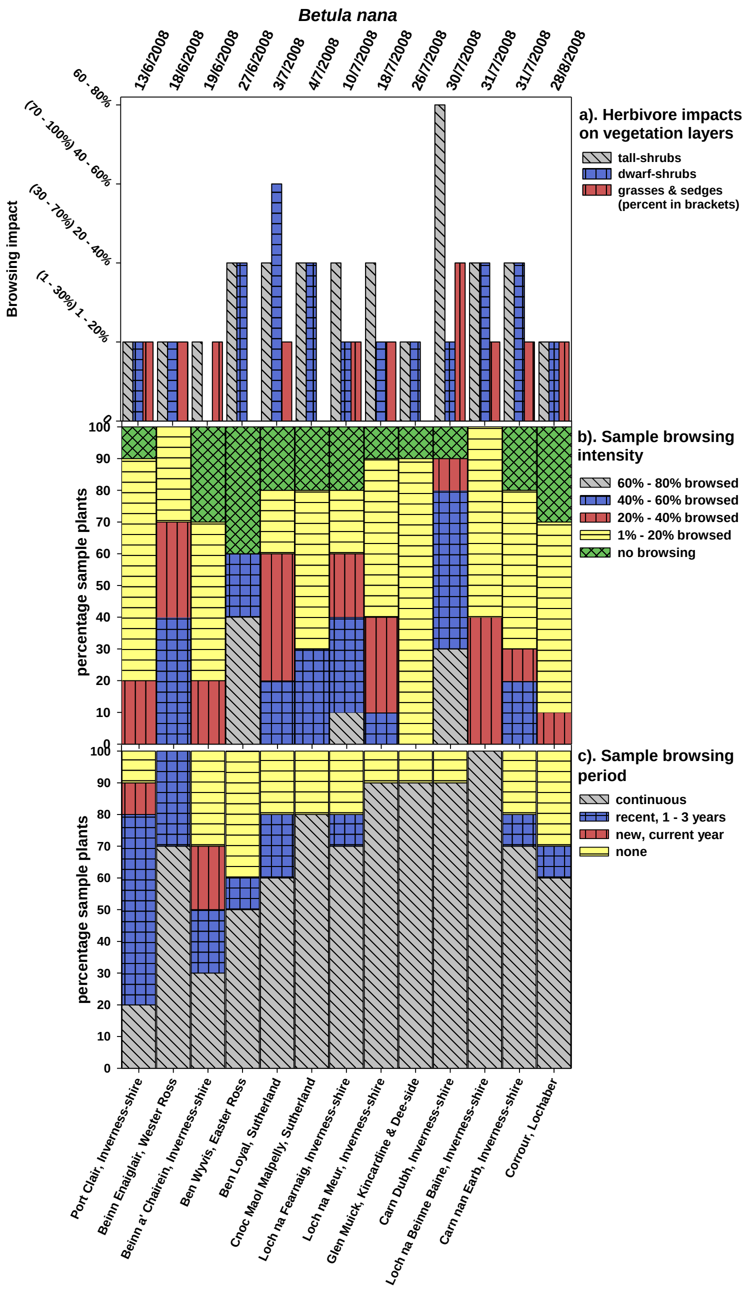


Figure 2.12 Herbivore impacts at *Betula nana* populations **a)** at a whole site scale, on different vegetation layers, Y-axis is % class of site vegetation cover browsed; **b)** on sample plants (n = 10), browsing intensity class relates to percentage of canopy affected; **c).** period of browsing impact on sample plants (n = 10).

dung or tracks or foot prints (Table 2.10, page 75). Most of the 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 occasional (Table 2.12b) however, at six sites it was frequent and at Cnoc Maol Malpelly it was abundant, which may have been due to confusion with sheep dung. Port Clair was the only site with evidence of roe deer where a number of twigs had been bark stripped. Hares were evident by droppings at three and one individual was seen at Loch na Meur. At Ben Wyvis there were several *B. nana* shoots severed with a diagonal cut, suggesting presence of hares. Voles were seen at Gen Muick, and holes and runs were found at Carn Dubh and Beinn a'Chaireinn.

Physical soil characteristics

All the sites had primarily moist soils (Table 2.12a, above), although three also had some areas of dry soil. Glen Muick on comparatively steep ground (38°) had the highest percentage of dry soils and no wet soil areas, while Corrour, a near level site had the highest percentage of wet soils but also scattered dry knolls. Loch na Beinne Baine was essentially blanket mire across a relatively rough loch shore with some well drained rocky areas. Generally maximum soil depths at all sites were more than 50 cm and at eight sites they were over 1 m (Fig. 2.9). But at five sites the mean depth was under 50 cm and at 4 the minimum was under 10 cm. At only two sites, Ben Loyal and Cnoc Maol Malpelly, were the peat depths greater than 1 m across the whole site. At Loch na Beinne Baine they were consistently greater than 60 cm (and may have been over 1 m but this was not recorded). Glen Muick had the shallowest soils.

Soil chemistry

There were no obvious relationships between the growth of *B. nana* and the available nutrient content of the soil or total carbon and nitrogen content, or pH (Fig. 2.13). Carbon content was similar across all the sites and reflected peaty soils, with the exception of Glen Muick, where carbon and nitrogen content were relatively low (Fig. 2.13). Mean pH values for Glen Muick were also relatively low, and those for all the available nutrients, particularly magnesium, were among the lowest figures (Fig. 2.13). In contrast the other site with high figures for current years' growth, Loch na Beinne Baine, had high values for phosphorus, calcium and nitrogen. Port Clair and Beinn Enaiglair had the highest pH, calcium and nitrogen contents, but the lowest phosphorus values.

Betula nana population condition assessment

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 in reasonably good condition, with relatively large plants and low levels of browsing impact. No 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 very small and the plants were among the smallest

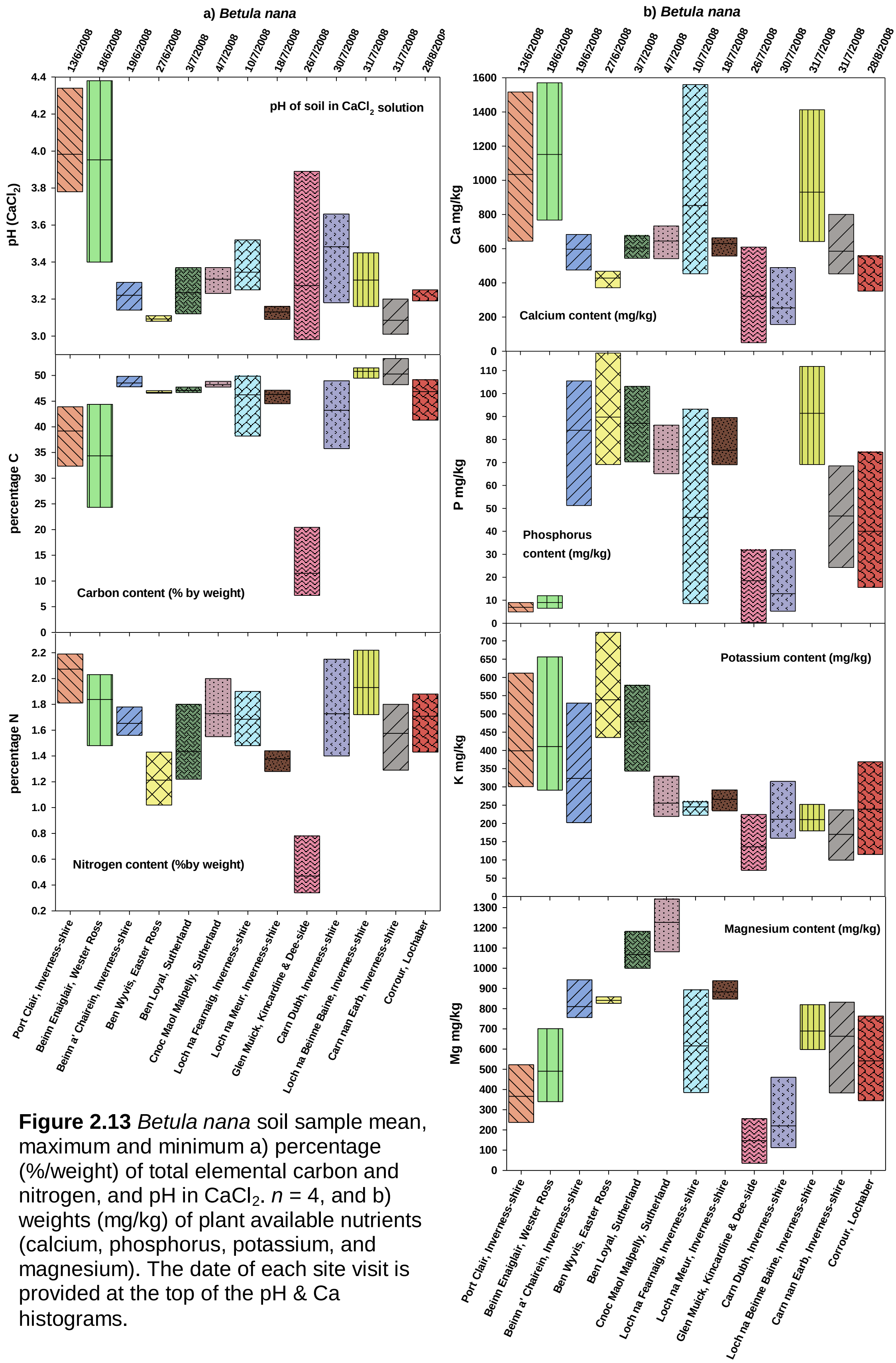


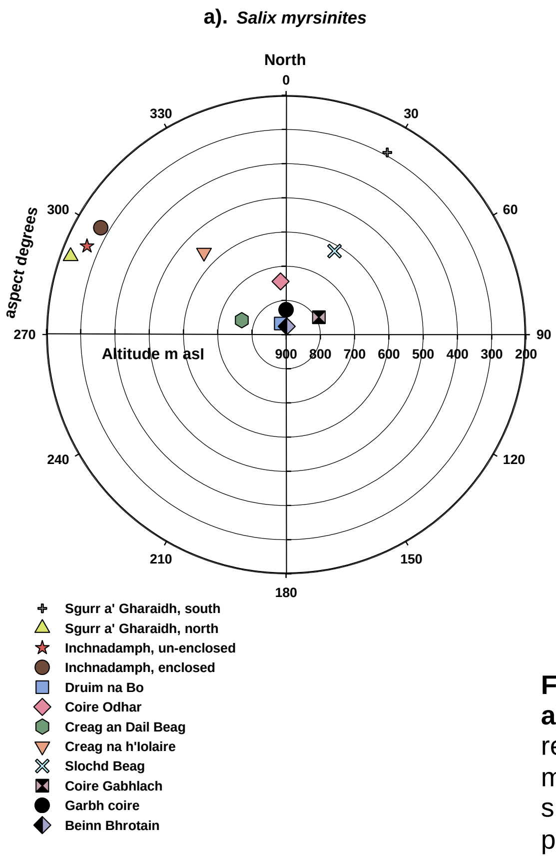
Figure 2.13 *Betula nana* soil sample mean, maximum and minimum a) percentage (%/weight) of total elemental carbon and nitrogen, and pH in $CaCl_2$. n = 4, and b) weights (mg/kg) of plant available nutrients (calcium, phosphorus, potassium, and magnesium). The date of each site visit is provided at the top of the pH & Ca histograms.

(height and spread) surveyed. Carn Dubh also had a clumped distribution but 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 the browsing pressure might allow year on year increase and improved health of the plants. All the other populations tended to poor condition with small plants and persistent browsing impacts. Corrour 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.

Salix myrsinites

Site characteristics

The populations of *Salix 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. All had an aspect between 288° and 62° north (Fig. 2.14), seven sites had a north-westerly aspect (most common for sites with this species) and four faced north-east. The twelfth site faced due north. The altitude of sites ranged from 200 m asl up to nearly 900 m asl. Ten sites were on slopes of greater than 30° angle with the steepest, Creag na h'Iolaire, over 50°. There was no relationship between altitude and aspect.



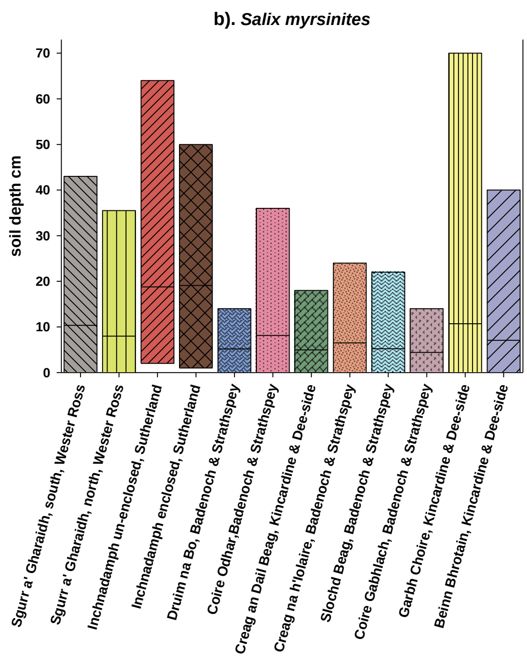


Figure 2.14 *Salix myrsinites* site characteristics **a).** Polar plot of range of site aspect (deg N) in relation to mean altitude m asl. **b)** Maximum, mean and minimum soil depths (cm) at each site. The mid horizontal line in soil depth box-plots gives the median value for the site.

Plant distribution and size

Generally the cover of *S myrsinites* at each site was low. The maximum was at Sgurr a' Gharaidh south (Table 2.13b). At Creag an Dail Beag most of the population was clumped, while at 5 other sites the populations were primarily sparsely distributed (spacing of more than 3 m). The tallest individual plants at nearly 50 cm were at Slochd Beag, but the site with the tallest mean was Coire Odhar (Fig. 2.15). The shortest plants were at Inchnadamph-unenclosed, although there was little difference between the longest canopy diameter in the enclosed and un-enclosed populations (Fig. 2.15). Druim na Bo had the greatest range in longest canopy diameter and the longest *S. myrsinites* diameters found during this survey (383 cm). Garbh Coire had similar maximum longest diameters but the mean at this site was the longest. The smallest plants were at Sgurr a'Gharaidh north and both Inchnadamph populations. 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.

Surrounding vegetation

All vegetation heights at all the sites were relatively low, although at both Inchnadamph sites the mean height of the *S. myrsinites* plants was lower than the mean height of the field layer (Fig. 2.16). The mean field layer heights only exceeded 15 cm at three sites, and mean moss layer heights exceeded 7 cm at two sites. The Inchnadamph-enclosed site had the tallest field and moss layers. Mean litter layer values for all sites were below 3 cm, the maximum at Garbh Coire was 17 cm, and at Coire Odhar and Beinn Bhrotain it was 11 cm.

Herbivory

The first site to be surveyed, Sgurr a'Gharaidh south, showed no evidence of browsing over a number of previous years, and at Inchnadamph-enclosed only one plant had been recently browsed but the damage was between 40% and 60% of the plant canopy (Fig 2.17). At all other sites the damage was predominantly continuous, but at a relatively moderate level. At eight sites at least 70% of plants had < 20% of their canopies damaged, and at five of those sites at least one plant showed no damage. At Craig an Dail Beag 60% of plants sustained damage to 20% - 40% of their canopies. The Inchnadamph-unenclosed population suffered damage to 60% of plants surveyed, all with 20% - 80% of their canopies damaged. Which herbivores were present at each site and their level of occupancy suggested by the evidence present are given in Table 2.13b. Fresh and old droppings were the primary evidence for red deer, hares and grouse (either *L. lagopus* or *L. mutus*). Sheep (*Orvis aries*) were seen at Creag an Dail Beag and in the general area at Sgurr a'Gharaidh north and Inchnadamph-

Table 2.13 a) *Salix myrsinites* site information, including date of survey, location coordinates (from a GPS) and slope (from a Clinometer) and the range of soil moisture and distribution of bare ground estimated from a walk round each site.

Site no.	Site name	Date	XCOORD	YCOORD	Slope degrees	Soil moisture on site[1] % Dry	% Moist	% Wet	Bare ground[2] % area	L *f*	M *f*	S *f*	T *f*
2088	Sgurr a' Gharaidh, South, Wester Ross	20/05/2008	186298	844030	31	100			6		O	O	O
2086	Sgurr a' Gharaidh, North, Wester Ross	21/05/2008	186297	844110	26	80	10	10	2			O	R
2103	Inchnadamph un-enclosed, Sutherland	01/07/2008	226367	919824	8	80	20		1				O
2102	Inchnadamph enclosed, Sutherland	02/07/2008	226576	919810	35	60	40		2		R		R
2022	Druim na Bo, Badenoch & Strathspey	21/07/2008	287358	792247	47	10	90		5			O	R
2017	Coire Odhar, Badenoch & Strathspey	23/07/2008	291326	797153	33		90	10	5			R	O
2001	Creag an Dail Beag, Kincardine & Dee-side	27/07/2008	314960	798272	41	95	5		65	F	F	F	F
2003	Creag na h'Iolaire, Badenoch & Strathspey	03/08/2008	283558	790682	50		98	2	5			F	
2002	Slochd Beag, Badenoch & Strathspey	04/08/2008	283981	789787	48	8	90	2	5		O	O	O
2016	Coire Gabhlach, Badenoch & Strathspey	05/08/2008	287678	794289	39	2	98		10		O	O	O
2055	Garbh Choire, Kincardine & Dee-side	16/08/2008	295982	798343	40		100		1		O	O	
2004	Beinn Bhrotain, Kincardine & Dee-side	17/08/2008	296449	793291	37		100		2			F	

[1]soil moisture was defined as follows: dry – soil was obviously dry and crumbled easily; moist – soil damp to wet but no standing water visible; wet – water visible on the surface of the soil. In making judgement account was taken of the current and previous 24 hours weather.
[2]bare ground was estimated as a percentage of the whole site and classified as follows: L – large patches >1m across; M - >30 cm to <1m across; S - >10 cm to <30 cm; T - <10 cm across. *f* is frequency: R – rare, O – occasional; F – frequent; A – abundant.

Table 2.13 b) *Salix myrsinites* plant distribution and form across survey sites. Figures area estimates from a walk round each site. Site names are given in table 2.15 a).

	Shrub distribution[1]								Shrub form[2]					Herbivores[3]				
Site no.	% Shrub cover on site	% Clumped	Individual diam (m)	clump diam (m)	% Medium spaced	Individual diam (m)	% Sparse	Individual diam (m)	% Multi St	% Single St	Intermediate	Up-right	Prostrate	Re Dr	Sh	Har	Gro	Vol
2088	30	34	1	2	66	1			99	1		10	90					O
2086	15				20	0.3	80	0.3	100		10		90	O				
2103	5	40	0.5	1.5	60	0.5			100				100	O				F
2102	15	30	0.5	2	30	0.3	40	0.3	98	2	50	10	40			O		F
2022	20	30	1	3	40	1	30	1	100		10		90	O		O	R	
2017	1				100	1			100		60	10	30	R			O	
2001	15	75	0.75	5	5	0.75	20	0.75	95	5	10		90	O	O	F	O	
2003	0.5				2	0.5	98	0.5	98	2	60	10	30	O		O		O
2002	5				2	0.5	98	0.5	98	2	30		70	O		O		
2016	2						100	1.25	98	1	40		60	R		O	R	O
2055	4	50	1	5			50	1	98	2	40		60	R		R	O	O
2004	3	30	1.25	3			70	1.25	99	1	50		50	F		O	F	

[1] Shrub distribution is given as an estimate of percentage cover across the whole site. Distribution is classified as the percentage of population that is: Clumped - >0.5 m <1m spacing; Medium spacing - >1m to <3m spacing; Sparse - >3m spacing (but <5m). Individual diam; and clump diam: – approximate diameter of individual or clump.

[2] Shrub form is given as estimates of the percentage of the population that are multi-stemmed (Multi St) or single stemmed (Sing St), and that had the following growth forms: Inter – intermediate between upright and prostrate, both vertically and horizontally growing branches; Upright – a generally upright growth with no branches growing horizontally; Prost – prostrate, growing primarily horizontally either along or just above ground level.

[3] Herbivore presence based on evidence on site (see text for explanation) Re Dr – red deer; Sh – sheep; Har – hares; Gro – grouse; Vol – voles. A – abundant; F – frequent; O – occasional; R – rare.

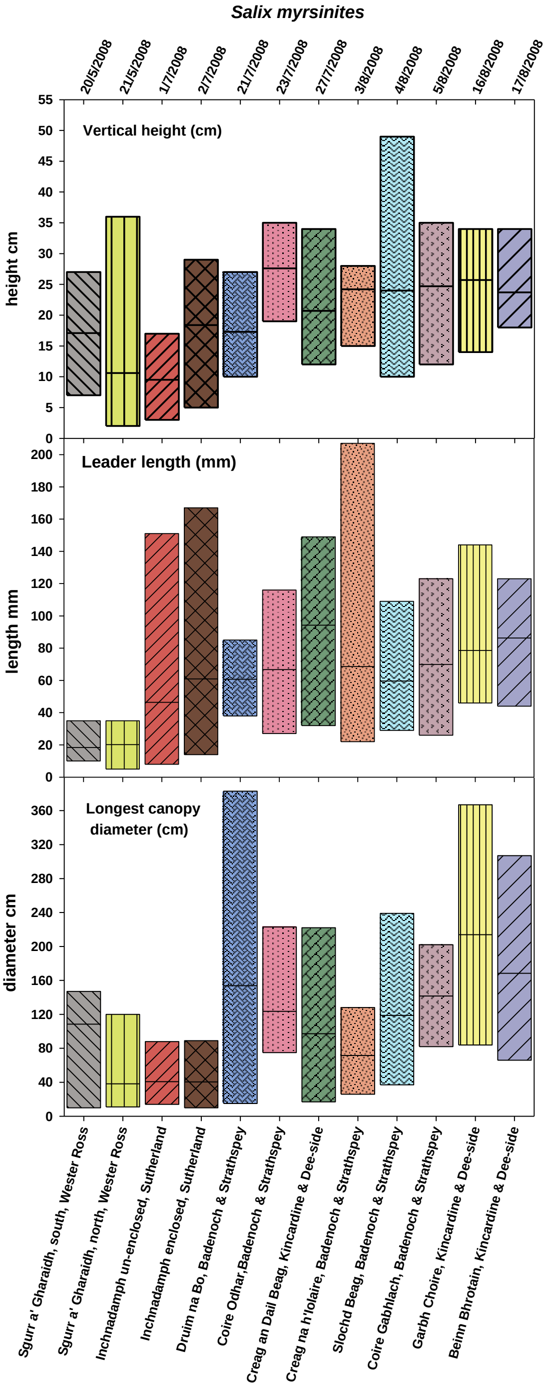


Figure 2.15 Mean, maximum and minimum site growth parameters (see titles) for *Salix myrsinites, n*=10. Dates of surveys are given at the top of each column.

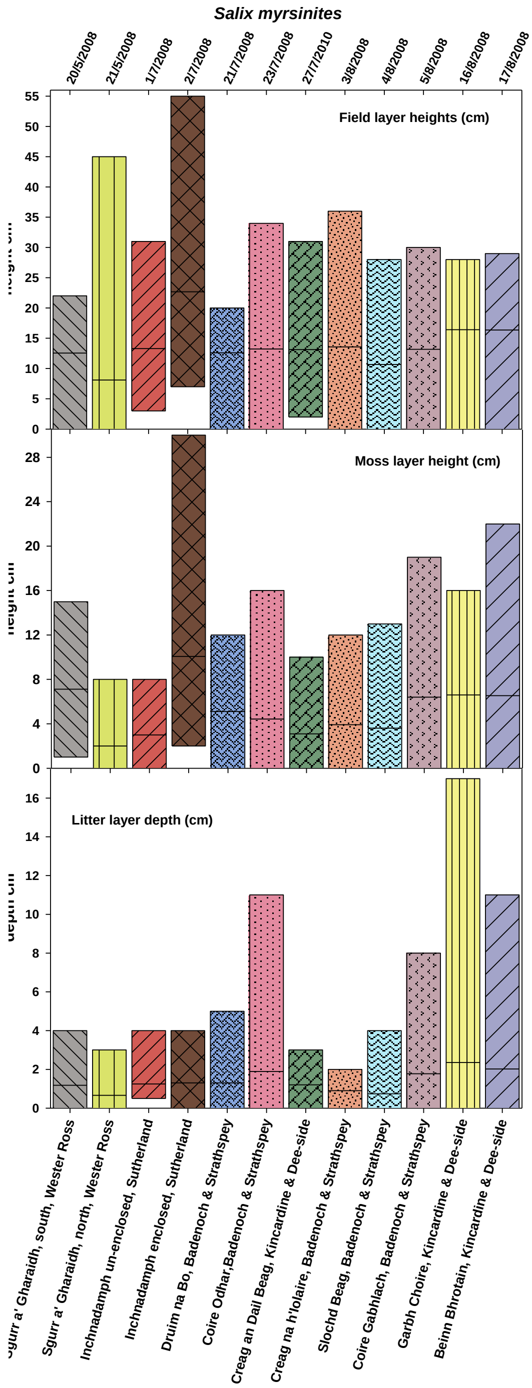


Figure 2.16 Mean, maximum and minimum sample site vegetation layer heights, *n* = 40.

unenclosed, otherwise were absent from sites. Voles were evidenced primarily from holes, which were frequently seen at both Inchnadamph sites. Generally, the evidence of herbivore presence at most sites was moderate or low, although red deer and grouse appeared to be frequent at Beinn Bhrotain. Hares were also frequent at Creag an Dail Beag.

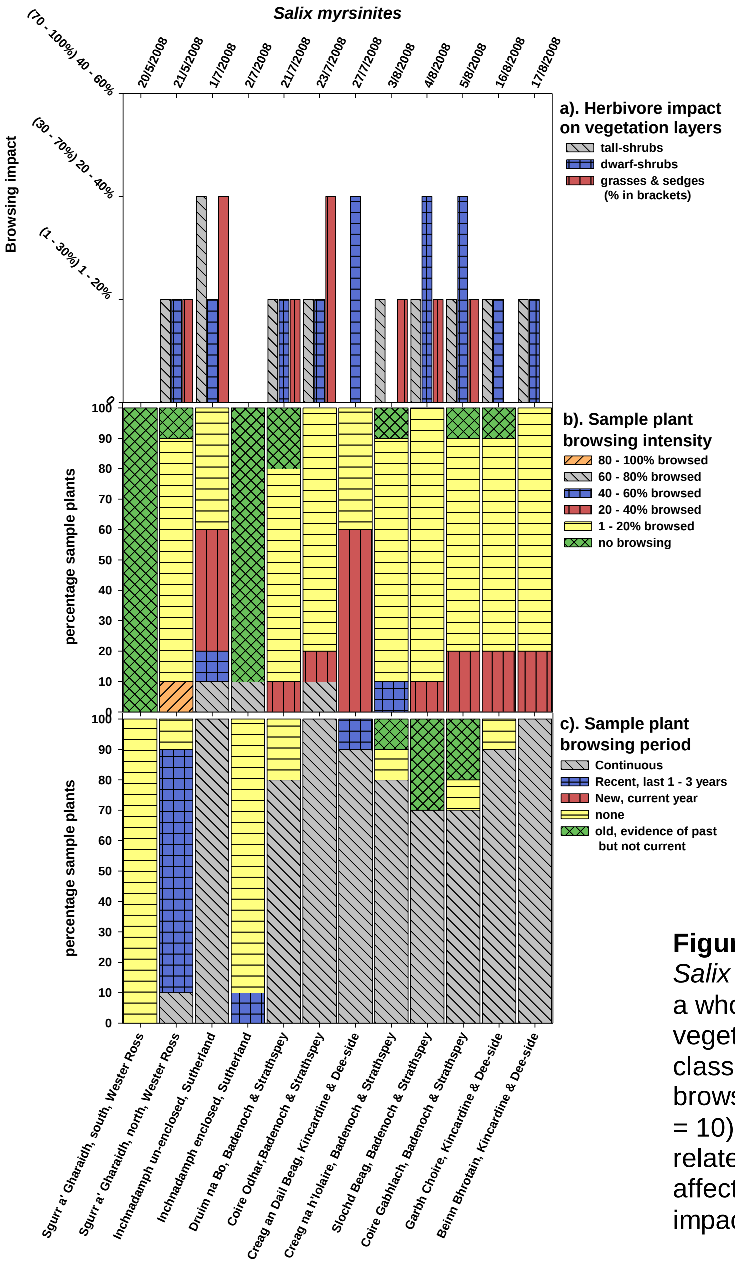


Figure 2.17 Herbivore impacts at *Salix myrsinites* populations **a)** at a whole site scale, on different vegetation layers, Y-axis is % class of site vegetation cover browsed; **b)** on sample plants (*n* = 10), browsing intensity class relates to percentage of canopy affected; **c)** period of browsing impact on sample plants (*n* = 10).

Physical soil characteristics

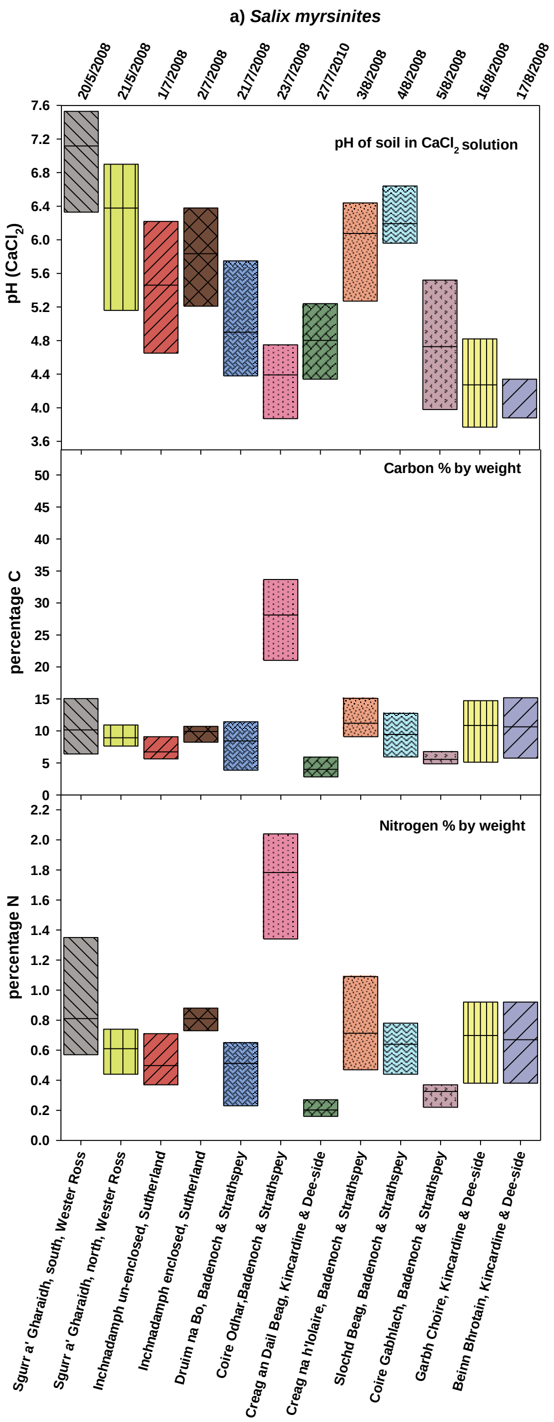
Five sites had predominantly dry soils and four of these were on the limestone in the north-west (Table 2.13a). Seven sites had predominantly moist soils. Sgurr a'Gharaidh north and Coire Odhar had some wet soils, and to a lesser extent so did Slochd Beag and Creag na h'Iolaire. Generally, soils were shallow at all sites (Fig.2.14). There was a tendency for the shallower soils to be on the steeper sloped sites, although the site with the deepest soil had a slope angle of 40°. Both Inchnadamph sites had the deepest mean soils, one on a shallow slope (unenclosed) the other on a relatively steep slope (enclosed). Creag an Dail Beag had the largest total area of bare ground with the widest range of patch sizes (Table 2.13a). This population was growing on a steep, actively eroding site. All other sites had some bare ground, excluding bare rock, mainly in small patches (10 cm - 30 cm across) suggesting that all sites contained at least some ‘space’ for the establishment of seedlings.

Soil chemistry

There was a wide range in pH values measured in $CaCl_2$ solution across the *S. myrsinites* sites from 3.89 to 7.5 (Fig. 2.18). The highest values were from both Sgurr a’Gharaidh sites. Only Creag na h’Iolaire and Slochd Beag also had means above 6, and the two Inchnadamph sites had values above 5. The pattern of content of total carbon and nitrogen across the site soils was very similar. Coire Odhar had the highest values for both C and N well within the range of the majority of *Betula nana* sites. The remaining sites all had mean values for C below 15 % and for N below 1.0%. Craig an Dail Beag had the lowest values for both chemicals. The two Sgurr a’Gharaidh sites both had the highest calcium levels, and wide intra-site ranges. Inchnadamp-enclosed had the next highest levels, while all other sites were comparatively low, with Beinn Bhrotain the lowest at 188 mg kg^{-1}, which was lower than the lowest means for *Betula nana* sites. Sgurr a’Gharaidh north and Inchnadamph-enclosed both had the lowest mean P contents, and relatively restricted intra-site ranges. Four sites were highly variable with a range of more than 15 mg kg^{-1} P, with the lowest minimum at Creag an Dail Beag. Site soils had relatively narrow ranges of potassium content. Coire Odhar had the greatest range and the highest mean K, Creag an Dail Beag had the lowest mean, while Slochd Beag had the lowest minimum. Magnesium content ranged slightly more widely across the *S. myrsinites* sites than the *Betula nana* sites. Nine of the 12 sites had maximum values less than 1,000 mg kg^{-1} and only the two Sgurr a’Gharaidh sites and Inchnadamph-enclosed had higher mean values, but their ranges were very wide (Fig 2.18).

Salix myrsinites population condition assessment

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 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 sexes of the catkins on the other two were indeterminable, as were the sexes of all the other plants. The evidence of browsing was limited because this population is on an inaccessible ledge amongst broken cliff formations and its potential for ‘browsing-protected’ expansion is very limited. Druim na Bo and Creag an Dail Beag also had relatively high site cover and, on the areas occupied, plants which were primarily within 3 m of each other. 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. Four plants



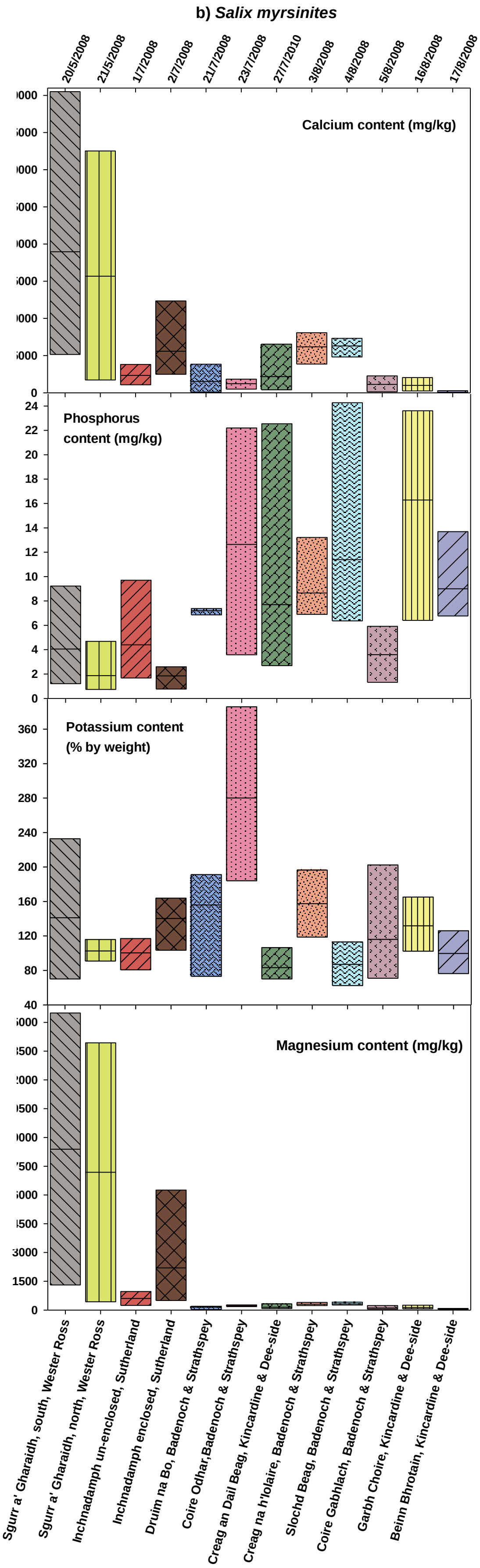
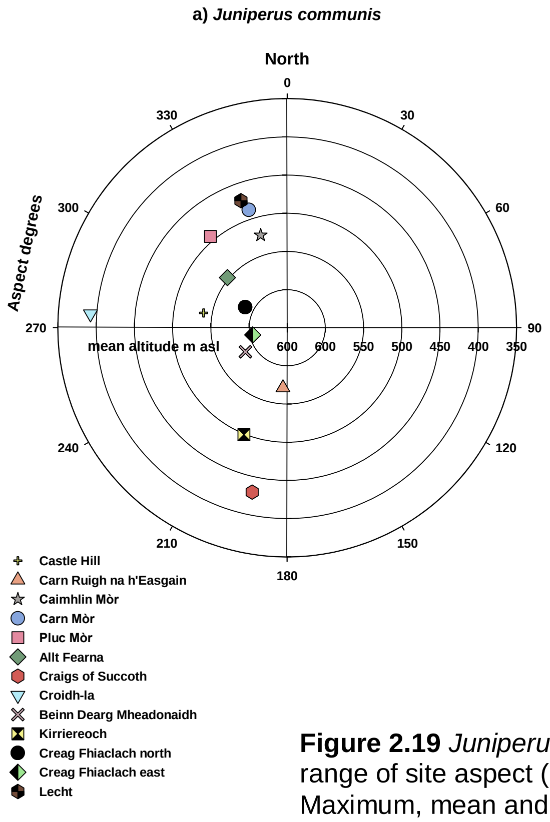


Figure 2.18
Salix myrsinites soil sample mean, maximum and minimum a) percentage (%/weight) of total elemental carbon and nitrogen, and pH in $CaCl_2$. $n = 4$, and b) weights (mg/kg) of plant available nutrients (calcium, phosphorus, potassium, and magnesium). The date of each site visit is provided at the top of the Ca & pH histograms.

were female and flowering. Browsing levels were low and there appeared to be potential for recruitment. Erosion damage was relatively local and this population can be considered to be in reasonable condition. Creag an Dail Beag had smaller than average plants but longer leader lengths, and five plants were female and flowering. Browsing impact was marginally higher and the willows occupied all the relatively stable ground that was less accessible to herbivores. Despite this browsing was still evident on any plant 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 had similar cover of willows most of which were within 3 m of each other. Two plants were flowering, 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 mean field layer taller than mean willow heights. The density and height of the surrounding vegetation and lack of recruitment on the site, despite controlled browsing, suggests this population is not in good condition, but not immediately at risk. Beinn Bhrotain, Garbh Coire and Coire Odhar also all had the majority of their populations within 3 m of each other and all had larger than average plants. Leader lengths on the first two were longer than average in August, while those of the third were average in July. At all three sites eight measured plants were flowering. At the first site three were undeterminable and the rest female, at the other two sites seven were female and one male. These three sites could be considered to be in reasonable condition. All the other populations were composed of plants which were more than 3 m apart, and because of the nature of the willow sites sometimes more than 5 m apart. In the cases of Slochd Beag, Creag na h'Iolaire, and Coire Gabhlach the plants themselves were growing well, and at Coire Garbhlach nine measured plants were flowering with three males and six females. Both Sgurr a'Gharaidh north and Inchnadamph-unenclosed were in the poorest condition with small plants and relatively higher browsing pressure, but despite that, at the start of July the latter site had a wide range of leader lengths, including some longer than in better growing populations. This suggests there may be potential for these plants to respond to reduced browsing pressure.

Juniperus communis



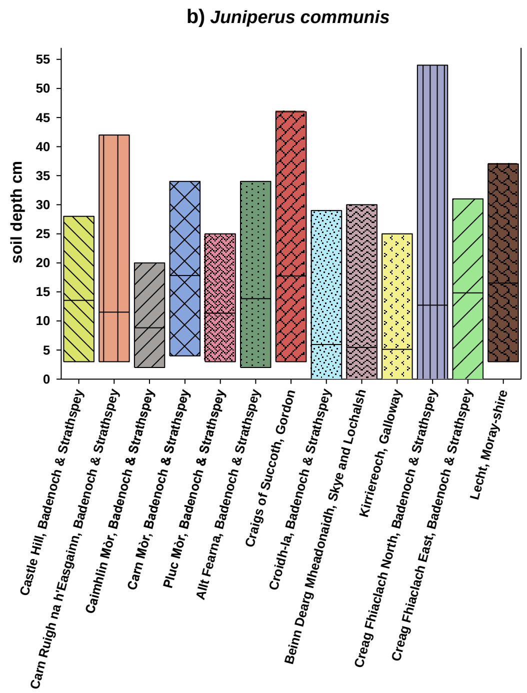


Figure 2.19 *Juniperus communis* site characteristics **a)** Polar plot of range of site aspect (deg N) in relation to mean altitude m asl. **b).** Maximum, mean and minimum soil depths at each site (*n* = 40). The mid horizontal line in soil depth box-plots gives the median value for the site.

Site characteristics

Juniperus communis populations surveyed 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. 2.19). The mean altitude of sites ranged between 392 m asl and 604 m asl (Fig. 2.19). The predominant slopes ranged between 1°, at the Lecht, and 44° at Kirriereoch (Table 2.14a). Apart from the Lecht all other sites had slopes greater than 10°. There was no clear relationship between altitude and aspect, or between either and slope.

Plant distribution and size

The Juniper populations surveyed covered a wide range of plant distributions. The populations with the highest percentage cover of their sites also tended to have the densest spacing. Four populations in Badenoch and Strathspey occupied more than 50% of their sites primarily in continuous cover stands. Other, more widely spread populations had clumped or medium spaced plants. Four populations with primarily small plants were sparsely distributed and three of these, Croid-la, Beinn Dearg Mheadonaidh and Kirriereoch were on the steepest slopes. Most populations were multi-stemmed (Table 2.14b).

Table 2.14 a) *Juniperus communis* site information, including date of survey, location coordinates (from a GPS) and slope (from a Clinometer) and the range of soil moisture and distribution of bare ground estimated from a walk round each site.

						Soil moisture on site[1]			Bare ground[2]				
Site no.	Site name	Date	XCOORD	YCOORD	Slope degree	% Dry	% Moist	% Wet	% area	L *f*	M *f*	S *f*	T *f*
3064	Castle Hill, Badenoch & Strathspey	23/06/2008	295185	806129	22		100		3			O	
3032	Carn Ruigh na h-Easgainn, Badenoch & Strathspey	07/07/2008	264548	811726	28	90	10		1				O
3029	Caimhlin Mòr, Badenoch & Strathspey	08/07/2008	268690	815475	27	90	10		2			O	O
3038	Carn Mòr, Badenoch & Strathspey	09/07/2008	273080	817324	26	90	9	1	5			O	O
3052	Pluc Mòr, Badenoch & Strathspey	17/07/2008	270905	820803	13	100			3			O	
3054	Allt Fearna, Badenoch & Strathspey	19/07/2008	272448	820667	16	98	2		5			O	
3127	Craigs of Succoth, Gordon	28/07/2008	343747	836183	11		100		0				
3171	Croidh-la, Badenoch & Strathspey	05/08/2008	276879	794136	35	85	15		3			O	O
3285	Beinn Dearg Mheadonaidh, Skye	23/08/2008	151338	827160	35	90	10		4		O	O	
3324	Kirriereoch, Galloway	25/08/2008	240502	586588	44	10	90		10		O	O	O
3057	Creag Fhiaclach North, Badenoch & Strathspey	05/10/2008	289604	805554	25		100		1			O	O
3056	Creag Fhiaclach East, Badenoch & Strathspey	10/10/2008	289697	805081	19		90	10	1				R
3290	Lecht, Moray-shire	19/10/2008	323644	814980	1	38	60	2	3		O		

[1]soil moisture was defined as follows: dry – soil was obviously dry and crumbled easily; moist – soil damp to wet but no standing water visible; wet – water visible on the surface of the soil. In making judgement account was taken of the current and previous 24 hours weather.
[2]bare ground was estimated as a percentage of the whole site and classified as follows: L – large patches >1m across; M - >30 cm to <1m across; S - >10 cm to <30 cm; T - <10 cm across. *f* is frequency: R – rare, O – occasional; F – frequent; A – abundant.

Table 2.14 b) *Juniperus communis* plant distribution and form across survey sites. Figures are estimates from a walk round each site. Site names are given in table 2.16 a).

	Shrub distribution[1]											Shrub form[2]				
Site no.	% shrub cover on site	% Continuous	Individual diam (m)	Patch diam (m)	% Clump	Individual diam (m)	Clump diam (m)	% Medium spaced	Individual diam (m)	% Sparse	Individual diam (m)	% Multi St	% Single St	Intermediate	Up-right	Prostrate
3064	15							10	0.5	90	0.5	60	40	70	20	10
3032	65	70	0.5		25	0.5	2	5	0.25			75	25	90	10	
3029	55	74	1		5	1	5	20	0.75	1	0.5	50	50	90		10
3038	60	89	1		6	0.75	3	5	0.75			80	20	90	10	
3052	60	89	3		3	2	6	6	1	2	0.75	98	2	90	10	
3054	60	60	1		20	1	5	20	1			95	5	60	40	
3127	20	20	1	15						80	1	99	1	60	20	20
3171	20	5	1.5		20	1.5	20			75	1.5	55	45	40	60	
3285	5				70	2	4			30	2	100				100
3324	1							20	1	80	1	100				100
3057	35				85	1.5	8	10	1	5	0.5	99	1	80	20	
3056	15				3	1.25	5	95	1	2	0.25	98	2	80		20
3290	30	20	2		70	2	7	9	1	1	0.5	95	5	100		

[1]Shrub distribution is an estimate of percentage cover across the whole site. Distribution is classified as the percentage of population that is: Continuous - <0.5 m spacing; Clump - >0.5 m to <1m spacing; Medium - <3m to >1m spacing; Sparse - >3m spacing (but <5m). diam – approximate diameter of individual plant or clump.

[2] Shrub form is given as estimates of the percentage of the population that are multi-stemmed (Multi St) or single stemmed (Single St), and that had the following growth forms: Intermediate – is between upright and prostrate, with both vertically and horizontally growing branches; Upright – a generally upright growth with no branches growing horizontally; Prostrate –growing primarily horizontally either along or just above ground level.

Table 2.14 c) Herbivore presence[1] at *Juniperus communis* sites (Table 2.13 gives definition of presence). Site names are given in table 2.16 a).

Site no.	Site name	Red deer	Roe deer	Sheep	Goats	Hares	Rabbits	Grouse	Voles
3064	Castle Hill, Badenoch & Strathspey	O						O	R
3032	Carn Ruigh na h-Easgainn, Badenoch & Strathspey	F			O	O	O	O	
3029	Caimhlin Mòr, Badenoch & Strathspey	F				R		O	
3038	Carn Mòr, Badenoch & Strathspey	F		A	O	O			
3052	Pluc Mòr, Badenoch & Strathspey	F							R
3054	Allt Fearna, Badenoch & Strathspey	F		O		O			O
3127	Craigs of Succoth, Gordon	R	R			R		R	O
3171	Croidh-la, Badenoch & Strathspey	O							O
3285	Beinn Dearg Mheadonaidh, Skye	F		O					O
3324	Kirriereoch, Galloway	O		F					O
3057	Creag Fhiaclach North, Badenoch & Strathspey	O						O	R
3056	Creag Fhiaclach East, Badenoch & Strathspey	O				R		O	
3290	Lecht, Moray-shire	R		O		O			O

[1]Herbivore presence based on evidence on site (see text for explanation): A – abundant; F – frequent; O – occasional; R – rare.

Croidh-la, Castle Hill and Caimhlin Mòr had significant proportions of single stemmed plants. Most Croidh-la plants were upright, and at Beinn Dearg Mheadonaidh and Kirriereoch all plants were prostrate, otherwise the majority of plants at each population were intermediate. The tallest plant in the survey was at Pluc Mòr (Fig. 2.20). Maximum plant heights were also over 1 m at Carn Mòr, Croidh-la and the Lecht, and the Lecht had the largest mean plant height. Leader lengths measured early in the season (June) are not comparable with those from sites surveyed in October at the end of the season (Fig. 2.20). The longest leaders were at Creag Fhiaclach east, recorded in October, where there was also the widest range in size. The shortest leaders were at Croidh-la, recorded in late August. The Lecht had the largest mean leader length (October), and Kirriereoch (September), Craigs of Succoth (July) and Creag Fhiaclach east also had mean leader lengths over 50 mm. The longest canopy diameters and the largest mean diameters were found at the Lecht, whilst the shortest and smallest mean canopy diameters were at Carn Ruigh na h'Easgainn.

Surrounding vegetation

At all sites the *J. communis* plants were taller than the surrounding vegetation (Fig. 2.21). Croidh-la had the highest mean heights for moss layer and greatest maximum and mean depths for litter. Carn Mòr has the lowest mean litter depth. There was no obvious relationship between vegetation layer heights and plant dimensions.

Herbivory

All the sites had evidence of browsing although this was low at Kirriereoch where seven plants had no evidence of browsing and the remaining three were lightly browsed (up to 20% of canopy affected) (Fig. 2.22). By contrast at Castle Hill all plants had some evidence of browsing and six were heavily browsed (up to 80% canopy affected). At eight sites all 10 plants had been continuously browsed over a number of years. There was evidence of red deer presence at every site and at six there appeared to be frequent use of the areas (Tables 2.14 & 2.10). An individual roe deer (*Capraeolus capraeolus*) was seen at Craigs of Succoth. Sheep were present at five sites, and particularly evident at Carn Mòr. Goats were seen at Carn Mòr and Carn Ruigh na h-Easgainn. There was evidence of hare at seven sites, and they were seen at Caimhlin Mòr, Carn Ruigh na h-Easgainn and Carn Mòr. There was occasional evidence of rabbit (*Oryctolagus cuniculus*) presence at Carn Ruigh na h-Easgainn. Grouse (*L. lagopus* and/or *L. mutus*) evidence existed at five sites, although they were rare at Craigs of Succoth. Field vole and/or bank vole holes were present at nine sites. The diet of bank voles is described as including shrubs and trees, compared with that of field voles which is only grass (Harris & Yalden 2008).

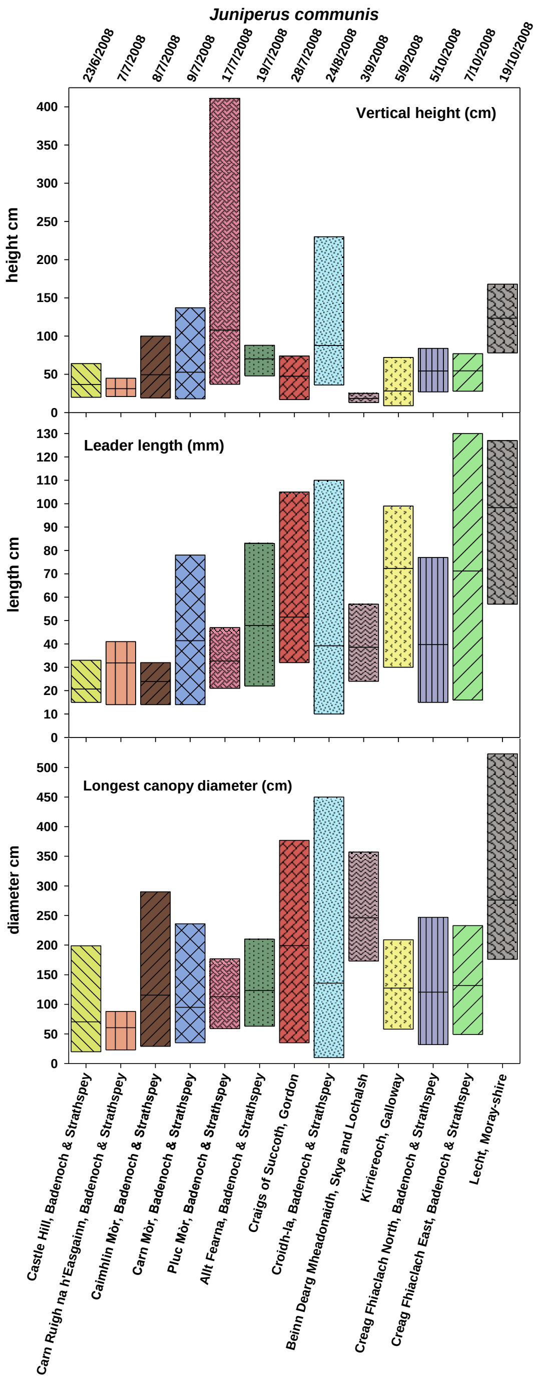


Figure 2.20 Mean, maximum and minimum site growth parameters (see titles) for *Juniperus communis, n*=10. Dates of surveys are given at the top of each column.

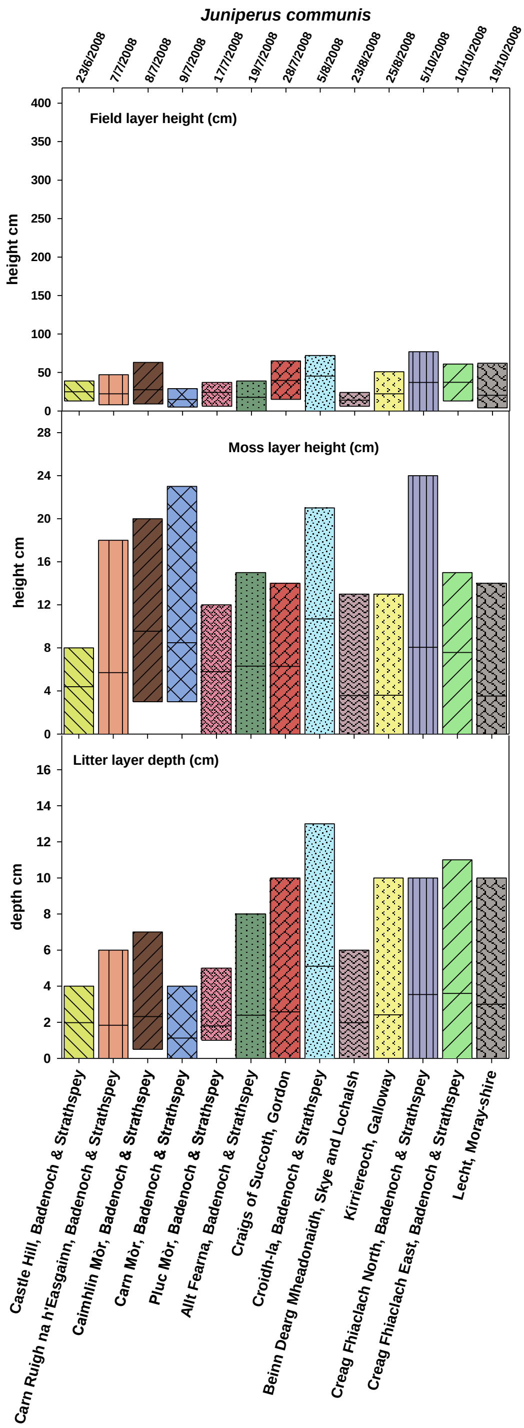


Figure 2.21 Mean, maximum and minimum *Juniperus communis* sample site vegetation layer heights (see titles), *n* = 40. Dates of surveys are given at the top of each column.

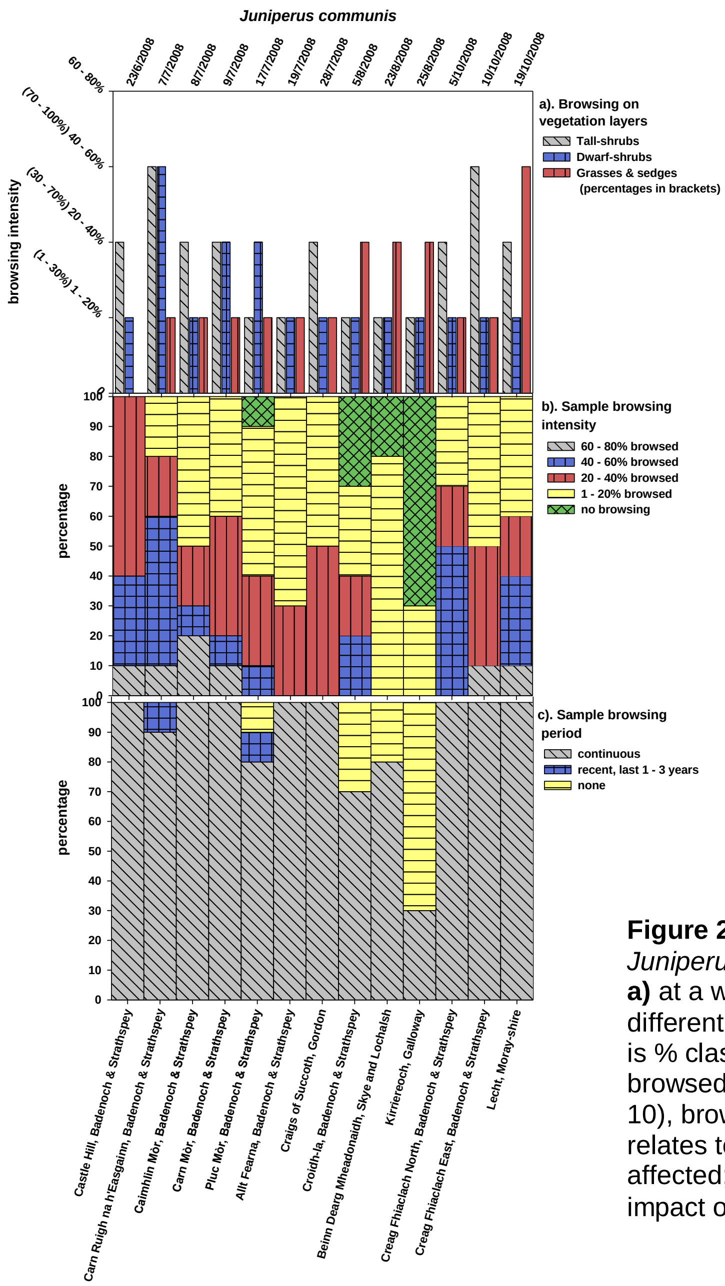


Figure 2.22 Herbivore impacts at *Juniperus communis* populations **a)** at a whole site scale, on different vegetation layers, Y-axis is % class of site vegetation cover browsed; **b)** on sample plants (n = 10), browsing intensity class relates to percentage of canopy affected; **c)** period of browsing impact on sample plants (n = 10).

Physical soil characteristics

Seven sites had primarily dry soils and five of these were also on steeper ground, although Kirriereoch was predominantly moist soils (Table 2.14a). Creag Fhiaclach east, Carn Mòr and the Lecht, all had small areas with wet soils. Kirriereoch had the highest area of bare ground and greatest range of patch sizes (Table 2.14a). 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. 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. Soil depths were generally less variable than for either *Betula nana* or *Salix myrsinites* sites. Across all sites the variation in means was only between 5 and 16.5 cm, with the shallowest being at Beinn Dearg Mheadonaidh, Kirriereoch and Croid-la.

Soil chemistry

The pH values measured in $CaCl_2$ solution covered a wide range across the sites, primarily due to the high values at Craigs of Succoth (Fig. 2.23). Creag Fhiaclach east was the next highest mean, but the majority of sites had mean values < 4. Beinn Dearg Mheadonaidh and Kirriereoch were notable for their lack of within-site variation. Beinn Dearg Mheadonaidh and the Lecht were notable for their similar, relatively low carbon values and lack of within-site variability, a pattern which was also evident in the nitrogen content of the soils at these sites. Generally the pattern of N content across the sites followed that of C. Calcium values were highest at Creag Fhiaclach east, and they were higher than all values at any site except the highest value for Craigs of Succoth. Both Pluc Mòr and Beinn Dearg Mheadonaidh had very low minimum values and very narrow ranges. The maximum phosphorus content at Carn Ruigh na h-Easgainn was higher than at any other site for any species in the survey, although the means for all the sites were below the averages for *Betula nana* sites. Beinn Dearg Mheadonaidh, Kirriereoch and the Lecht all had the smallest range of variation and low P values. Potassium showed a very similar pattern to P. The key difference was that at Kirriereoch K values were relatively much higher with a mean above the average across all the sites. The magnesium mean concentration at Craigs of Succoth, a site on serpentine soils, was more than 10 times that at any other *J. communis* site, well above any *B. nana* site and in the range of the higher concentrations at limestone-based *Salix myrsinites* sites. The lowest concentrations and least variation were again at Beinn Dearg Mheadonaidh and the Lecht.

Juniperus communis population condition assessment

Juniperus communis is dioecious so the density of plants and the sex ratio are important factors in ensuring recruitment. The former was unlikely to have been an issue at any site except Kirriereoch where the plants were primarily sparsely spaced, and due to the nature of the ground often more than 5 m. Eight sites had either seedlings or saplings present, although in all cases they were in low numbers. Saplings were present at Creag Fhiaclach east, one of the highest altitude sites and where the plants were relatively low growing but were above average spread and had good leader growth. Only two (out of 10) plants had female cones suggesting that the incidence of flowering has been low for the past two or three years but despite that this population could described as in reasonable condition. At Craigs of Succoth the plants were also of a low, spreading growth form but generally the population appeared to be old and a number of plants had high percentages of dead

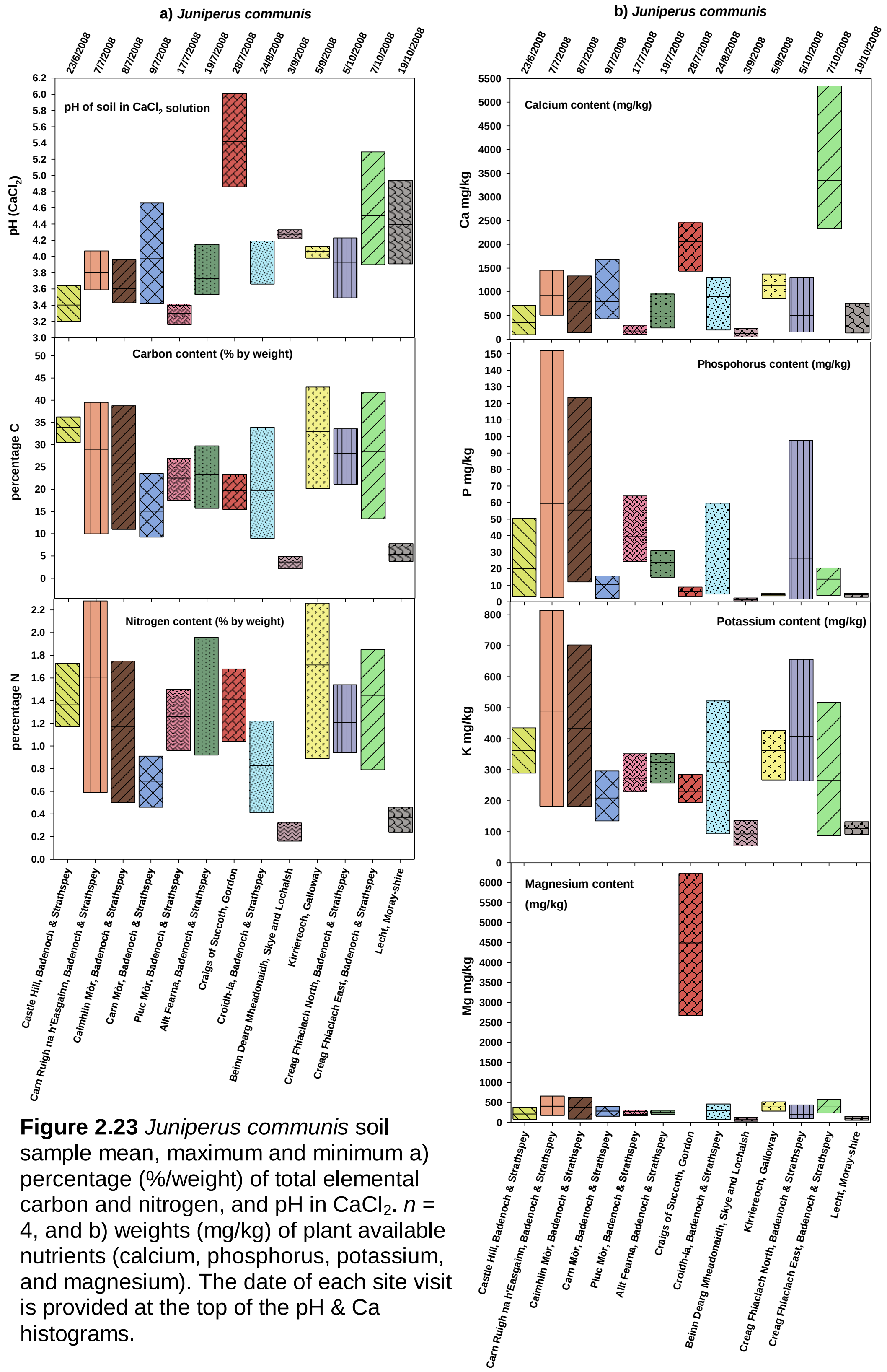


Figure 2.23 *Juniperus communis* soil sample mean, maximum and minimum a) percentage (%/weight) of total elemental carbon and nitrogen, and pH in $CaCl_2$. n = 4, and b) weights (mg/kg) of plant available nutrients (calcium, phosphorus, potassium, and magnesium). The date of each site visit is provided at the top of the pH & Ca histograms.

wood. There were no young plants seen at this site and no, or only very limited, broken ground which might be suitable for seedling establishment. At Beinn Dearg Mheadonaidh the juniper was very prostrate and growing in stable patches of vegetation surrounded by mobile scree across which sheep freely roam. There were no young plants seen within the population and no male or female cones on any plants. This site was very exposed and many plants showed evidence of either trampling or rock fall damage. At both these two sites it appears to be the longevity of the plants which is maintaining the population. However, at both sites vegetative spread is likely to be inhibited; at Craigs of Succoth the dense unbroken sward may be difficult for suckers to penetrate, whereas erosion and trampling are major detrimental factors at Beinn Dearg Mheadonaidh and neither site could be considered in good condition. Three other sites are in exposed locations, Castle Hill, Kirriereoch, Carn Ruigh na h'Easgainn and all have relatively small plants. The first two are also widely spaced populations which in the case of Kirriereoch are subject to damage from rock fall. Despite this that population had a few saplings present and most plants were out of reach of sheep and although it is a small population it appeared to be in relatively healthy condition. Castle Hill is less isolated than Kirriereoch but no young plants were seen and no female cones were seen, although one plant with male cones was seen. This site had the highest levels of browsing and could not be considered to be in good condition. Carn Ruigh na h'Easgainn, along with Carn Mòr and Caimhlin Mòr, all showed evidence of relatively heavy browsing. At the first two sites a few seedlings were found but no saplings. If the seedlings are evidence of the start of recovery the condition of these populations could be considered to be improving. More saplings and taller adult plants were found at Pluc Mòr than other sites. Allt Fearna had no saplings or seedlings and medium-sized adult plants, while at the Lecht saplings were rare but the adult plants were among the largest. All these populations border grouse moors and their upper edges were controlled by burning. At the Lecht there were the remains of dead juniper following the previous year's muirburn. Generally, these populations could be considered to be in reasonable condition but the land management is a serious impediment to their self-perpetuation and expansion.

2.5 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 analysis of existing information and remotely accessed data the records were categorised in order to identify any distinct 'site types' that might exist for each species. That process directed the selection of field sites which means the field data gathered encompassed the range of characteristics for all current records of sites occupied by populations of each of the three selected species. With the exception of a small collection of *B. nana* sites all the records for each species showed a continuous scatter across the PCA analysis component plots (Figs. 2.2, 2.4, 2.6). This may be because the remote datasets are based on fairly small resolution data (for example soils 2 km, LCS88 1 km, GDD 5 km which are larger than the size of most shrub populations) so the data parameters are unlikely to relate specifically to the exact site location. However, selecting sites from each quadrant of the PCA C1 & C2 plot was likely to have included the main range of site types and so provides a good basis to explore the relationships between distribution and land management pressures and the range of site characteristics.

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*. Plant available nutrient cations (Ca, P, K and Mg) content of soil is known to vary throughout the growing season (William Towers *pers com*), and so does the associated pH. The sites for all three species were surveyed, inter-mixed over several months. As a result it is reasonable to conclude that there are real differences between the three species soil site types, but the exact values need to be treated with caution in relation to the individual species site types.

2.5.1 Do existing populations only exist where they are protected from land management pressures?

Betula nana

It is unlikely that *B. nana* would be found where it is entirely protected from browsing as it is most commonly found in open expansive moorland areas. These areas have been or are generally subject to drainage, rotational burning and grazing. There were features common to the areas where *B. nana* was surveyed which, in the context of these wider land management practices, may indicate whether or not the present distribution is a result of land management or not.

At every site with the particular exception of Glen Muick and less emphatically Loch na Beinne Baine, the *B. nana* plants are below the height of the surrounding vegetation, regardless of what that vegetation is, indicating a possible browsing limitation to height growth because the plants are known to grow taller.

At every site there was a high level of moss cover, most commonly *Sphagnum* species but also pleurocarpous mosses. None of the sites had been recently burned, although apart from Glen Muick most sites had been burned in the past (probably within twenty years) and all the *B. nana* aerial stems appeared to be relatively young. At the majority of sites there were frequent horizontal 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).

There was no evidence of drainage at any site. Although at Loch na Meur the population may have been growing towards the edge of an old (more than 100 years old) peat excavation site.

The three features, tall surrounding vegetation, a ground level moss layer and lack of drainage, may be critical to the continuing survival of this plant at many sites. The latter two features tended to be common at sites with deeper soils and it is worth asking the question: Is *B. nana* showing a preference for the features, or are these sites simply a refuge from the effects of drainage and fire? The site with the most 'healthy' population of *B. nana* (in terms of plant growth, size and presence of young plants) was at Glen Muick, a steep, relatively dry and shallow-soil site with no history of burning and low grazing pressure, which suggests that none of the listed features are "preferred". Two sites on the original field survey list no longer supported *B. nana* within the 1 km square for the record. One was close to the Lochaber – Argyll border, the other was in Sutherland and neither had a moss layer. The surface of the peat soil was visible between the recovering vegetation, perhaps due in the first case to burning and in the second burning and drainage. The first of these sites was surveyed in 1988 (Coupar, unpublished report to NCC, Highland Birchwoods 2000 dataset) and the *B. nana* was described as "extensive", the second was surveyed in 1987 and described as "fine stands with *Arctostaphylos uva-ursi..*" (Ferrera, Highland Birchwoods 2000 dataset). Where the horizontal stems are associated with a damp moss layer they appear more able to withstand burning and readily produce shoots, and possibly roots, from these stems. Whittaker's (1993) description of *B. nana* as a tree growing on its side seems to be supported by these circumstances. Once the moss layer protection is lost the plants may become vulnerable. In support of this proposal is the fact that at the Sutherland site, a small population of *B. nana* was found in the neighbouring 1 km square, between peat pools with an intact *Sphagnum* mat, in an area which had not been drained. This requires further research.

It is interesting to contrast the situation of low-statured and young aerial-stemmed plants growing on blanket bog with Glen Muick, a steep, un-even sloped site of wet heath with primarily tall, large plants with old, mature stems. In contrast to De Groot *et al.* (1997) and Ashton (1984) who describe *B. nana* in the UK as a plant of blanket peat with peat depths of 2 m, ten out of the 13 sites surveyed had mean peat depths of less than 1 m. Given the nature of the site selection process, soil depth must be an important characteristic of the sites where this species currently grows and therefore an important consideration in discussion of management for the future of *B. nana* sites. This suggests that more work on the actual site preference of the plant is needed.

Further work would also be valuable on herbivore preference of winter browse between *Calluna vulgaris* and *Betula nana*. The evidence at a number of sites suggests that *B. nana* is preferentially browsed when visible which suggests that individual plants are unlikely to out grow the surrounding vegetation in areas where there are high herbivore numbers. This is supported by Carn Dubh the site which had the highest impacts from browsing, with the smallest plants and the lowest *B. nana* cover.

Salix myrsinites

The most notable feature of the *S. myrsinites* sites is the range in soil pH from sites with means just above 4 to those whose means are over 7. This is a wide range, and includes values which are very low for a plant described as calcicolous. The sites include a number which are described on geological maps as granite, an acidic rock. The geological details for these areas is poor and any richer intrusions or outcrops, such as occurs at Coire Gabhlach, are not identified. Willows are deep rooting plants (Wilkinson 1999, Kuzovkina & Volk 2009) and high base-status intrusions may be present below the surface soil and accessible to the plants but do not necessarily feature in samples of the surface soils. 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). Despite the wide range of pH there was no correlation with plant size, suggesting that either the pH is an anomaly of the sampling or the species is genuinely more tolerant of low base status than previously thought. Further detailed study is required to confirm .

Salix myrsinites plants were taller than the surrounding vegetation at most sites. The two exceptions to this were both Inchnadamph sites. One site has 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; the other is un-enclosed and has 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 approximately 50 mm longer on the protected plants). At several sites, including enclosed Inchandamph 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 been raised concern for the health of *S. myrsinites* plants (A. Scott, *pers comm.*) and requires further investigation.

The majority of populations are in areas where the surrounding vegetation is 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 Gabhlach, 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. These sites all have a degree of inaccessibility which has discouraged what might otherwise have been heavy use by herbivores. The exception is Creag an Dail Beag on a heavily eroding crag, frequently used by sheep. In this case the main part of each remaining plant was largely out of reach of the sheep.

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 these willow populations.

Competition and browsing appear to be two major factors in the distribution of *Salix myrsinites*, although neither was directly tested in this survey (see Chapter 3 for browsing / exposure experiment). Experience at Inchnadamph has shown that managing these two factors for the benefit of *S. myrsinites* away from high exposed sites, where both are kept in check, is challenging. The results of this study suggest that these two factors may be more important than the base status of the soil. It is possible that tolerance of the generally nutrient poor condition of the sites is a way of avoiding competition (Crawley 1997, Grime 2001). This is potentially a critical issue for the restoration of this species and requires further investigation.

Juniperus communis

Eleven of the populations surveyed, all *J. c.* ssp. *communis*, were taller than the surrounding vegetation. One definite prostrate *J. c.* ssp *nana* population at Beinn Dearg Mheadonaidh was shorter than the surrounding vegetation, although the vegetation was sparse and did not interfere with the juniper canopy. At Kirriereoch, the mean height of *J. communis* (subspecies not confirmed) was the same height as the surrounding vegetation. The plants at Beinn Dearg Mheadonaidh had similar leader lengths to all other sites and one of the longer mean canopy diameters.

The sites are generally acid, with a mean pH range from 3.3 to 4.5, except Craigs of Succoth, with a mean pH of 5.5. Craigs of Succoth soil also had exceptionally high mean values for plant available magnesium (4,500 mg/kg, compared to < 500 mg/kg). The growth at this site was not exceptional (either large or small) for any parameter.

Six sites are, or have been in the recent past, within sporting and / or agricultural holdings. 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, as it extends onto the *Calluna vulgaris*-dominated moor, has (and is being, Estate staff, *pers com.*) been constrained by burning. The charred stems from the previous season's burn were still present at one site. Secondly, the boundaries of the population across the slope have generally been constrained by grazing of the grass dominated sward. The grazing it likely to have constrained the successful development of any seedlings, and the dense sward had few bare-ground niches suitable for seedling establishment (Thomas *et al.* 2007). Sullivan (2001) cites the loss of a relatively large stand of mature *J. communis* ssp *communis* in Strathdearn (and is misquoted by Thomas *et al.* (2007) who refer to *J. c. nana*) as being lost in the winter of 1983 /84 to heavy snow fall. This strath 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 above explanation for the demise of this population may be over simplistic. It is possible that in a hard winter the old juniper were unable to cope with the heavy toll of browsing, and bark stripping that is likely to have ensued, rather than necessarily the direct effects of snow. This suggests that some of the existing populations may be vulnerable to future heavy snow fall.

From this 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.

2.5.2 Are existing populations restricted by edaphic conditions to the sites they currently occupy?

Nothing from the results of this field survey or during the site selection process suggested that the distribution of these plants is constrained by narrow edaphic niches. Rather it seems more likely that there is potential scope for populations to occur away from their existing sites with careful consideration of land management, including wild herbivore presence, and competing vegetation. The disparity in site characteristics between a) the three features most commonly associated with *B. nana* sites (moss, moist to wet soils and tall surrounding vegetation) and b) those associated with the best *B. nana* plant growth suggests that the current perception in the UK that this plant has a preference for deep peat soils may be incorrect. Such sites may in fact simply be refuges least affected by other pressures on this plant such as grazing and fire.

2.5.3 Conclusions

All three study species tend to exhibit, through their current site types and growth habits, some traits common to stress-tolerant species (Grime 2001). They appear to tend to allocate resources to survival and longevity over annual sexual reproduction (*K* – selection, Grime 2001). However, this may be simplistic if low levels of seed production are the result of herbivory. They are all comparatively slow growing and, from the data presented here, all are able to tolerate a level of browsing (Bryant and Kuropat 1980, Herder *et al.* 2008). 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. This is a feature shared with *S. myrsinites* (Meikle 1984). Oksanen and Ranta (1992) proposed a modification to Grime's triangular growth strategy model reported in by Crawford (2008), which introduces *g*-strategists or plants adapted to relatively unproductive systems and high frequency, low intensity biomass loss and disturbance, (e.g. through herbivory and/or trampling). This modification appears to better explain the circumstances of these three species in the UK, although *B. nana*, from its Scandinavian habitats was categorised as a *K* strategy plant (see above). Tall-shrub montane willows were not included in the study by Oksanen and Ranta (1992) and further work to better clarify the important factors in the growth 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.

For all species there was limited evidence of recent recruitment at any sites. It appears possible that the presence of domestic and wild herbivores across upland Scotland over the past two centuries may have limited the opportunity for successful seedling establishment over that time. There is only limited published information of the age of any of these species, particularly for *J. communis* at higher altitudes, but it is possible that populations may be composed primarily of old plants. 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 levels of flowering at each population in just one visit, or the numbers of viable seeds produced. These may be limiting factors and would warrant further attention.

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APPENDIX 2.1 LAND COVER SCOTLAND VEGETATION AND SOIL TYPES

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

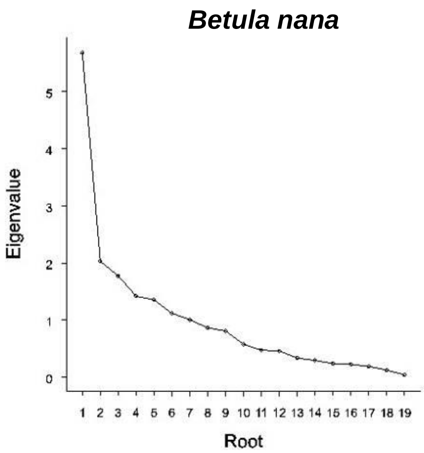
Table A2.3 contd. Land Cover Scotland vegetation type (LCS88, MLURI 1993) and soil type (MISR 1984) at *Juniper communis* record sites.

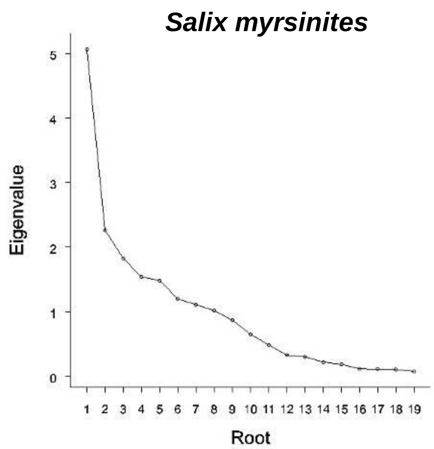
LCS88 units and indices for sites characteristics									Soil type code and indices for site characteristics				
Vegetation code no.	Bogginess	Heather cover	Grass cover	Tree cover	Stability	Rockiness	Burning	Bracken	Soil type code	Peat cover	Wetness	Mineral cover	Alpine
182	3	1	0	0	1	0	0	0	191	3	2	0	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 *Juniper 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 2.2 Eigen values from Principal Component Analysis for each species





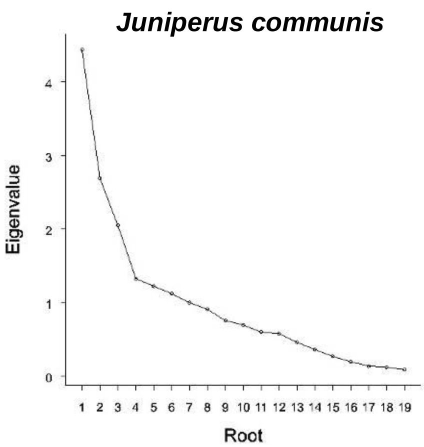


Figure A2.1 Eigen values of the Principal Component Analysis of 19 dimensions for *Betula nana* and *Salix myrsinites* and 20 dimensions for *Juniperus communis*.

APPENDIX 2.3 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		**pr**ostrate	
Multi		**I**ntermediate	
		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	

for area < or = 1ha

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

Figure A2.2 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										
.eader 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 A2.2 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 | **U**pright

Intermediate | **l**ollipop

Bare ground record large areas on map

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

Grazing presence **r**are **o**ccasional **f**requent **a**bundant Record for each species, for dung record whether **F**resh or **O**ld

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 **C**urrent: 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.

Soil cores up to 4x 5cm diam, 15 cm deep cores to be taken for up to 4 quadrats at any site & the A horizon (excluding litter layer) placed separately in polythene bags. Each sample point to be grouped & labelled in another bag. For some sites using a trowel may be simpler than a corer (heathery/vacc, sites with lots of roots!

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**

Figure A2.2 contd. Field survey **c)** protocol for completion of survey forms.

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.

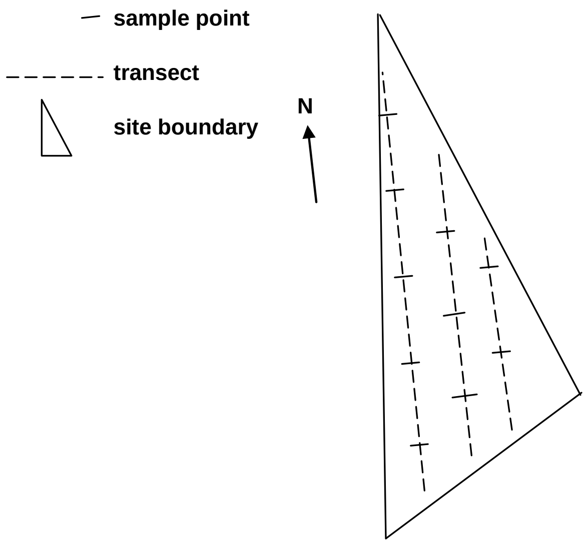


Figure A2.2 contd. Field survey **c) contd.** protocol.

Chapter three: TREELINE ECOTONE SCRUB, HERBIVORY & EXPOSURE

3.1 INTRODUCTION

Previous research on the impact of browsing on woody plants has demonstrated strong but varied responses in a range of species and to a range of herbivores, as summarised below. Scotland, as described in chapter one, has recently been supporting high levels of domestic and wild herbivores in the uplands. Geographically Scotland sits on the north-western seaboard of Europe with a prevailing west north-westerly air flow (Harrison 1997). Although the complex topography creates a highly variable climate across the country as a whole, the dominant and strong westerlies are the primary climatic characteristic. Superimposed on this pattern are increased exposure and cloudiness with altitude, and increased oceanicity and cloudiness with increased latitude and westerly longitude. Wind can have a range of impacts on plants depending on its speed and this has been described in detail by Grace (1977). In the uplands browsing and wind are two important drivers affecting the productivity and distribution of treeline scrub species. Few studies have examined plant responses to the compounding effects of herbivory and wind.

There is a body of literature which discusses browsing of sub-arctic treeline and scrub vegetation, including willows, birches and to a lesser extent juniper (e.g. Archer and Tieszen 1980, Clark and Gilbert 1982, Crête and Doucet 1998). Suomela *et al.* (1997), for example, demonstrated that captive wild hares and voles differentiate between mature winter shoots of different individuals of *Betula pubescens* ssp *czerepanovii* and to a greater extent between *Salix phylicifolia* individuals, and between individuals of the two species grown at different altitudes. Stuart Chapin *et al.* (1980) demonstrated changes in nutrient status over the growing season in *Betula nana* ssp *exilis* and *Salix pulchra* and suggested that first leaf flush following snow melt is likely to be a valuable source of nitrogen and phosphorus for large mammalian herbivores. Hjältén (1992) showed that given the choice wild un-caged hares preferred male *Populus tremula* and *Salix caprea* to females or either sex of *S. pentandra* or *Myrica gale* and that they all but ignored *Juniperus communis*. The preference for male *P. tremula* and *S. caprea* was coincident with higher nitrogen concentrations in their bark compared to the female plants. Stolter *et al.* (2005) demonstrated that the responses to browsing differ between species, even ones that are closely related such as *Salix myrsinifolia* and *S. phylicifolia*. However, herbivory and plant responses not only vary between species and sexes, but are modified by climate and geography (Graglia *et al.* 2001, Millett *et al.* 2006) and only the generality of much of this work is directly relevant to the UK treeline scrub. It has been acknowledged that there is very little ecological information available about the nature and dynamics of these habitats on which to base realistic restoration methodology. The movement of treelines in response to climate change has attracted recent attention from researchers, particularly in Scandinavia (Aas and Faarlund 1996, Kullman 2002, Holtmeier and Broll 2005, 2007). Dullinger *et al.* (2003) suggested that temperature rises were not the only drivers and that the invasibility of the sward above the treeline would play a significant role in determining whether and how quickly tall-shrub species would expand up hill. In North America Myers-Smith (2007) documented the advance of the shrub lines in Alpine tundra and explained the feed-back loop which helps drive the advance. Again the generalities of these studies are useful, but the detail cannot be directly translated to the UK situation due to the very different climatic conditions.

The intensity and timing of browsing generates different responses in different woody plants (Danell *et al.* 1994, Hester *et al.* 1996, 2004, Mayer *et al.* 2005). In Finland Stolter *et al.* (2005) reported increased growth of individual *Salix phylicifolia* shoots following the removal of the new season's growth from the same shoot by Moose (*Alces alces*). She showed that this new growth had lower concentrations of secondary compounds, making them more attractive forage than un-browsed shoots on the same plant. These latter shoots continued to produce flowers, whereas the browsed shoots did not. The response of the willow to the loss of all new growth was not examined in the study. Bryant and colleagues (1989) demonstrated that juvenile phase plants of subspecies of *Betula pubescens* and four northern *Salix* species were less palatable, due to the presence of secondary compounds, than stems on mature plants. In addition to seasonal differences in plant responses, the deciduous *Betula pendula* and *Sorbus aucuparia,* which have widely distributed buds on aerial stems and store nitrogen below ground and in old wood, respond flexibly to the loss of above ground biomass over winter (Millard *et al.* 2001, Shipley *et al.* 1999). Conversely, *Pinus sylvestris,* with most buds located at the shoot tips and much of its nitrogen in 1-year old needles (Millard *et al.* 2001), tends to show a more negative response to winter browsing in both above and below ground organs (Hester *et al.* 2004). It is not known if this is a specific difference between deciduous and coniferous species and whether *J. communis* would respond in a similar way to *P. sylvestris*.

Wind has a major impact on the temperatures experienced by plants (Grace 1977, Stoutdejisk and Barkman 2003) and Wilson *et al.* (1987) showed that the taller a plant is above the sward the more closely linked it will be to atmospheric temperatures. Shorter plants tend to be more sheltered and so are able to absorb more incident radiation, assuming they are not over-shadowed by taller vegetation. Rather than static air, a gentle wind can enhance respiration and photosynthesis through increased gas circulation close to the leaf surface (Grace 1977). However, at high wind speeds this effect can be negated and in extreme circumstances leads to mechanical damage. The direct effect of wind on plants takes several forms. It can cause physical damage, abrasion of plant parts, breaking stems and changing the architectural structure of the plant (Cordero 1999, Grace 2003). Plant productivity can be affected, which in turn may restrict growth and the potential for recovery from damage, due either to wind or browsing. In the UK the Forestry Commission have developed a method for predicting the suitability of upland areas for timber production (Miller *et al.* 1987, Quine and White 1994, Bell *et al.* 1995) based on the exposure of a site to wind, called DAMS (Detailed Aspect Method of Scoring), and accumulated temperature (AT). A DAMS score of 19 was proposed as the maximum for commercial forestry (FCS 1996). For treeline woodland scores between 19 and 24 are considered reasonable, with a range in AT of 500^o C to 690^o C-days above 5 ^{o} C. Ninety percent of samples from a small study of known treeline woodland sites in the UK fell between DAMS 19 and 22.5, and had AT higher than 575^o C-days above 5 ^{o} C (Hale *et al*. 1998).

Smith (1983) used two time series of data, one of actual wind speeds (1965 – 1979), and the other of wind speed derived from records of atmospheric pressure (1881 – 1980) to demonstrate that there was a sinusoidal fluctuation of wind speed annually, with the strongest winds between December and March and relatively quiet months from June to August. As a result plants are likely to experience high winds annually during winter when deciduous plants will offer less wind resistance than conifers.

Research need

Tall treeline scrub in the UK now survives in scattered populations, usually with widely spaced individuals. The individual plants are thought to rarely reach their potential height because of a) browsing and b) increased height often increases exposure to browsing and wind leading to shoot damage. Expansion of many populations would generally increase their vulnerability to browsing as many current stands are inaccessible to herbivores. Much of the work of Hester, Millard, and others (Hester *et al.* 1996, 2004) on tree-herbivore interactions has included birch and pine, but almost exclusively in areas below the treeline. There is no published work documenting the effect of timing or intensity of browsing on specific treeline ecotone tall-shrubs in the UK. In northern Finland, Herder *et al.* (2008) demonstrated that *Salix glauca* plants exposed to summer reindeer (*Rangifera tarandus*) browsing at three to five individuals km^{-2} over a six year period were stunted compared to plants growing in an enclosure and that this had a serious effect on the amount of browse available for willow grouse (*Lagopus lagopus lagopus*). In support of the findings of Hester *et al.* (2004) Herder & colleagues (2008) found that browsing did not affect the length of new growth on browsed individuals but did affect the number of new shoots. Mountain willow populations occur in areas with relatively productive grassland and the author has observed that red deer (*Cervus elaphus*) tend to focus on the grassland throughout the summer and move to browse the willows towards autumn. For all tall-shrubs, and stunted trees at the treeline, there will be occasions following heavy snow fall when they may be the only vegetation visible to herbivores. The current perception is that tall-shrubs are subject to browsing at the end of the summer and over the winter when, in their exposed locations, they are also likely to be subject to the strongest winds. There is only very limited data on the current level of tall-shrub recruitment into populations, but it is apparently very low. However, there is growing interest in establishing new or enhancing existing populations of treeline tall-shrubs and it is expected that this will be achieved through the propagation and planting out of young plants.

So browsing remains a key factor in the dynamics of vegetation in upland Scotland. At the same time it is predicted that the generally windy climate will become more erratic and stormy. The young plants in any treeline scrub establishment or expansion projects will therefore be subject to these combined factors and to minimise the potential losses it would be useful to answer the following questions:

a) Does exposure increase the impact of browsing?

b) Does exposure have a different impact if browsing is of medium or heavy intensity?

c) Does the impact of exposure vary depending on what time of year browsing occurs?

d) Does the interaction between exposure and browsing differ between conifer and deciduous species?

To answer these questions an experiment was set up to measure the combined impact of simulated browsing (clipping with secateurs) and wind exposure on young *Betula nana, Salix myrsinites* and *Juniperus communis* ssp *communis*.

Clipping, as an alternative to natural browsing, is controllable and so reduces potential compounding variation in the intensity and timing of browsing. The use of simulated browsing was questioned by Baldwin (1990) because it did not mimic the side-effects of the browser, such as leaving saliva on the plant and tearing plant tissue. Pruning plants, particularly in winter is generally considered an acceptable alternative to natural browsing because the plants are dormant and it is unlikely that saliva would have an effect. Bergman (2002) tested the use of previously frozen moose (*Alces alces*) saliva on regularly fertilised sapling *Salix caprea* grown in controlled environments and demonstrated an apparent growth promoting property to the saliva. The conditions of the experiment were far removed from the natural situation and Danell *et al.* (1985) had previously studied herbivore-plant-herbivore interactions in *Betula pendula* and *B. pubescens* using both simulated and natural browsing. Although not specifically compared during the study they were able to conclude that the responses were very similar.

The growth responses of the young plants were measured following each of two growing seasons to address the following hypotheses:

a) 'Browsing' (simulated by clipping) at 100 % of new growth will have a negative effect on all three species; browsing at 50% will have a negative effect on the conifer *J. communis* but not on the deciduous species *B. nana* or *S. myrsinites*.

b) Browsing in late summer (pre-senescence) will be more damaging than during dormancy for *B. nana* and *S. myrsinites.*

c) *J. communis* will respond similarly to both pre-senescent and dormant clipping.

d) The negative effect of clipping will be exacerbated in areas of high exposure, for all three species.

The results of the clipping/exposure experiment are reported and discussed in the following sections.

3.2 METHODS

3.2.1 Location Description

The area selected for this experiment is on the Ben Lawers National Nature Reserve, on the west-facing slopes of Meall Corannaich (56°4'N 4°3'W), in a north – south orientated U-shaped valley. The reserve supports existing populations of both *Salix myrsinites* and *Juniperus communis* but no *Betula nana*. National-scale data maps of exposure (DAMS – Forestry Commission Scotland) confirmed that it is an exposed site (DAMS 20 - 22), too exposed to be recommended for commercial forestry (FCS 1996), and when combined with existing vegetation cover maps (NVC Scottish Natural Heritage) suggested that it was potentially suitable for treeline scrub. The area selected also lay within the altitudinal range of all three species at a mean altitude of 698 m above sea level (asl) (*B. nana*: 129 – 889 m asl; *S. myrsinites*: 86 – 1036 m asl, and J. *communis*: 1 – 1151 m asl, MacKenzie 2000). The experimental site had no existing woodland, although cliffs and exposed crags in the area supported *S. reticulata* and very occasional *Sorbus aucuparia*, and the neighbouring sward, *S. arbuscula*. The area is owned by the National Trust for Scotland (NTS), a land owning conservation charity, and tenanted to a sheep farmer. The NTS were very agreeable to the research being undertaken. As well as domestic sheep, the site is grazed by red deer and short-tailed field and/or bank voles (*Microtus agretis*, *Myodes gareolus*, respectively).

3.2.2 Young plant propagation and use

This experiment used 270 young plants (90 of each species). Cuttings collected for the purpose were propagated to be ready to plant out in the summer of 2007. Between October 2006 and January 2007 cuttings of *Betula nana, Salix myrsinites* and *Juniperus communis* were collected from three geographically spread populations for each species (see Table 3.1). The cuttings were propagated in Rapid Rootrainers© (0.1 litre soil volume, 8 cm tall by 3.5 cm x 3.5 cm), in two equal groups either in pure perlite and left outside over winter, or in a peat / perlite mix and placed in a controlled environment (16 hr daylight at 12°C, 8 hr dark at 10°C, humidity set to 75%). At the end of January 2007 all the cuttings were brought into the controlled environment to encourage growth. At the end of March they were all transferred to an outdoor location at 250 m asl in Strath Spey to acclimatise ready for planting at the experiment site in the summer. The cuttings were watered once a week prior to showing signs of growth and at least once every three days once green leaves were visible and while in root trainers. Two weeks following the first showing of green leaves each cutting was fed weekly by saturating the soil / perlite with a 1:10 solution (fertiliser to water) of N:P:K fertiliser (14:10:27, plus 2.5% MgO and 7.5% SO_3. Full details are provided in Appendix 3.1, Table A3.1) in liquid form in order to keep it alive until planting out but ensure, as far as possible, that there was minimal residue of fertiliser transferred to the planting site.

Table 3.1 Origin of young plants used in the experiment

Species	Site Name	Location	Altitude m asl
Betula nana	Glen Muick	56°54'N 3°12'W	627
	Port Clair	57°12'N 4°38'W	428
	Ben Wyvis	57°38'N 4°32'W	425
Salix myrsinites	Garbh Coire	57°3'N 3°42'W	820
	Meall More	56°39'N 5°5'W	580
	Inchnadamph	58°7'N 4°56'W	272
	Glen Einich[1]	56°9'N 3°8'W	744
Juniperus communis	Creag Leek	57°1'N 3°22'W	505
	Creag Fhiaclach	57°7'N 3°50'W	574
	Glen Elrick	57°11'N 4°11'W	597
	Coire Etchachan[2]	57°6'N 3°3'W	680

[1] Origin of mature willow plants used Expt. 2 in 2007, and replacement willows used in 2008. [2] Origin of replacement juniper used in 2008

The aim of the cutting collection was to achieve 200 softwood cuttings from each site (Appendix 3.1 details the protocol agreed with Scottish Natural Heritage for collecting cuttings). At each collection site details were recorded of the location of parent plant including altitude, and sex for the dioecious species where possible. There had been poor growth in 2006 on many *S. myrsinites* plants at all sites and it was only possible to collect 60 cuttings from Meall Mhor, 117 from Inchnadamph and 185 from the Garbh Coire.

At the end of the first growing season, any fatalities were replaced. For *B. nana* the replacement plants were 2nd season seedlings from seed collected at the mid origin site, Port Clair (57°1'N 4°6'W, 428 m asl). In general these seedlings were smaller than the cuttings that had been planted originally. For *S. myrsinites*, cuttings struck in late summer 2007 from cloned mature plants were used. These cuttings were roughly the same size as those originally planted out. The original propagation material was from a wild population at Glen Einich, Cairngorms (56°9'N 3°8'W, 744 m asl). For *J. communis* the new plants were nursery reared three-year-old seedlings from high altitude wild parents collected in Coire Etchachan, Cairngorm massif (57^{o} N 3^{o} W, 437 m asl). A slow release fertilizer (no details available) had been added to each root trainer cell. The plants when planted out were generally taller, had more and longer shoots and had larger more complex root systems. At planting out it was not possible to remove all the fertilizer pellets from within the root systems and as a result it is likely that these plants benefited from a small amount of residual fertilizer independent of the site. Original plant size and planting year were taken into account in all analyses (section 3.2.6).

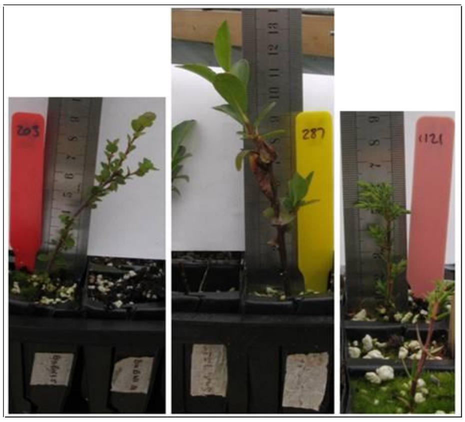


Figure 3.1 (left) Cuttings of *Betula nana, Salix myrsinites* and *Juniperus communis* prior to planting on site.

Figure 3.2 (right) The black, open cage netting (top) and white shelter cage netting with 1, 2 & 3 layers (bottom, see text for explanation).

3.2.3 Experimental design and site selection

Three separate locations with different levels of exposure to the wind (Table 3.2) across the slope of Meall Corannaich were identified. At the same time an attempt was made to ensure that the sites did not differ in vegetation type, were as close as possible in altitudes and that the topography was reasonably uniform to avoid the terrain creating a sheltering effect for any cage. For the low exposure site this was considered less important because the aim at this site was for the cages to be sheltered, but the cages were positioned to avoid generating turbulence between them.

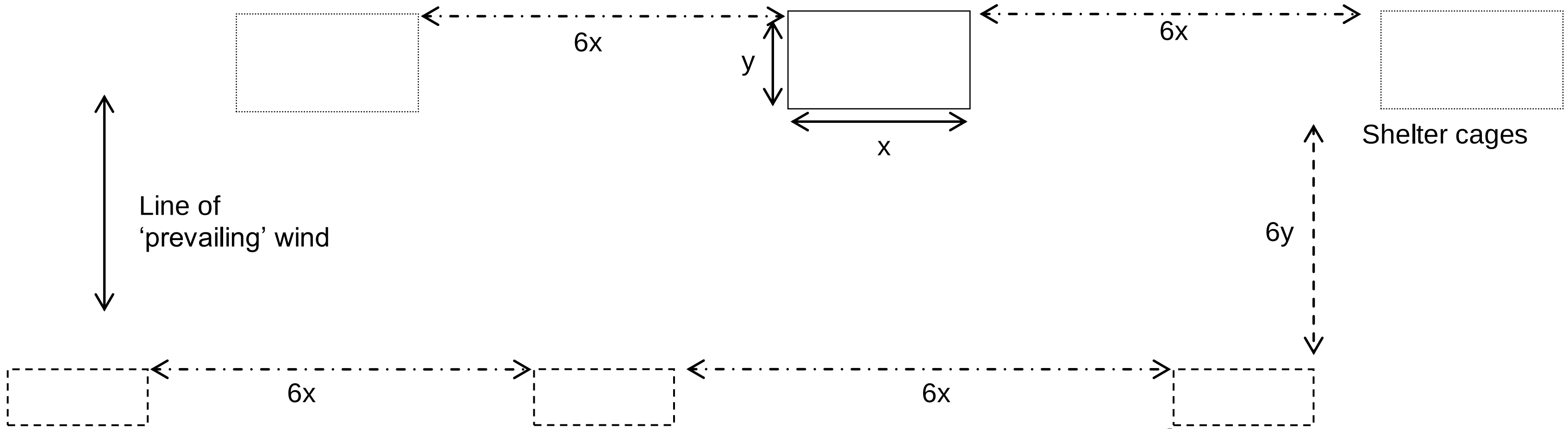
Table 3.2 Location details for different exposure levels.

Exposure level	Low exposure	Mid-exposure	High exposure
Grid Ref	NN6050540116	NN6047839722	NN6045440120
Elevation (m asl)	702	666	722
Aspect deg North	90°	280°	280°

The experiment consisted of 18 cages, two for each species at the three different locations for exposure to wind. In late August 2007 15 young plants of each species (Fig. 3.1) were planted in each of a pair of large-mammal-proof cages at each exposure level (low, mid- and high). One of each pair of cages was open to the wind and the other was sheltered around the sides by the use of graded shelter netting. The highest section of the netting (20 cm deep) was composed of one layer of small mesh netting (Table 3.3), the next 20 cm down had two layers of netting, and the bottom 20 cm was composed of three layers (Fig. 3.2). Each pair of cages for the high and mid-exposure sites were positioned to ensure uninterrupted exposure to the prevailing wind (Fig. 3.3), which generally blew straight up or down the glen (south - north). The details of the sizes of the cages and the materials used are given in Table 3.3. Despite the different sizes of cage the plants were set out in the same pattern and the same distance apart in each cage (Fig. 3.4).

The plants were planted into the soil on site with the material from the Rootrainers in order cause minimum disturbance to the roots. Where there was an option *Salix myrsinites* and *Juniperus communis* cages were sited on more mineral soils, determined by the vegetation, and *Betula nana* cages on more organic soils. If additional material was required to fill the planting holes this was taken from nearby mounds created by moles (*Talpa europaea*) for the former two species and peat from banks on the site for the birch. This avoided the need to break into the vegetation on the site. Because there was a high vole population, with both short-tailed field vole and bank vole present, there was concern that the young plants might attract vole damage. To reduce the potential for this the bottom section of each stem was wrapped with unwashed sheep's wool teased out to create a fibrous barrier (Fig. 3.5). At the time of planting the experiment the vegetation on all sites was as tall as or taller than the height of the young plants. In order to ensure that the plants were exposed to different levels of wind at the different sites the vegetation in each cage was cut down to ground level with shears prior to planting. This was not repeated.

Figure 3.3 Cage and site layout. Relative positions, although not to scale, of cages with and without shelter netting. X = 2.6 m, y = 1.4 m. The distance between cages in the line of the wind was at least 6 times the width of the largest cage, and between cages perpendicular to the wind was at least 6 times the length of the largest cage. This arrangement was used where the terrain allowed, and particularly at the two more exposed sites. It was not used at the sheltered site



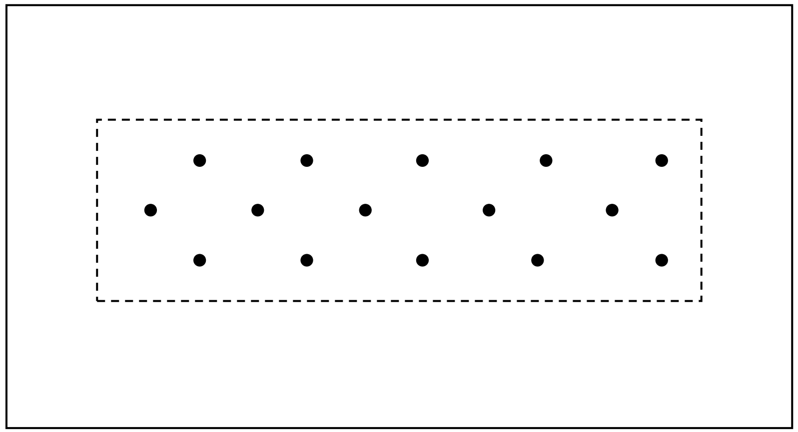


Figure 3.4 Diagram of plant (●) layout in cage and size of planted area in relation to the size of each type of cage. Inner rectangle is an open cage, outer is the larger shelter cage.

Table 3.3 Specifications of cage sizes and materials used for open and shelter cages

	Size (m) at ground level:			Netting mesh size (mm):		Netting material	Comments
	length	width	height	sides	top		
Open	2.0	0.8	0.5	50	50	Knotted, multi-plied polythene cord (~ 2mm)	Sides slanted inwards 20 cm difference between ground length and lid length for both cages.
Shelte-red	2.6	1.4	0.5	1.35	50	Side net: woven, single strands, single layer gives 20% shade, 3 layers up to 60%	Graduated shelter, bottom 20 cm 3 layers thick; mid 20cm 2 layers; top 20 cm 1 layer

Figure 3.5 ***Salix myrsinites*** planted cutting with wool around the base of the stem to deter voles.

Within each cage the 15 plants were divided between two clipping intensities and two different clipping timings, and a no-clip control. The clipping intensities were 100% and 50% of new growth. The clipping methods followed Hester *et al.* (2004, 2005). In the first case all the most recent season's new growth was removed with secateurs. For 50% removal half the number of new shoots was completely removed starting with the apical shoot and removing alternate shoots down the stem. Secondary or tertiary shoots were also removed alternately. Where no lateral shoots were present 50% of the apical shoot was removed. The clipping timings were pre-dormant, in the autumn (19.09.2007 and 26.09.2008) and dormant (11.02.2008 and 23.02.2009). This gave five combinations of clipping treatment. Although some authors suggest that woody plants tend to be vulnerable to browsing at the beginning of the growing season (Shaw 2006, Stuart Chapman *et al.* 1980), in Scotland it has been observed that treeline scrub is also browsed at the end of the growing season when grass is losing palatability (*pers. obs.*).

The treatments were randomised in a line of five, running down the length of the cage. In the case of the high exposure and mid-exposure sites this was perpendicular to the direction of the prevailing wind. This line was replicated twice and across the three lines the three different origins of plants were represented in each treatment combination as far as propagation success allowed. Each line was off-set in order to reduce the shelter effect between plants (Fig. 3.4, above).

3.2.4 Data collection and handling

Site habitat assessment

Each cage location was surveyed at 2 m x 2 m level for vascular plant cover, dominant bryophyte cover and common lichens. In the centre of each quarter of the quadrat, soil depths and vegetation layer heights were measured and one 5 cm diam. x 15 cm deep soil core was colleted, from below the sward, for pH measurement and chemical analysis. This data was entered onto a form on which information about the cage location and presence and impact of herbivores was also recorded (Appendix 3.2 Fig. A3.1).

Soil samples were frozen within 24 hr of collection. Once defrosted they were air-dried at 30°C for at least five days and then sieved through a 2 mm sieve. pH was measured in a 0.01 M solution of $CaCl_2$ as described in Chap. 2.3.2 (page 77).

Concentrations (mg kg^{-1}) of plant-available calcium, phosphorus, potassium and magnesium were measured in each soil sample. The cations were extracted using 0.43 M acetic acid (CH_3COOH), and analysed by MLURI Analytical section using inductively coupled plasma-atomic emission spectroscopy (ICP-AES). The extraction method is described in Chap. 2.3.2 (page 77).

Exposure site assessment

Wind measurements

Tatter flags (Baldwin and McNeill 1985) were used to generate a relatively simple measure of the levels of exposure between the different exposure sites. Tatter flags are standardised rectangles, 380 mm long by 305 mm wide, made of Indian Mogadon cotton which 'tatter' relatively quickly in the wind, similar to prayer flags, at a rate which is correlated to the level of exposure at a site (Baldwin and McNeill 1985). Tatter flags are routinely used to test the level of exposure of a site in order to determine its suitability for forestry. In this case one flag is normally exposed for a two month period before being replaced. The loss of material over the two months is then measured and converted into a mean tatter rate in cm^2 day^{-1}. Generally, a mean tatter rate of 13 cm^2 day^{-1} over a three year period is considered the maximum advisable for commercial forestry (Baldwin and McNeill 1985). Because it was anticipated that the tatter rate would exceed this maximum the tatter flags changed monthly. Five flags were distributed between the three exposure sites, one at the low exposure and, because these were larger areas, two each at the mid-exposure and high exposure sites. The flags were supplied by Forest Research (FR) ready and comprise the cotton rectangle sewn to a metal frame which freely rotates on a rigid wire rod mounted on a wooden stake so that the top of the flag is 1.5 m from the ground. The first tatter flags were set up on site on 3rd September 2007, and replaced between 28 and 35 days later until the last flags were removed on 5th October 2009. On two occasions the flags were left out for longer periods (January 2008 for 42 days, August 2008 for 38 days). Flag 3, from the exposed site, was lost completely in February 2008 and both flags 2 and 3 from the exposed site were torn and reported un-measurable by FR for the period between 21st November and 26th December 2008. On a number of site visits some tatter flags were found to be folded flat and not flapping despite others flapping quite strongly. This appeared to result from a rain-wetted flag drying out during a calm spell whilst 'daggling' around the supporting rod. There was no way of determining how long any flag had been in this condition, and so how much "tatter" had been lost.

In order to concurrently achieve a more accurate measure of the wind experienced by the young plants in each cage, four NRG Systems® three-cup anemometers were used in pairs, one pair on each of two masts. Each pair consisted of one anemometer at 1.25 m and the other at 0.25 m above the ground on the same mast but not vertically above each other, in order to concurrently measure wind speed at the height of the tatter flags and at the height of the plants in the cages. The two pairs of anemometers facilitated comparison of the following combinations of cages and sites:

Between two different exposure sites;

Between a shelter cage and an open cage;

Between an open cage and no cage.

Table 3.4 provides a summary of the different combinations that were measured over two years of recording. Two CR10 data loggers (Campbell Scientific), one per pair of anemometers, were programmed to record the maximum and minimum wind speeds every three seconds and to average the wind speed every 30 minutes. Generally each combination was recorded for at least four weeks. Fig. 3.6 shows the anemometer equipment in the field.

Temperature measurements

Over the first winter 2007/08, three temperature loggers (Thermachron ibuttons©, Maxim Integrated Products, MIP, Inc., Sunnyvale, CA, USA) were installed in each cage in the soil (s) at a depth of 10 cm, at ground level (g) and at canopy height (15 cm) (c). All loggers were held in 'fobs' supplied by MIP, which screened one side. Those loggers at canopy height were in white painted fobs and positioned so the fob, rather than logger, faced south. The temperature loggers were programmed to record the average temperature every 2 hours. Due to failure of a high percentage of the loggers there was incomplete cover of temperature data and cages for which data were collected are given in Table 3.5. No loggers were used in the second winter. The temperature data sets that were compared were from the same

Table 3.4 Combinations of site and cage types and timings of wind speed records from two pairs of anemometers at 1.2 m and 0.25 m above the ground respectively.

		High exposure			Mid-exposure			Low exposure		
Year	Month	open	shelt	no cage	open	shelt	no cage	open	shelt	no cage
2007	September				x	x				
2007	October				x	x				
2007	November					x			x	
2007	December							x	x	
2008	January	x	x							
2008	March	x		x						
2008	April	x		x						
2008	May			x				x		
2008	June	x						x		
2008	July	x						x		
2008	August	x				x				
2008	September	x			x					
2008	October	x			x					
2008	November	x			x					
2008	December	x								
2009	January				x					
2009	February				x					
2009	March				x					
2009	April				x					
2009	May				x			x		
2009	June				x			x		
2009	July						x	x		
2009	August				x		x			
2009	September				x					

Figure 3.6 Anemometer mast with a pair of 3-cup anemometers and box with CR10 data-logger and battery.

level (c, g, or s) in a cage and for the same time period, and comparisons have been made between the daily mean minimums and maximums.

Plant growth parameters

In all cases plants used in the experiment were measured prior to planting out in the experimental cages in 2007 (Table 3.6 provides mean 2007 values of all parameters). Subsequently, they were re-measured in late summer in 2008 and again in 2009, prior to the pre-dormant clipping treatment. For each plant above ground measurements were made of the following parameters (Fig. 3.7): vertical plant height, overall plant length, maximum crown diameter (longest canopy diameter) and that measured horizontally perpendicular to it, basal diameter using callipers, the total length of all new growth (total new growth), and the length and breadth of the five largest leaves. The new growth was recorded per shoot, which was numbered starting at the apex of the main stem, including secondary and tertiary level shoots (Fig. 3.7). It was also recorded whether shoots were alive or dead, new in the measurement year, or old. This would allow for a future assessment of the change in the shape of the plants. In 2009 the number of buds was also counted.

Table 3.5 Summary of temperature data collected from working loggers. The data used in comparison of temperatures between sites were those of the same colour with overlapping time periods. *Bn – Betula nana; Sm – Salix myrsinites; Jc – Juniperus communis*

	Logger position in cage[1]	Cage type	*Bn*	*Sm*	*Jc*	overall	start date	end date
High exposure	canopy							
		open	x		x	x	12.09.07	29.02.08
		shelter	x	x	x	x	12.09.07	29.02.08
	ground	open	x		x	x	12.09.07	29.02.08
		shelter			x	x	12.09.07	30.10.08
	soil	open	x			x	12.09.07	16.02.08
		shelter	x		x	x	12.09.07	29.02.08
Mid-exposure								
	canopy	open	x			x	12.09.07	29.02.08
		shelter	x	x	x	x	12.09.07	30.10.08
	ground	open						
		shelter	x			x	20.09.07	8.03.08
	soil	open			x	x	12.09.07	29.02.08
		shelter	x			x	12.09.07	12.11.07
Low exposure								
	canopy	open	x			x	12.09.07	29.02.08
		shelter	x			x	12.09.07	30.10.08
	ground	open		x		x	12.09.07	29.02.08
		shelter	x	x	x	x	12.09.07	29.02.08
	soil	open	x					
		shelter	x			x	12.09.07	29.02.08

[1] Position in the cage was canopy -15cm above ground, ground – ground level, soil - 10 cm depth in soil

Table 3.6 Mean values for all growth parameters at the start of the experiment in 2007. Figure 3.7 gives definitions of different parameters.

	Betula nana			*Salix myrsinites*			*Juniperus communis*		
	Mean	*n*	SE	Mean	*n*	SE	Mean	*n*	SE
Plant length (mm)	82.6	87	4.4	65.8	90	2.4	45.1	89	1.4
Vertical height (mm)	71.0	86	3.6	61.9	90	2.4	37.9	89	1.2
Longest canopy diameter (mm)	38.7	86	3.1	27.9	89	1.5	22.3	88	1.0
Canopy area (cm^2)	5.6	86	1.1	3.3	89	0.3	2.2	88	0.2
Basal diameter (mm)	2.0	84	0.1	2.6	89	0.0	1.4	87	0.0
Leader length (mm)	24.3	86	4.1	11.5	90	1.6	4.5	90	0.5
Longest shoot (mm)	35.0	88	3.7	19.4	90	1.6	9.3	90	0.4
Total new growth (mm)	51.2	87	4.8	36.0	90	2.5	43.0	90	2.5

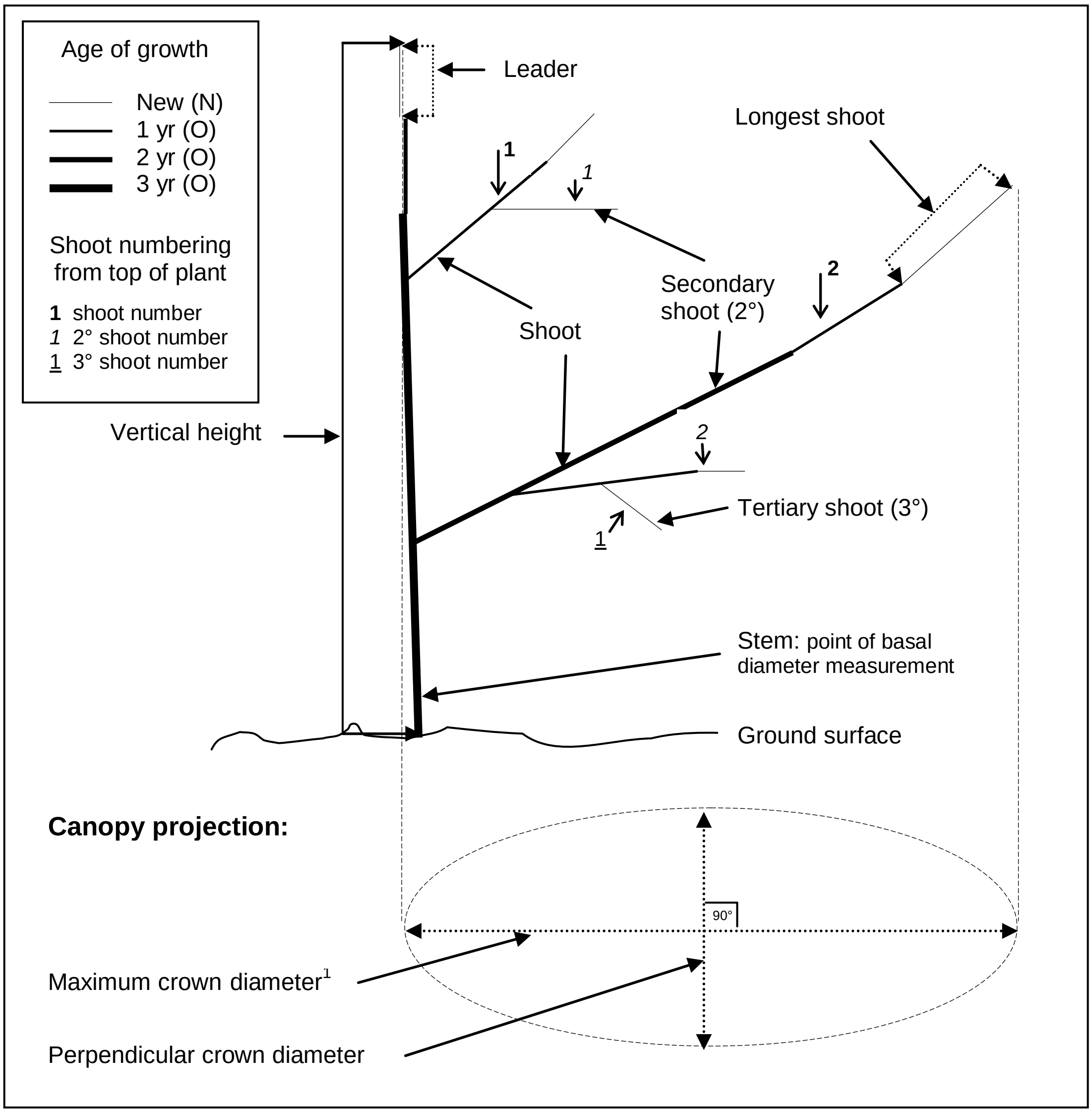


Figure 3.7 Diagrammatic plant showing plant measurements taken for growth analysis. For more detail and explanation see text section 4.2.4. [1]The crown (or canopy) measurements are taken horizontally across the widest part of the crown and then horizontally perpendicular to it.

3.2.5 Data analysis

Exposure site assessment

Tatter flag wear was assessed by Forest Research Technical Services branch in Wykeham, northern England. The area lost over the period of exposure was measured on each flag and converted to a mean rate of cm^2 loss per day.

The raw data collected from the CR10 data loggers for the anemometers was the 30 minute maximum, minimum and mean wind speeds either in the cage or above (Fig. 3.6). The NRG Systems three cup anemometers have a low wind speed threshold of 0.35 m s^{-1}. In addition, it takes one revolution to generate one pulse on the data logger, and at low speeds the cups are unreliable. For these reasons 1 revolution per second maybe a more useful threshold. Using the inbuilt NRG formula for calculating wind speeds, ν (m s^{-1}):

$$\nu = 0.765f + 0.35$$

where f = anemometer frequency (Hz).

If a frequency of 1 Hz is a realistic minimum the lowest reliable wind speed is 1.115 m s^{-1}. To remove all low values of wind speed from the raw data would potentially distort the findings. Instead only maximum wind speed data were included in the analysis and all were used to calculate daily-maximum means. Prior to plotting the graphs comparing paired datasets (i.e. different cage types or different exposure sites) as described below, the pairs of data which included at least one value below the threshold were removed.

Linear regression was used to quantify the relationship between contrasting treatments (e.g. open and shelter cages from each site or comparison of sites).

Plant growth parameters

Dimensional growth responses, including vertical height, canopy measures and basal diameter, were expressed as proportions of the previous year's size in annual growth analyses, or as proportions of the pre-planting measures for two-year growth analyses. New growth measures, including leader and total new growth (the sum of all new shoot lengths) were expressed as either the annual measurement or in the case of two-year assessments the sum of the two years' growth. The "longest shoot" was simply the measure for the particular year of analysis. All growth parameter datasets were checked for normality on histograms. The degree of skew in the majority of data confirmed the need to transform all measures to their natural logarithm to ensure normality. If leader length, longest shoot and total growth data included zeros the logarithm transformation was $\log_e$ (x +1 mm).

Six *Betula nana* plants were lost over the two years of the experiment, including in the first year all three of the heavy autumn clipping treatment in the open cage at the exposed site.

There were 26 fatalities in *Salix myrsinites*, 19 were in year two and predominately at the low exposure site. There were 30 *Juniperus communis* fatalities in the first year and a further 23 in the second. In both years the losses were evenly spread across all treatment combinations. In the first year only 3 treatments did not loose a plant. Table 3.7 shows how many plants of each species remained per treatment combination. The effect of the treatments on the levels of mortality in each species was analysed by a Generalised Linear Model (GLM, GenStat 10© 2007 Lawes Agricultrual Trust) using logit transformed data. The model used was exposure + shelter + clipping in each case.

An initial analysis using linear residual maximum likelihood (REML) (GenStat 10) was undertaken to test the magnitude of the effect of the two clipping treatments on each of the species, to see whether or not to leave both in the full analysis. Timing of browsing was rarely significant and so was removed from the fixed model, but included in the random model (see below). Each of the three species were analysed separately to examine the response of the different growth parameters to the exposure level (high, mid- or low exposure), whether they were in a shelter or open cage, and the intensity at which they were clipped (un-clipped, 50% or 100% of new growth). For *B. nana* and *S. myrsinites* two models were used. Because the experiment used young propagated cuttings and it was expected that their first year would primarily be an establishment year the first model analysed growth responses by year (2008 and 2009). The second analysed growth over two years for all the plants surviving until 2009. A random model for clipping time, cage and individual cutting number was used in the first model and for clipping time and cage in the second. The 2008 replacement plants were excluded from the analysis.

Due to the higher levels of mortality in *J. communis*, in addition to the second above, a third model was analysed which examined the effects of exposure and clipping on the growth increments over the second year (2008 to 2009) for all plants, including the 2008 replacements. In both planting years there were a number of treatment combinations with none or only one plant (Table 3.7). As a result, although planting year (PYear) was retained in the fixed model (exposure*shelter*clipping intensity; random model: clipping time/cage number), a number of the interactions were removed to ensure the analysis was able to run. The interactions that were retained are given in Table 3.15 in the results.

In all cases the differences between treatment means provided by the REML analysis were tested for significance using the Least Significant Differences (LSD) at $P < 0.05$, calculated from Standard Errors of Differences (S.E.D.), also provided by REML. The REML generated means are those presented in the results. For all three species the factor

Table 3.7 Number of plants of each species alive per treatment, and so available for analysis in each period. The maximum number of plants for 50% and 100% clip treatment was 6, for no-clip treatment it was 3. Plants replaced in 2008 are not included in 07 - 09 analysis. Cage types are open and shelter (Shel).

	Exposure	High exposure						Mid-exposure						Low exposure					
	Species	Bn		Sm		Jc		Bn		Sm		Jc		Bn		Sm		Jc	
	Cage type	Open	Shel	Open	Shel	Open	Shel	Open	Shel	Open	Shel	Open	Shel	Open	Shel	Open	Shel	Open	Shel
Year	Clip intensity																		
07 - 08	no-clip	3	3	3	3	1	2	3	3	3	3	1	3	3	3	3	3	3	3
	50%	6	6	6	6	4	4	5	6	6	5	4	2	6	6	5	5	4	4
	100%	3	6	6	5	6	4	6	6	5	6	4	5	6	6	5	5	2	4
07 - 09	no-clip	3	3	3	3	1	2	3	3	3	3	1	3	3	3	2	0	2	3
	50%	6	6	6	6	4	2	5	5	6	5	4	2	6	6	2	1	3	1
	100%	3	6	6	5	2	2	6	6	5	6	0	3	6	5	2	0	2	0
08 - 09	no-clip	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	0	2	3
	50%	6	6	6	6	6	4	5	5	6	5	6	6	6	6	2	1	5	3
	100%	3	6	6	5	2	4	6	6	5	6	2	4	6	5	2	0	6	2

combination exposure*shelter, which equates to cage, was kept in the REML analysis because there was no indication that it would be compounded by differences between cages.

The results are presented using the following conventions. Single-level factors, or one-way effects, which were significant across a number of growth parameters, such as exposure, treatment year or clipping are presented as tables. Figures are used to present significant interactions between two or three factors, either singly for one growth parameter, or in multiples where the same interaction was significant across several growth parameters. Where only two, or three means were significantly different these have been quoted in the text with the relevant *P* values.

3.3 RESULTS

3.3.1 Exposure site assessment

Wind measurements

The tatter flag rates are presented in fig. 3.8 and show a clear separation between the two flags from the high exposure site and the other three, except during periods of very low tatter, for example May to June 2008. These two flags show close similarities in the tatter plots. The tatter rates do not clearly separate the mid-exposure and low exposure sites.

Wind speeds in the open cage at the mid-exposed site were at least 1.4 times those in the shelter cage (Fig. 3.9). When the wind speed for each cage is plotted against time they

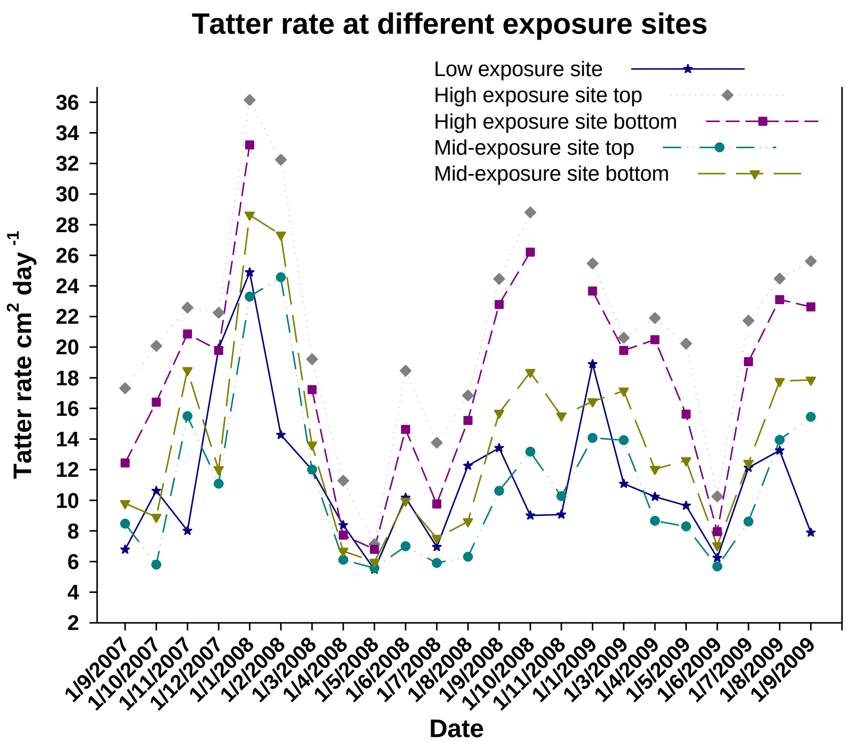


Figure 3.8 Tatter rate (cm^2) per day based on monthly exposure of flags.

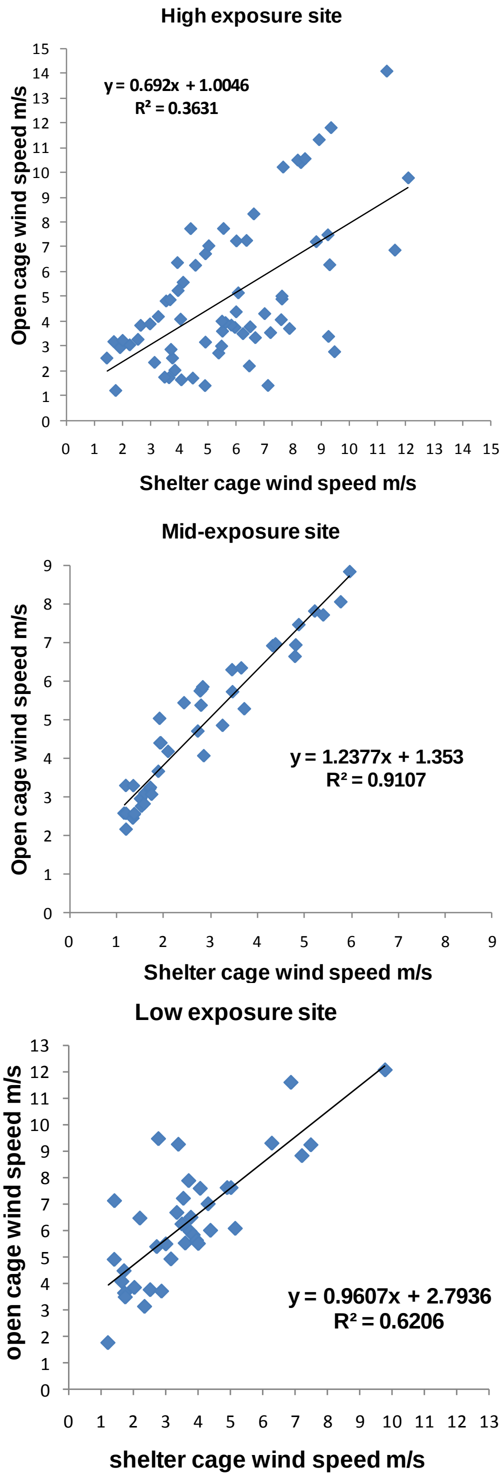


Figure 3.9 Wind speed (m s^{-1}) in shelter versus open cages at high, mid and low exposure sites. Equations quantify the value of shelter provided at each exposure level. Wind speed is daily means of 30 minute maximums, measured every 3 s. Values below 1.115 m s^{-1} were removed prior to plotting (see text for details).

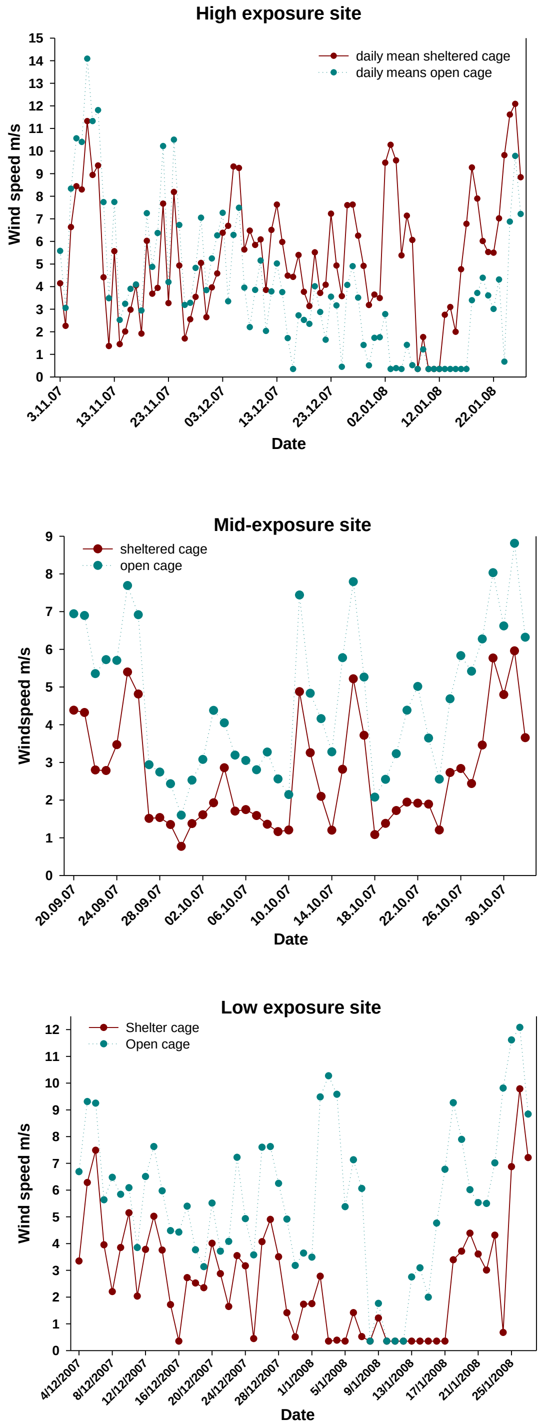


Figure 3.10 Different wind speeds (m s^{-1}) recorded in shelter and open cages at high, mid and low exposure sites. Wind speed is daily means of 30 minute maximums, measured every 3 s. Values below 1.115 m s^{-1} are unreliable and should be ignored (see text).

show very similar patterns but at different amplitudes (Fig. 3.10). The low exposure site had consistently higher wind in the open compared to the shelter cage (Fig. 3.9). At the high exposure site during November open cage wind speeds were clearly higher than those in the shelter cage (Fig. 3.10) but during December and January the open cage wind speeds were lower than those in the shelter cage. These results appear to be anomalous and there may be several reasons for this: snow cover deeper than the anemometers in one cage and not the other, ice freezing the anemometer cups to the casing, or another short term malfunction of the anemometer. Any malfunction is likely to have been short-term because there is no obvious evidence of malfunction in subsequent sets of data.

Wind speeds at the high exposure sites were consistently 1.5 times higher than those at the mid-exposure site (Fig. 3.11). Generally, over time, the wind speeds at the two sites showed similar patterns (Fig. 3.12). The relationship between the mid-exposed and low exposure sites was less clear. Fig. 3.12 shows occasional periods of higher wind speeds in the mid-exposed site but more frequent periods where the two sites show little difference. There is no clear difference between the wind in the open cage at the high exposure site and the wind in the open cage at the low exposure sites (Fig. 3.11). At the high exposure site the "plant height" anemometers were in a cage with *J. communis* which had a sward of mixed heather and grasses (Appendix 3.3), while at the low exposure site the anemometers were in a cage with *B. nana* which was dominated by mosses and low growing dwarf shrubs. Over the summer months the grassy vegetation in the *J. communis* cage flowered and impeded the movement of the anemometer (inflorescences were removed during routine visits to ensure the anemometer was free running). The wind speeds from an anemometer mounted above the high exposure site cage (1.25m above ground) was consistently 1.16 times higher than wind above the low exposure cage (Fig. 3.13).

Temperature measurements

There was very little difference between daily maximum and minimum temperatures recorded at different exposure sites at canopy height in shelter cages (Fig. 3.14). Generally, both maximum and minimum soil temperatures tended to be lower at the low exposure site than the high exposure sites, particularly over the December and January. There was less variation between temperatures in open and shelter cages at all exposure sites at canopy, ground or soil levels (Fig. 3.15 provides an example). The results are for winter temperatures only because most loggers failed after the first winter.

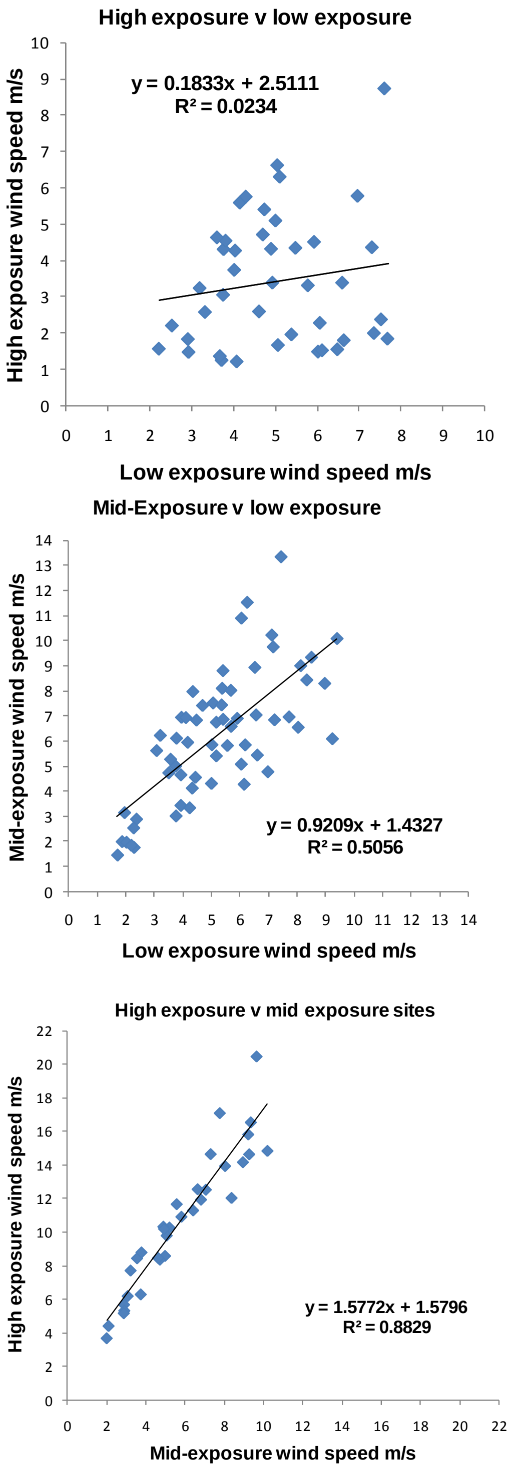


Figure 3.11 Wind speed (m s^{-1}) at 0.25m above ground level in experimental cages at different exposure levels: high and low; mid and low; and high and mid. Equations quantify the difference between wind speeds at each site. Wind speed is the daily means of 30 minute maximums measured every 3 s. Values below 1.115 m s^{-1} were excluded (see text for details).

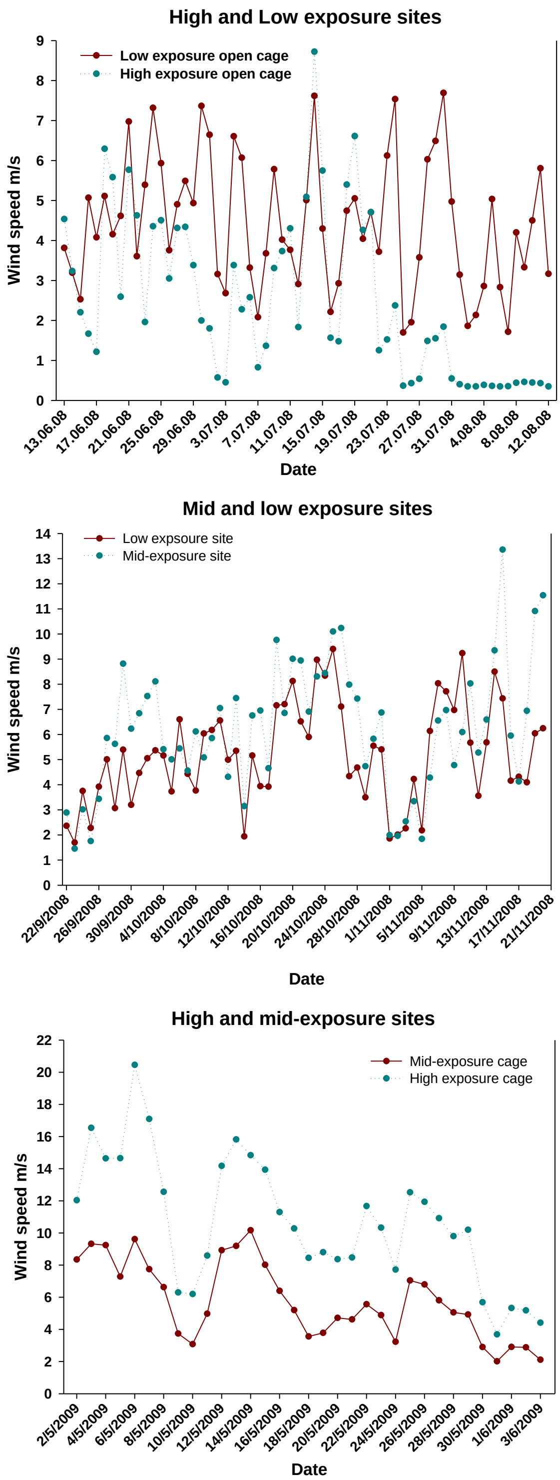


Figure 3.12 Different wind speeds (m s^{-1}) between high and low exposure, mid and low exposure and high and mid-exposure sites. Wind speed is the daily means of 30 minute maximums measured every 3 s. Values below 1.115 m s^{-1} are unreliable and should be ignored.

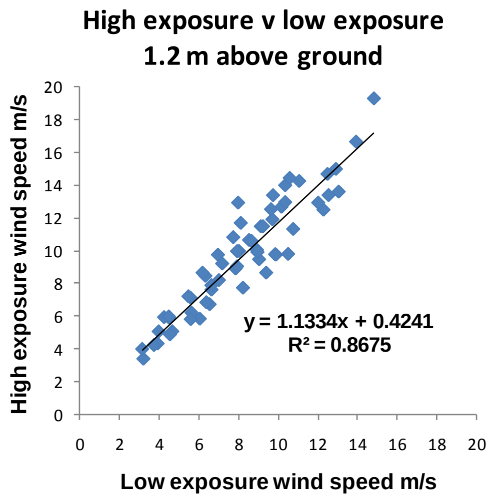


Figure 3.13 Comparison of wind speed between high and low exposure sites at 1.2 m above the ground. The equation quantifies the increased level of wind at the high compared to low exposure site. Wind speeds are as given above.

Background weather variations

The meteorological office publishes weather data for past years in map-form on its website (Meteorological Office, no-date) at 5 km x 5 km resolution for the whole of the UK. They also provide data on how that information varies relative to the 1971 to 2000 averages. In both 2008 and 2009 the mean annual temperature was between 0.2°C and 0.5°C higher than the 30 year average. If only spring (March to May) and summer (June to August) are considered the deviation for 2008 was between 0.5°C and 1°C, while for 2009 it was between 0.75°C and 1.25°C. The actual mean spring temperatures were the same in both years, 5°C, whereas the mean summer temperatures in 2009 were 13°C, 2°C higher than in 2008. Annual rainfall figures were also consistent between the two years at an average 2000 mm, or 110 % of the thirty year average. The summer figures were higher than average in both years but by different amounts, 10% in 2008, and 40% in 2009. Annual mean sunshine also varied between the two years. In 2008 it was only 92% of the 30 year average. In 2009 it was 110% of the average. Owing to the large scale of the map on which the data are provided it was not possible to determine with any accuracy the 30 year average for rainfall or sunshine for the experimental area.

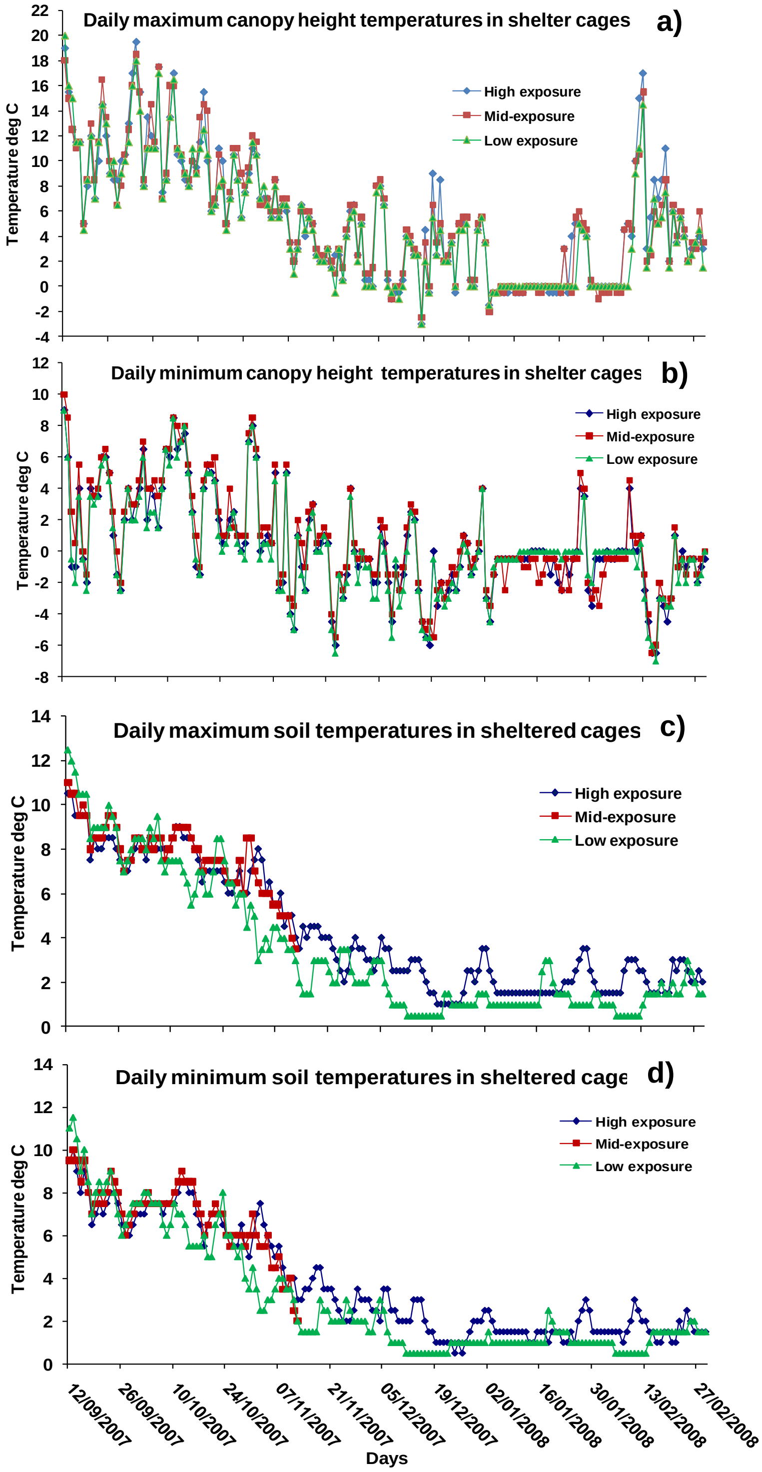


Figure 3.14 Daily maximum and minimum temperatures (deg C) in sheltered cages: **a)** & **b)** at canopy height (15 cm above the ground); **c)** & **d)** in the soil (10 cm depth). The temperatures were collected as 120 minute averages. The mid-exposure soil temperature logger stopped recording temperatures on 12th November 2007.

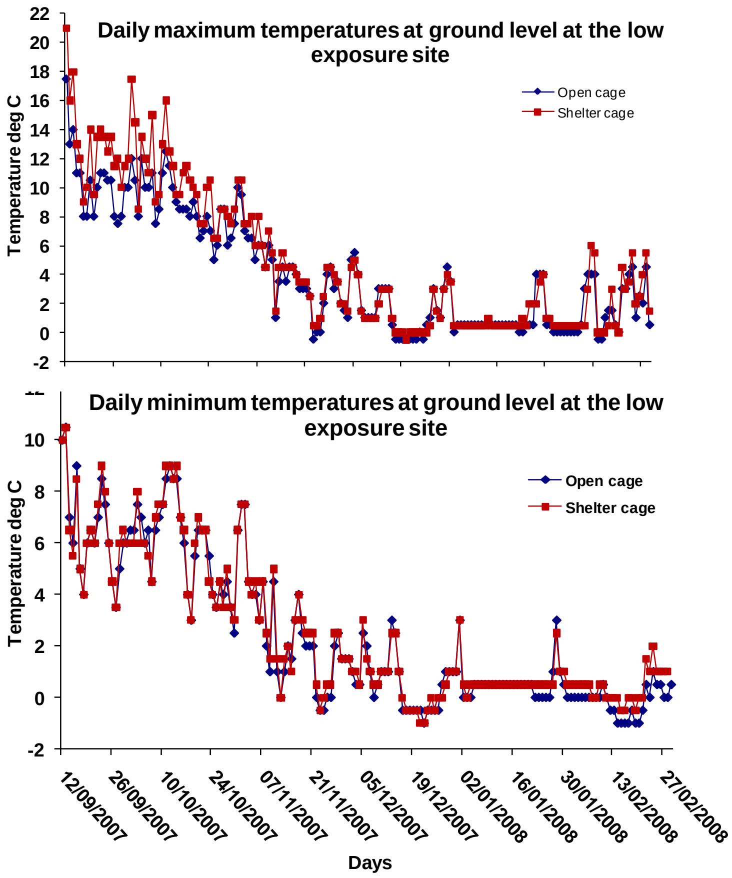


Figure 3.15 Open and shelter cage daily maximum and minimum temperatures at the low exposure site at ground level. The temperatures were collected as 120 minute averages between 12th September 2007 and 29th February. 2008.

3.3.2 Plant growth responses

Mortality of all species

The six *Betula nana* fatalities over the three years of the study show no correlation with any treatments in the outcome of the GLM analysis (Table. 3.8). Significant numbers of *Salix myrsinites* losses were associated with low exposure (logit transformed GLM-estimated mortality is 5.2, Standard Error, S.E. 1.3 $t_P < 0.001$), and the shelter cage (logit transformed GLM-estimated mortality is 1.3, S.E. 0.87, $t_P < 0.05$). *Juniperus communis* suffered 53 fatalities (out of 90) and, although these were well spread across the treatments, clipping had a significant effect (Table 3.8). 100% clip was associated with a high level of losses (logit transformed GLM-estimated mortality is 1.8, S.E. 0.63, $t_P < 0.005$).

Betula nana

The main effects arising from the REML analysis are shown in Table 3.9.

Betula nana annual increments over two years, 2007 to 2009

The dominant affect arising from the analysis was Year with six of the eight growth parameters showing a significant difference between growth in 2008 and 2009 (Table 3.10). Five of the growth parameters (plant length, vertical height, longest diameter, canopy area

Table 3.8 Accumulated analysis of deviance from GLM output for all species mortality figures. There were 3 levels of exposure (high, mid and low) at different locations on the site, 2 levels of shelter were provided by different cage types (open and shelter) and 3 levels of clipping: none or control, 50% and 100% of new growth.

Factor	d.f.	deviance	mean deviance	deviance ratio	approximate χ^2 probability
Betula nana					
Exposure	2	1.118	0.559	0.56	0.572
Shelter	1	0.736	0.736	0.74	0.391
Clipping	2	3.578	1.789	1.79	0.167
Residual	12	14.118	1.176		
Total	17	19.549	1.15		
Salix myrsinites					
Exposure	2	52.1468	26.0734	26.07	<.001
Shelter	1	4.6629	4.6629	4.66	0.031
Clipping	2	1.8883	0.9442	0.94	0.389
Residual	12	8.7873	0.7323		
Total	17	67.4853	3.9697		
Juniperus communis					
Exposure	2	0.37	0.185	0.18	0.831
Shelter	1	0.046	0.046	0.05	0.83
Clipping	2	9.089	4.544	4.54	0.011
Residual	12	21.617	1.801		
Total	17	31.121	1.831		

and basal diameters) were plant dimensions which had been recorded as proportional annual increments and were all larger in 2008 than 2009. The only new growth parameter, longest-shoot, was larger in the second year. The reduced incremental growth in 2009 might result from one or more factors. Firstly, in 2009 the plants, particularly no-clip plants, are larger than they were in 2008 and so although the absolute total new growth was similar in both years (there was no significant year effect) the 2009 proportional increments were smaller. Secondly, after measurement in the first year 12 out of 15 plants in each cage had either 100% or 50% of their new growth removed. As the plants were very young this meant complete removal of either all or 50% of the number of shoots on each plant resulting in considerable reduction in the plant length and canopy dimensions before growth started in 2009. This is supported by the significant effect of clipping on canopy area. Finally, there is a possibility that there was a short-term increase in nutrients available to the plants in 2008 following the disturbance of soil during planting in 2007, and residual fertilizer around the roots from the propagation period.

Table 3.9. ***Betula nana*** fixed effects resulting from REML models analysing annual growth over two years. Significant factors at P<0.05 are highlighted in bold. Others at P < 0.1 indicate trends. Table 3.8 provides an explanation of the treatments. Year is the year of growth, either 2008 or 2009.

Betula nana 1 yr incr over 07 09	**Plant length Increment**	**Vertical Height Increment**	**Long Canopy diameter increment**	**Canopy Area increment**	**Basal Diameter increment**	**Leader length (mm)**	**Longest shoot (mm)**	**Total shoot growth (mm)**
Exposure					**0.028**			
Shelter								
Clipping			0.088	**0.025**				0.05
Year	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**		**0.003**	
Exposure.Shelter	**0.006**		0.085	**0.042**		0.087		
Exposure.Clipping								
Shelter.Clipping								
Exposure.Year	0.065					**0.014**		
Shelter.Year	**0.034**	**0.029**	0.053	**0.015**				
Clipping.Year								
Exposure.Shelter.Clipping								
Exposure.Shelter.Year						**0.032**		**0.009**
Exposure.Clipping.Year					**0.007**			
Shelter.Clipping.Year					0.075			
Exposure.Shelter.Clipping.Year					0.099			
***Betula nana* 2 yr incr over 07 09**								
Exposure					0.084			
Shelter						**0.013**		
Clipping	**0.019**		0.095	**0.011**				
Exposure.Shelter	0.055		**0.035**	**0.034**		**0.006**	**0.02**	
Exposure.Clipping								
Shelter.Clipping								
Exposure.Shelter.Clipping								

Table 3.10 Mean annual growth for different growing seasons, 2008 and 2009 (back-transformed from natural logarithms) for *Betula nana* and *Salix myrsinites*, and different planting years, 2007 and 2008 for *Juniperus communis* for all growth parameters, with significant differences between the annual measures shown.

	Betula nana			*Salix myrsinites*			*Juniperus communis*		
	2008	2009	*P*	2008	2009	*P*	2007	2008	*P*
Plant length proportional increment	1.60	1.20	<0.001	1.12	1.05		1.02	0.96	
Vertical Height proportional increment	1.60	1.14	<0.001	1.08	0.98	<0.05	1.06	1.0	
Longest canopy diameter proportional increment	2.35	1.20	<0.001	1.72	0.79	<0.001	0.78	0.82	
Canopy area proportional increment	10.22	1.05	<0.001	4.48	0.46	<0.001	0.56	0.63	<0.05
Basal diameter proportional increment	1.41	1.08	<0.001	1.23	0.96	<0.001	0.93	1.17	<0.001
Leader length mm	30.6	33.0		12.46	12.53		15	23.1	<0.01
Longest shoot mm	34.9	51.6	<0.01	16.07	17.92		16.6	26.3	<0.001
Total new growth mm	114.8	128.9		35.69	12.52	<0.001	49.1	253.8	<0.001

Clipping intensity had a significant effect on canopy area proportional increments. Control, or ‘no clip’, increments were significantly larger than 100% clip increments (back-transformed logarithms are 4.5 times and 2.3 times, Least Significant Difference L.S.D. for logarithm 0.41, *P*<0.05). This effect supports the suggestion that the between-year difference may result from the loss of 50 % or 100% of shoots from each clipped plant at treatment. There was a strong trend (*P*=0.05) to greater total new growth in 50% clip plants than in either the no-clip or 100% clip treatments, but the differences were not significant.

High exposure significantly reduced basal diameter proportional increments compared to low exposure (117 % compared to 129 % increase, *P*<0.05). However the effect of browsing was inconsistent across different exposure levels and between the two years (Fig. 3.16). In 2008 the high exposure no clip plants and mid-exposure 50% clip plants were significantly smaller than high exposure 100% clip plants (*P*<0.05). In 2009 the high exposure 100% clip plants were significantly smaller than no-clip and 50% clip at mid-exposure and 50% and 100% clip at low exposure, but not no-clip plants (*P*<0.05, Fig.3.16).

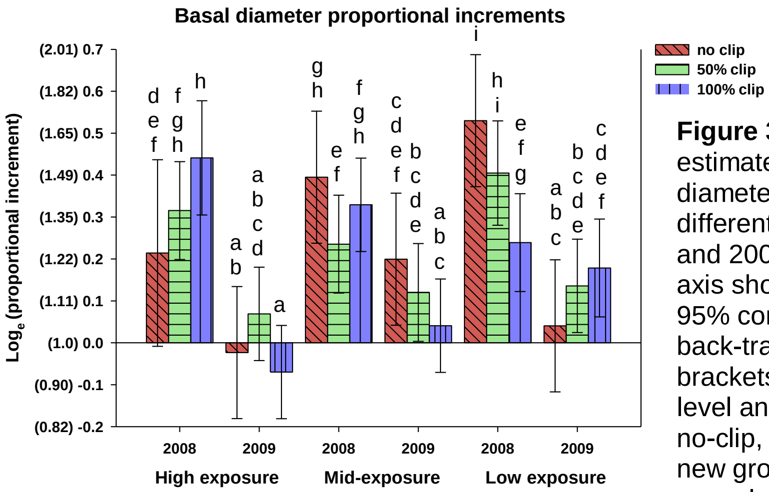


Figure 3.16 ***Betula nana*** REML-estimated annual means for basal diameter proportional increments at different clipping intensities in 2008 and 2009 across exposure sites. Y-axis shows natural logarithms (+/- 95% confidence intervals) with back-transformed values in brackets. X-axis shows exposure level and year. Clipping intensity is no-clip, 50% clip or 100% clip of new growth. Columns sharing the same letter are not significant at *P*<0.05.

An interactive effect between exposure level and shelter (different cage types) was evident in plant length and canopy area proportional increments. In both parameters the largest increments were in the shelter cage at low exposure (*P*<0.05, Figure 3.17). In the high exposure open cage plant length increments were significantly larger than those in the shelter cage (*P*<0.05). This unexpected result may be because half the open cage 100% clip plants had died and so were excluded from the analysis, potentially inflating the cage means.

Leader lengths were similar between years with the exceptions of significantly shorter growth at high exposure in 2008 than 2009 (*P*<0.05, Fig. 3.18). In 2008 the open cage leaders at high exposure were significantly shorter than all mid-exposure leaders and those in

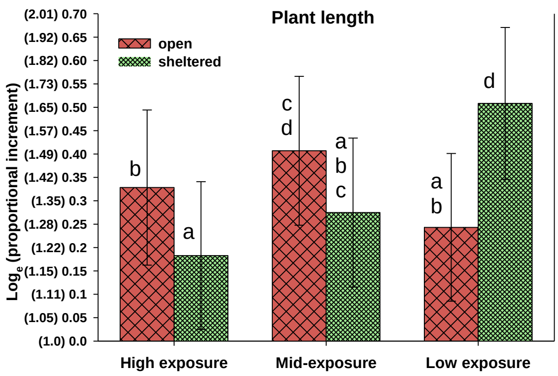


Figure 3.17***Betula nana*** REML-estimated annual means for plant length proportional increment in open and shelter cages across exposure sites. Y-axis shows natural logarithms (+/- 95% confidence intervals) with back-transformed values in brackets. X-axis shows exposure level and cage type (open or shelter). Columns sharing the same letters are not significantly different at *P*<0.05.

the low exposure shelter cage (*P*<0.05) in either year. However, in 2009 the open cage growth at low exposure was significantly shorter than any other 2009 cage or exposure (*P*<0.05, Fig. 3.19). There was less difference between the two years in total new growth, and no significant difference between years for any individual treatment (not shown). The key significant effect in 2008 was less growth in the high exposure open cage compared to the low exposure shelter cage (*P*<0.05), and in 2009 less growth in the high exposure shelter cage than in both the mid-exposure open cage and the low exposure shelter cage. The lack of a consistent between-year difference in leader lengths and total new growth supports the suggestion that the significant main effect of year in the REML output results from the use of proportional increments as a measurement tool.

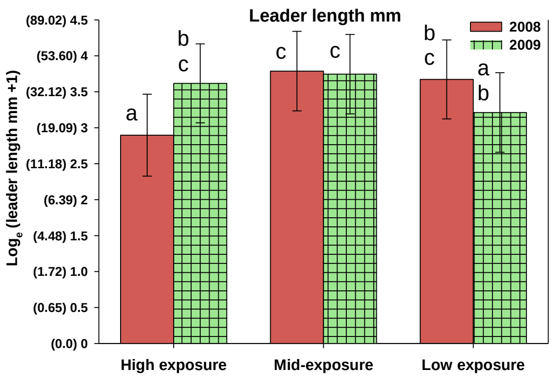


Figure 3.18 ***Betula nana*** REML-estimated means for leader length (mm) in 2008 and 2009 across exposure sites. Y-axis shows natural logarithms (+/- 95% confidence intervals) with back-transformed values in brackets. X-axis shows exposure level and treatment year (2008 or 2009). Columns sharing the same letters are not significantly different at *P*<0.05.

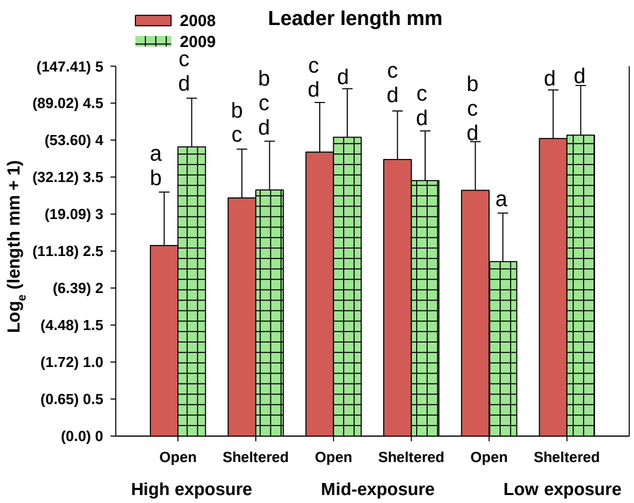


Figure 3.19 ***Betula nana*** REML-estimated annual means for leader length (mm) in open and shelter cages across exposure sites and different years. Y-axes show natural logarithms of measure +1 mm (+/- 95% confidence intervals) with back-transformed values in brackets. X-axes show exposure level, cage type (open or shelter) and treatment year (2008 or 2009). Columns sharing the same letters are not significantly different at *P*<0.05.

Betula nana 2 year increments from 2007 to 2009

Table 3.9 provides the main effects resulting from the REML analysis.

Shelter had a significant effect on leader lengths with longer growth in shelter cages (97 mm) compared to open cages (68 mm, *P*<0.05). Canopy area and longest canopy diameter proportional increments, and leader and longest-shoot lengths were all larger at low exposure in the shelter cage, than in the low exposure open cage or the high exposure shelter cage, as illustrated by longest shoot lengths in Fig. 3.20 (*P*<0.05). Otherwise there were no significant differences.

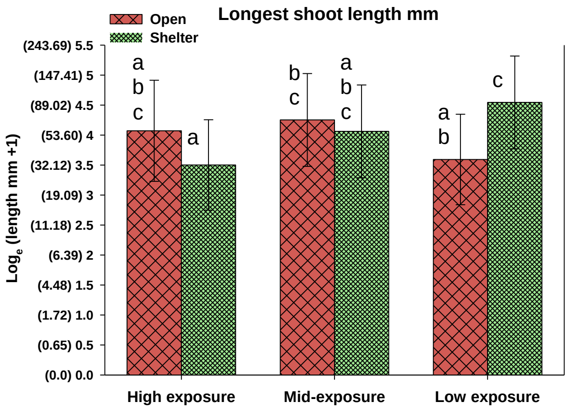


Figure 3.20 *Betula nana* REML-estimated 2 yr means for longest shoot lengths in open and shelter cages across exposure sites. Y-axes show natural logarithms (+/- 95% confidence intervals) with back-transformed values in brackets. X-axes show exposure level and cage type (open or shelter). Columns sharing the same letters are not significantly different at *P*<0.05.

Clipping had a significant effect on both plant length and canopy area proportional increments (*P*<0.05, Table 3.11). Plant lengths in no-clip plants were larger than either clipping intensity, while canopy areas in 100% clip plants were smaller than either 50% clip or no-clip plants.

Table 3.11 *Betula nana* mean 2 year proportional increments, back-transformed from natural logarithms, for two growth parameters at different levels of clipping intensities. Clipping is proportional of new growth removed. Columns with the same subscript are not significantly different at *P* < 0.05. Standard Errors of Differences (SED) are for logarithm transformed values.

	No-clip	50% clip	100% clip	S. E. D. Log_e
Plant length 2 yr proportional increment	2.47_b	1.92_a	0.54_a	0.15
Canopy area 2 yr proportional increment	20.49_b	12.26_b	5.23_a	0.48

Salix myrsinites

The main effects resulting from the REML analysis are given in Table 3.12.

Salix myrsinites annual increments over two years

Exposure had a significant effect on five growth parameters (out of eight), plant length and long canopy diameter proportional increments and leader, longest-shoot and total new

Table 3.12 ***Salix myrsinites*** Fixed effects resulting from REML models analysing annual and two year growth. Factors with *P*<0.05 are highlighted in bold. For others *P* < 0.1 indicate trends, see text for details. There were 3 levels of Exposure (high, mid and low) at different locations on the site, 2 levels of Shelter (open and shelter cages) and 3 levels of Clipping (no-clip, 50% clip or 100% clip of new growth). Year is the year of growth, either 2008 or 2009.

Salix myrsinites 1 yr incr over 07 09	**Plant length Increment**	**Vertical Height Increment**	**Long Canopy diameter increment**	**Canopy Area increment**	**Basal Diameter increment**	**Leader length (mm)**	**Longest shoot (mm)**	**Total shoot growth (mm)**
Exposure	**0.003**		**0.007**	0.083	0.065	**0.004**	**<0.001**	**<0.001**
Shelter								
Clipping							**0.007**	
Year		**0.043**	**<0.001**	**<0.001**	**<0.001**			**<0.001**
Exposure.Shelter						**0.004**	**<0.001**	**0.005**
Exposure.Clipping								
Shelter.Clipping	0.078							
Exposure.Year	**0.004**		**0.035**	0.054	0.060	0.053	**0.012**	**0.048**
Shelter.Year					**0.008**			
Clipping.Year								
Exposure.Shelter.Clipping								
Exposure.Shelter.Year			0.096		**0.021**			
Exposure.Clipping.Year								
Shelter.Clipping.Year					**0.018**			
Exposure.Shelter.Clipping.Year								
Salix myrsinites 2 yr incr over 07 09								
Exposure	**<0.001**	**0.041**	0.077	**0.038**	**<0.001**		**0.037**	**0.018**
Shelter								
Clipping							0.061	0.057
Exposure.Shelter								
Exposure.Clipping				0.085				
Shelter.Clipping	**0.018**	0.079	0.066					
Exposure.Shelter.Clipping								

growth lengths were all significantly larger at high and mid-exposures than at low (P<0.05, Table 3.13). Longest-shoots were also significantly larger at mid-exposure than at high (*P*<0.05). The significantly short leaders, longest-shoots and total new growth at low exposure were concentrated in the shelter cages as illustrated by the leaders in Fig. 3.21 (*P*<0.05).

Table 3.13 ***Salix myrsinites*** mean annual growth over two years (back-transformed from natural logarithms) at different exposure sites. Columns sharing same subscript for each parameter are not significantly different at *P* < 0.05. Standard Errors of Differences (SED) are for logarithm transformed values.

Plant growth parameter	High exposure	Mid-exposure	Low exposure	SED Log_e
Plant length annual proportional increment	1.02_b	1.22_b	0.96_a	0.06
Long canopy diameter annual proportional increment	1.20_b	1.48_b	0.80_a	0.11
Leader length mm	13.54_b	18.61_b	4.55_a	0.19
Longest shoot mm	19.24_b	27.62_c	5.77_a	0.17
Total new growth mm	26.26_b	34.45_b	6.92_a	0.17

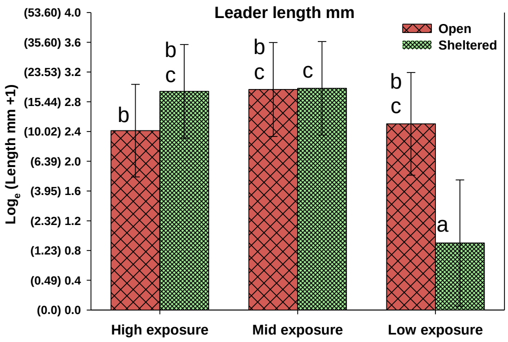


Figure 3.21 ***Salix myrsinites*** REML-estimated means for annual leader lengths (mm) over two years in open and shelter cages across exposure sites. Y-axis show natural logarithms (+/- 95% confidence intervals) with back-transformed values in brackets. X-axis show exposure level and cage type (open or shelter). Columns sharing the same letters are not significantly different at *P*<0.05.

As shown in Table 3.10, growth in 2008 was significantly larger than in 2009 for four dimensional parameters and total new growth. However, this significant difference was only evident in plant length proportional increments at high exposure, while longest-shoot lengths were only different between years at mid-exposure (*P*<0.05, Fig. 3.22). Longest canopy proportinal increments and total new growth lengths were significantly larger in 2008 than 2009 at all three exposure levels, but the reduction in growth was greatest at high exposure (*P*<0.05, Fig. 3.22). Across the different parameters shorter growth at low exposure in both years was the most dominant effect and in 2009 always significant.

Clipping had a significant effect on longest-shoot lengths with the longest shoots found on 100% clip plants (back-transformed logarithms are 21 mm compared to 13 mm on 50% clip and 12 mm on no-clip plants, logarithm L.S.D 0.35, *P*<0.05). Despite a significant interactive effect of shelter, clipping and year on basal diameter proportional increments (Table 3.12) the overriding difference was between years (not shown). In 2008 the key

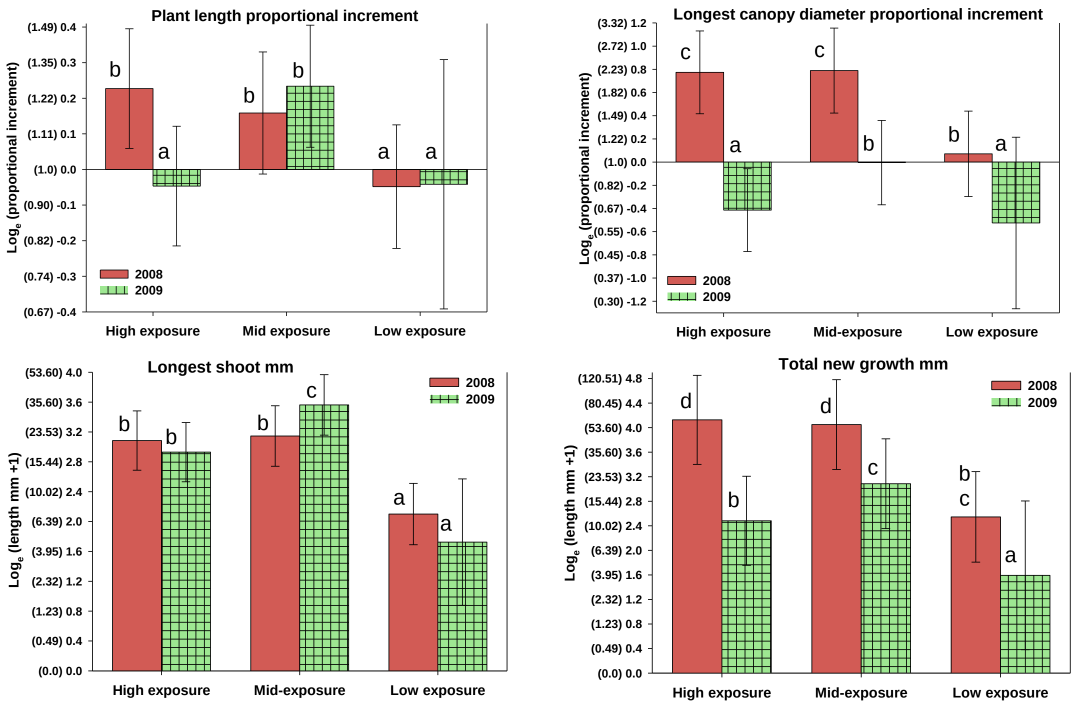


Figure 3.22 ***Salix myrsinites*** REML-estimated means for annual growth for four growth parameters (see titles) in 2008 and 2009 across exposure sites. Y-axes show natural logarithms (+/- 95% confidence intervals) with back-transformed values in brackets. X-axes show exposure level and Year. Columns sharing the same letters are not significantly different at $P < 0.05$.

difference was the unexpected significantly larger increment in no-clip shelter cage plants than the no-clip open cage plants. In 2009 there was no difference between shelter cages or between different clipping treatments.

Salix myrsinites two year increments

Across the two year increments exposure was the dominant effect with significant responses recorded in six parameters (Table 3.12). The shortest growth was always at low exposure, while the plant length proportional increments and total new growth lengths were largest at mid-exposure (P<0.05, Table 3.14).

No-clip plant length proportional increments were significantly larger in the shelter cage than in the open cage (P<0.05, Fig. 3.23). Across the 50% and 100% clip treatments there was no difference between cage types.

Table 3.14 *Salix myrsinites* mean two year growth (back-transformed from natural logarithms) at different exposure sites. Columns sharing same subscript for each parameter are not significantly different at $P < 0.05$. Standard Errors of Differences (SED) are for logarithm transformed values.

Plant growth parameter	High exposure	Mid-exposure	Low exposure	SED Log_e
Plant length 2 year proportional increment	1.20_b	1.48_c	0.86_a	0.10
Vertical height 2 year proportional increment	1.09_b	1.20_b	0.83_a	0.09
Canopy Area 2 year proportional increment	$3.10_{a,b}$	5.26_b	1.36_a	0.39
Basal diameter 2 year proportional increment	1.24_b	1.33_b	0.98_a	0.05
Longest shoot mm	17.8_b	34.4_b	5.1_a	0.34
2 year Total new growth mm	83.8_b	109.6_c	49.8_a	0.16

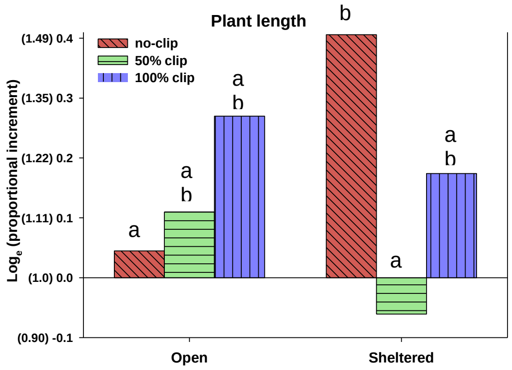


Figure 3.23 *Salix myrsinites* REML-estimated 2 yr means for plant length proportional increments in open and shelter cages for different clipping treatments. Y-axis shows natural logarithms (log_e) with back-transformed values in brackets. X-axis shows exposure level and clipping intensity. Columns sharing the same letters are not significantly different at $P < 0.05$. Least significant difference for log_e transformed values is 0.34.

Juniperus communis

The main effects resulting from the REML analysis are given in Table 3.15.

Juniperus communis annual increment for 2008 to 2009

Exposure had a significant, but not entirely consistent, effect on five out of eight growth parameters (Table 3.16). For the three dimensional parameters the low exposure proportional increments were always smaller than those at mid or high exposure; for the two new growth parameters mid-exposure growth was always largest ($P<0.05$).

There was no significant main effect of shelter compared to open cage. However there was a strong trend of longer growth in open cages for vertical height and plant length proportional increments, and longest shoots (not shown). When combined with exposure, shelter cage growth at low exposure was always the shortest. Significantly so in longest canopy diameter and canopy area proportional increments compared to mid and high exposure shelter cages ($P<0.05$) , and in longest shoots and total new growth, compared to any other exposure, open or shelter cage ($P<0.05$, Fig. 3.24), except longest shoots in the high exposure shelter cage.

Table 3.15 ***Juniperus communis*** fixed effects resulting from REML models analysing annual growth over one year. Significant factors with P<0.05 are highlighted in bold. For others P < 0.1 indicates trends, see text for details. There were 3 levels of Exposure (high, mid and low) at different locations on the site, 2 levels of Shelter (open and shelter cages) and 3 levels of Clipping (no-clip, 50% clip or 100% clip of new growth). Pyear is the year of planting, either 2007 or 2008.

	Plant length Increment	Vertical Height Increment	Long Canopy diameter increment	Canopy Area increment	Basal Diameter increment	Leader length (mm)	Longest shoot (mm)	Total shoot growth (mm)
Juniperus communis 1yr incr for 0809								
Exposure	**0.006**	**0.017**	0.077	**0.049**			0.062	**0.032**
Shelter	0.098	**0.09**					0.06	
Clipping	**<0.001**	**0.011**	**<0.001**	**<0.001**				
Pyear				**0.022**	**<0.001**	**0.009**	**<0.001**	**<0.001**
Exposure.Shelter			**0.025**	**0.004**			**0.041**	**0.007**
Exposure.Clipping								
Shelter.Clipping								0.061
Exposure.Pyear								
Clipping.Pyear		0.060	**0.044**	0.079			**0.049**	**0.023**
Exposure.Shelter.Clipping								

Table 3.16 ***Juniperus communis*** mean growth (back-transformed from natural logarithms) relative to exposure level. Columns sharing same subscript for each parameter are not significantly different at P < 0.05. Standard Errors of Differences (SED) are for logarithm transformed values.

Plant growth parameter	High exposure	Mid-exposure	Low exposure	S.E.D. (log_e)
Plant length proportional increment	1.01_b	1.03_b	0.83_a	0.06
Vertical height proportional increment	1.02_b	1.06_b	0.86_a	0.07
Canopy area proportional increment	0.51_b	0.55_b	0.28_a	0.18
Longest shoot mm	13.75_a	22.06_b	10.48_a	0.21
Total new growth mm	54.65_b	94.20_c	27.08_a	0.28

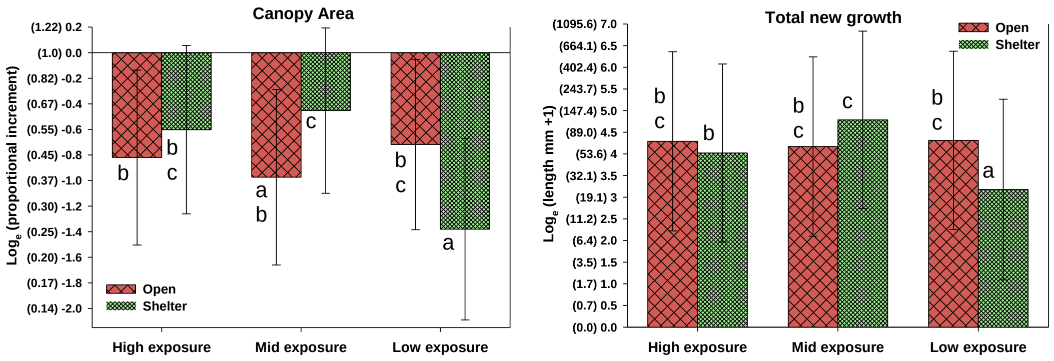


Figure 3.24 ***Juniperus communis*** REML-estimated annual growth means for exposure-shelter interactions across two growth parameters (see titles). Y-axes show natural logarithms (+/- 95% confidence intervals) with back-transformed values in brackets. X-axes show exposure level and cage type (open or shelter). Columns sharing the same letters are not significantly different at $P < 0.05$.

Clipping had a significant and consistent affect on four dimensional parameters (Table 3.17). No-clip was always larger than 100% clip (P<0.05). 50% clip was less consistent across the parameters, but for plant length and canopy area increments there was a clear negative relationship between clip level and growth. Cage type (shelter or open) had a significant effect on the response of total new growth to clipping. Open cage response to clipping was weak with no clear difference between the treatments, but in shelter cages there was a significant clear relationship of reduced growth with increased clipping (P<0.05, Fig. 3.25).

Table 3.17 ***Juniperus communis*** mean growth (back-transformed from natural logarithms) relative to clipping intensity. Columns sharing same subscript for each parameter are not significantly different at $P < 0.05$. Standard Errors of Differences (SED) are for logarithm transformed values.

Plant growth parameter	No-clip	50% clip	100% clip	S.E.D. ($\log_e$)
Plant length proportional increment	1.19_c	0.96_b	0.82_a	0.07
Vertical height proportional increment	1.18_b	0.96_a	0.86_a	0.09
Long canopy diameter proportional increment	0.93_b	0.81_b	0.53_a	0.10
Canopy Area proportional increment	0.87_c	0.46_b	0.24_a	0.17

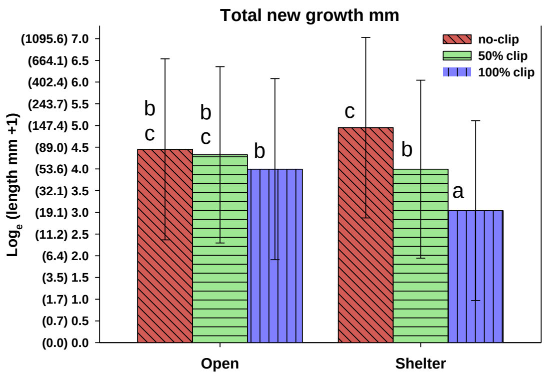


Figure 3.25 ***Juniperus communis*** REML-estimated annual growth means for shelter-clip interaction on total new growth. Y-axis shows natural logarithms (+/- 95% confidence intervals) with back-transformed values in brackets. X-axis shows cage type (open or shelter) and level of browsing. Columns sharing the same letters are not significantly different at $P < 0.05$.

Planting year had a significant effect on two dimensional parameters and all new growth parameters (Table 3.10) with 2008 plants always showing more growth than 2007 plants. This is an expected result because junipers planted in 2008 were larger, with many more shoots, than those planted in 2007. In addition 2008 plants had received more fertiliser prior to planting and slow release fertiliser capsules were present around the roots at planting. In longest canopy diameter increments the clipping-planting year interaction showed that the mean increment in the 100% clip treatment was shorter in 2008 than all others except the 100% clip in 2007. The 2007 no-clip was not different from the 2008 no-clip. Longest shoot and total new growth lengths were always longest in 2008 no-clip plants and always shortest in 2007 100% clip plants (*P*<0.05, Fig. 3.26).

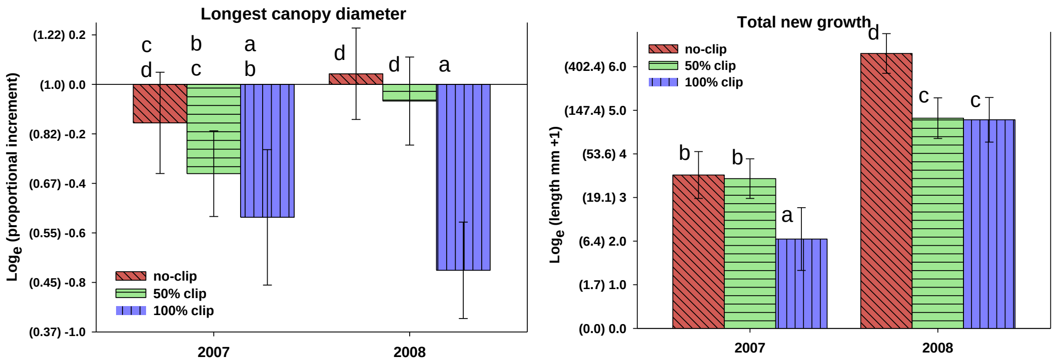


Figure 3.26 REML-estimated 1 year growth means for two parameters (see titles) for clipping-planting year interaction. Y-axis shows natural logarithms (+/- 95% confidence intervals) with back-transformed values in brackets. X-axis show cage type (open or sheltered) and level of browsing. Columns sharing the same letters are not significantly different at *P* < 0.05.

3.4 DISCUSSION

Over two growing seasons the experiment tested the growth response of young *B. nana*, *S. myrsinites* and *J. communis* to combined treatments of simulated browsing (clipping) and exposure.

Three different levels of exposure were identified at different locations in the field and open and shelter cages at each location isolated the exposure effect from other environmental factors. These measures generally proved effective. The shelter cages consistently reduced the strength of wind experienced by the plants in them, compared to those in open cages. The high exposure site recorded consistently higher wind speeds than either the mid- or low exposure sites. The data is less categorical in separating the wind speeds in mid-exposure and low exposure sites, and the wind speeds in the open cage at low exposure site were similar to those in the open cage at high exposure. Despite the difference in wind speeds between the exposure sites there was very little difference in winter temperatures at canopy level between sites. The soil temperatures were relatively stable for most of December and January due to snow cover. Despite this the low exposure shelter cage temperatures were generally lower than the mid or high exposure by less than 1 degree. This difference was not explored further.

3.4.1 Growth responses

The difference in growth between the two timings of the clipping treatments (pre-senescent and dormant) was always insignificant and therefore the hypothesis that pre-senescent browsing would be more damaging than dormant browsing for the two deciduous shrubs has not been proven.

The cause of the second year reduction in basal diameters is unclear. Many of the examples of this were at high exposure in *B. nana*, and low exposure in *S. myrsinites* where generally growth was poor and the change in basal diameter might be expected to be very small. The callipers used record diameter to 0.01 mm accuracy but there is greater error related to the circularity of the stems, the actual height above the ground the measurement is taken and the consistency of 'tightness' on the stems. The error involved in measuring the stems might be in the order +/- 0.3 mm which would suggest most increments were closer to zero.

The following discusses the principal results for each species independently.

Betula nana

The response of this deciduous shrub to clipping generally supports the hypothesis that loss of 100% of new growth has a negative effect on subsequent growth. Whether exposure exacerbated this effect is less clear in part due to the loss of all 100% clipped plants in the high exposure open cage. The response to 50% clip was less consistent with some growth similar in size to no-clip plants and some similar to 100% clip. Overall there was a small negative effect of high exposure on growth, and a positive effect of shelter. Again, the missing plants in the high exposure 100% clip reduced the potential impact of the exposure-shelter interaction. There is no suggestion yet in the results that the plants at high exposure are becoming more prostrate, a feature found in mature *B. nana* at exposed locations in Finland (Kallio & Mäkinen 1978). A reduction in leader length, between the two years, coupled with no or only minimal reduction in total new growth length would suggest that this might be the case however this effect was not observed. It is possible that the short growth in the open cage at low exposure, which was generally similar to that at high exposure, reflects the similarity in wind speed between this cage and the high exposure site. These results from the analysis of annual growth were echoed, although less emphatically in the analysis of two year increments. These results suggest that the experiment is still young and the treatments have yet to take full effect.

Salix myrsinites

The overriding treatment effect found in the willow plants was the sharp reduction in growth and high mortality at low exposure, particularly in the shelter cage. This was not mirrored by a similar increase in growth at high exposure, and in some cases the largest growth was measured in the mid-exposure cages. This suggests that the exposure effect may reflect a negative response to shading or competition from other plants rather than a positive response to increased wind (Fig. 3.27). There were no significant responses found to the interaction between exposure and clipping and therefore the hypothesis that increased exposure will exacerbate the impact of clipping has not been proven.

Removal of 100% of new growth promoted longer growth, compared to no-clip plants, in longest shoots, but there was no similar increase in total new growth measures. This finding supports those of Hester *et al.* (2004) that some deciduous trees respond to severe browsing by concentrating growth in fewer shoots. There was no clear difference between no-clip and 50% clip growth thus supporting the hypothesis that 50% clip will not have a negative effect on *S. myrsinites*, but the hypothesis that 100% clip would be damaging was not proven. Interestingly overall no clip plants grew better in shelter, than in open, cages, an effect that was not evident in either clip treatment. This result was stronger at mid and high exposures (due to the loss of all shelter cage plants at low exposure), and it is possible that no-clip plants were similar in height to, or taller than, the surrounding vegetation. This suggests that the plants benefited from the more sheltered conditions in the shelter, compared to open, cage. If this were the case it would further support the suggestion that shade from, or competition with other plants is important, and negative, rather than that wind-exposure is intrinsically positive.

Overall growth in 2009 was less than in 2008 in both dimensional and new growth parameters. As with *B. nana* the use of proportional increments means that smaller increments might be anticipated in dimensional parameters. However there was also significantly smaller total new growth in 2009 and many of the dimensional proportions were less than one, indicating that the plant size had decreased. The most likely reason for this was the elevated nutrient levels around plants in 2008, due to soil disturbance and residual fertiliser, which would have been exhausted by 2009 growing season.

Figure 3.27 Photograph of *Salix myrsinites* shelter cage at low exposure site showing dense grass growth inside compared with outside cage. No *S. myrsinites* plants are visible.

Juniperus communis

The strongest result from the experiment for *J. communis* was the negative response to removal of 100% new growth, including a significant number of losses. This concurs with previous findings of Hester *et al* (2001) for the conifer *Pinus sylvestris*. However, *J. communis* responded inconsistently to the loss of 50% of new growth with some mean growth similar to that of no-clip plants. This is an interesting response when compared with the strong negative response of *Pinus sylvestris* to a 50% winter clip reported by Hester *et al.* (2004). In the *Pinus sylvestris* experiment it was shown to respond more negatively than birch (*B. pubescens*) and rowan (*Sorbus aucuparia*) (Hester *et al.* 2004). It is possible that *J. communis* has an intermediate growth response between that of *P. sylvestris* and the deciduous species. Each whorl of shoots has auxiliary buds which may be able to respond to loss of apical shoots by elongation, similar to deciduous species, but this would require further investigation to confirm.

Although the response to exposure was relatively weak there was a consistent negative response to low exposure. There was no corresponding positive effect of high exposure which suggests that the negative response may relate to increased shade or competition, as found more strongly in *S. myrsinites,* rather than to lack of wind. The negative effect of low exposure was exacerbated in shelter cages, compared to open.

There was a relatively large difference between growth in *J. communis* planted in 2007 and those planted 2008, as was expected because of the very different initial size of the plants and the fertiliser available to 2008 plants. So it was interesting that the heavy clip, but not the other clip inetnsities, affected the overall plant size similarly for each planting year, while total new growth lengths were longer in 2008 plants. Although there was a year difference in planting time the plants were similar ages, in terms of growing seasons. 2008 were not only larger, than 2007 plants, but also more branched and as a result the plants had a larger number of shoots for re-growth. The results suggest that the 2008 plants extended a larger number of shoots, than the 2007 plants, but only to the same proportional amount.

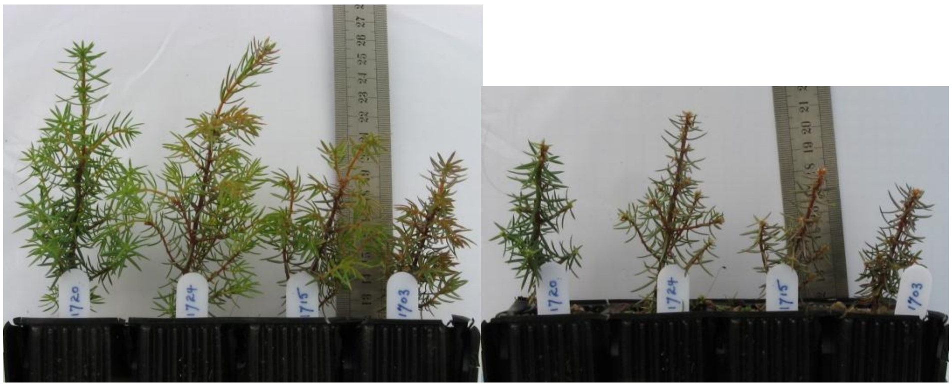


Figure 3.28 *J. communis* 2008 replacement plants before (left) and after (right) 100% clipping treatment.

3.4.2 Conclusions

The data did not support the hypothesis that late summer and winter clipping differ in their effects on *B. nana*, *S. myrsinites* and *J. communis.* Generally there was not a consistent response to clipping across any growth parameter on any species. There was a much stronger response from *J. communis* to clipping than either other species supporting the suggestion that deciduous and coniferous species may respond differently to clipping (Hester *et al.* 2004). These results provide some supports for the hypothesis that 100% clipping will have a negative effect, but there is no evidence that 50% clipping also has a negative effect on any of the species. The data suggest that of the three species *B. nana* is most sensitive to exposure, but *S. myrsinites* and *J. communis* are both more sensitive to shelter. Overall the response of the young plants to the clipping and exposure treatments was not strong and the hypothesis that high exposure would exacerbate the negative effect of clipping was not supported. The short time the experiment has been running is considered the primary reason for a lack of strong effects and a key recommendation is that the experiment is maintained for at least five years.

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APPENDIX 3.1 CUTTING COLLECTION AND PROPAGATION

Introduction

Young plants were required for two investigations into the response of young *Betula nana, Salix myrsinites* and *Juniperus communis* to different treatments. In order to achieve at least two growing seasons it was necessary to start the experiments in the summer of 2007 and the planning was started in the autumn of 2006 requiring the indentification of suitable material quickly. Although a limited number of nursery origin *B. nana* and *J. communis* seedlings were available this was not considered appropriate because: there were insufficient plants; the origin of the plants was uncontrolled and particularly for *J. communis* was not from an appropriate provenance, or from high altitude; and in the case of *B. nana* there was a possibility of inadvertently using hybrid material. No nursery source of *S. myrsinites* was identified.

As a result it was decided to collect and propagate cuttings and between October 2006 and January 2007 cuttings were collected from three separate, geographically spread existing sites for each species (Table 3.1, page 136).

Collection of plant material

Between two experiments 170 young plants of each species were required. It was anticipated that the take rate would be a maximum of 50% and less for juniper, and the aim was to collect bewteen 100 and 200 cuttings from each of 3 sites per species.

Cuttings were between 6 & 10 cm long, or smaller where growth dictated, and primarily of 2006 growth material. There were two main types of cutting: those that included a 'heel' of 2005 growth; and those that included a short length of 2005 growth. Where 2006 growth exceeded 15 cm it was possible to produce more than one cutting from a shoot.

Protocol for collecting material

The protocol set out below was agreed with SNH particularly for the collection of material from designated sites, but it was followed at all sites.

- Each locality had at least 50 well-grown plants. Cuttings were taken from most plants in order to reduce the impact to any one individual.
- Young shoots with obvious flower buds were not taken.
- SNH have grazing damage targets for different habitats which provided the basis for the amount of material removed from any one site. These are set out below for the relevant habitats:

- Where *Betula nana* is a component of Annex 1 type Blanket bogs, and NVC type M19 *Calluna vulgaris – Eriophorum vaginatum* blanket mires, the target is: "In pioneer stage re-growth, or where there is *Betula nana* or *Myrica gale* (at any growth stage), less that 66% of the dwarf-shrub shoots, collectively, should show signs of browsing."
- For *Juniperus communis* ssp *communis*, as a component of Annex 1 type *Juniperus communis* formations on heaths and calcareous grasslands, and NVC type W19 *Juniperus communis* ss*p communis Oxalis acetosella* woodland and other heath and grassland communities where upright juniper is frequent, the target is "less than 33% of the current year's shoots (pale fawn to pale orange brown) should show any evidence of having been browsed." In addition "less than 33% of shoots should show any evidence of having been browsed into shoot or stem material older than the current year's growth (mid-tone orange brown to dark brown)."
- For *Salix myrsinites*, as a component of Montane willow scrub, including Annex 1 type Sub-arctic *Salix* spp scrub, and NVC type W20 *Salix lapponum – Luzula sylvatica* scrub the targets are: The height, or length, of at least 50% of willow stems should be at least 20 cm; and where stands are safely accessible and close inspection can be made, less than 33% of the most recent long shoots should show signs of having been browsed.

Therefore, material was removed such that the cumulative effect of taking cuttings and browsing impact was less than 33% of shoots from any one plant, and those plants selected had stems longer than 20cm. For example, where a plant has at least 18 shoots on stems of 20 cm or more, 6 shoots were taken.

The location of all parent plants was recorded by GPS, including altitude, and each cutting was individually numbered and can be identified with its site and parent plant. Weather generally did not allow photography of individual parent plants but general site photographs were taken where possible.

Propogation method

Each cutting was randomly allocated to a cell in a Rootrainer book (4 x 1 cells per book, Ronash Ltd., Rootrainers© model volume) in one of two different growing mediums (2:1 peat / perlite mix and perlite only), and potted within twenty-four hours of collection. Before potting, the length of each cutting was recorded as well as details of whether it included hard wood from the previous season or a "heel" from the adjoining branch, and its position in the rootrainer book, as well as the position of book in the tray (8 books per tray in 8 x 4 cell layout). Within five days of potting, the Rootrainers with the peat / perlite mixed medium were placed in a growth room at 16 hr day and under a controlled day (16°C)/ night (10°C) temperature regime. The day length and temperature regimes were monitored against soil temperatures and reduced to 12°C and 8°C, respectively, to ensure soil temperatures did not exceed 10°C. The day-time light was 350 – 370 μmol m^{-2} s^{-1}, and humidity was set at 75%, which gave an actual reading of 80%. The rootrainers with perlite growing medium were placed outside on the Black Isle at 50 m asl, exposed to the ambient weather. At the end of January 2007 all the cuttings were brought into the growth room (at the same settings) to encourage growth, before being transferred to an outdoor location at the end of March, at 250 m asl in Strath Spey to acclimatise ready for planting at the experiment site. The cuttings were watered once a week prior to showing signs of growth and at least once every three days once green leaves were visible and while in Rootrainers. Two weeks following the first showing of green leaves each cutting was fed weekly by watering to saturation with a 1:10 solution of N:P:K fertiliser (14:10:27 Phostrogen© Table A3.1) in order to keep it alive until planting out, but ensure that there were minimal residue of fertiliser when it was planted on site.

Table A3.1 Chemical composition of Phostrogen plant food, as supplied by Phostrogen website.

Phostrogen plant food Details of chemical composition of Phostrogen©	
Chemical and formulation	**Percentage concentration**
Total N	14
Ammonical N	2
Ureic N	12
Phosphorus pentoxide P_2O_5 (soluble in Ammonium citrate and water)	10 (P 4.4)
Phosphorus pentoxide P_2O_5 (soluble in water)	10 (P 4.4)
Potassium oxide (K_2O) soluble in water	27 (K 22.4)
Magnesium oxide (MgO) soluble in water	2.5 (Mg 1.5)
Calcium oxide (CaO) soluble in water	2 (Ca 1.43)
Sulphur trioxide (SO_3) soluble in water	7.5 (S 3)
Boron (B) soluble in water	0.012
Copper (Cu) chelated by EDTA	0.0055
Iron (Fe) chelated by EDTA	0.04
Manganese (Mn) chelated by EDTA	0.02
Zinc (Zn) chelated by EDTA	0.0055
Molybdenum (Mo) chelated by EDTA	0.0016

APPENDIX 3.2 CAGE HABITAT SURVEY FORMS

This two page form was used to record the habitat for each cage site for both experiment 1 and 2 (Chapter 4).

PhD Expt Cage Location Habitat Assessment Form (2 pages)

Site Name Cairngorm	**GR:** NH	**+/-**	**WP NO.**	**Alt:**
Date 20	**Cage no**	**Surveyor**	**NVC** (SNH)	
Vegetation height: field		Litter	Moss	
Inflor:	**pH :**		**Soil Depth**	
% cover: Bare ground	Rock	**Aspect**	**Slope**	
Ext of comm:	**Weather on day:**			
General cage site description (topography, nature of vegetation) **:**				

Spp list	P %		P %		P %	P %
Cal vulg		Alch alp		Dipha alp		
Eric cin		Alch glab		Huper sel		
Eric tetr		Filip ulm		Sela sela		
Emp herm		Gal sax				
Vacc myr		Geum rival		Athyr felix		
Vacc ulig				Blech spic		
Vacc vitis-ida		Oxal acet		Dryo bor		
Lois proc		Persic vivip		Dryo dila		
		Poten erecta		Oreo limb		
Agro capill		Prim vul				
Agro canin		Ran acris		Blin acut		
Anthox odo		Saxif aiz		Callier trifa		
Danth dec		Saxif hynoi		Camply stell		
Desc flex				Dicran maj		
Fest ovina		Saxif oppo		Dicran scop		
Fest vivip		Suc prat		Drep coss		
Mol caer		Thali alp		Drep revol		
Nard stric		Thym prae		Hyloc sple		
		Tofiel pus		Hypn jutl		
Car bigel		Troll euro		Palu comm		
Car bine		Viol rivin		Pleu schr		
Car nigra				Poly com		
Car panic				Rac lanu		
Car piluli				Rhyt lore		
Car vir brac[1]				Rhy squar		
Car vir oedo[2]				Scler pur		
Car vir vir[3]				Scor scor		
Eroph ang				Fiss adian		
Junc eff				Press quadr		
Junc squ						
Junc tri				Clad ragif		
Luz multif				Clad arbu		
Luz syl				Clad gracil		
				Clad potent		
Trich cesp				Clad uncia		

[1] lepidocarpa [2] demissa [3] serotina

NOTES:

Figure A3.1 Experiment cage habitat survey **a)** Page 1 vegetation community and location details.

Any particular surrounding area description notes (e.g. nearest water course/seepage lines)

List photos, particular features included and directions taken,

Neighbouring plant communities

Grazing impacts

	Present		Impacts			Dung groups present
Sheep	yes	no	Medium	Low	High	
Deer	yes	no	Medium	Low	High	
Hares	yes	no	Medium	Low	High	
Rabbits	yes	no	Medium	Low	High	
Voles	yes	no	Medium	Low	High	

Geology

Soil

Figure A3.1 Experiment cage habitat survey **b)** Page 2 land management impacts and other descriptive details.

APPENDIX 3.3 CAGE HABITAT ASSESSMENT

Table A3.2 Species recorded at experimental cage sites as part of habitat assessment prior to setting out experiment at Ben Lawers NNR.

	Betula nana						*Salix myrsinites*						*Juniperus communis*								
	High expos		Mid-expos		Low expos		High expos		Mid-expos		Low expos		High expos		Mid-expos		Low expos		Ave	No.	
spp code	open	shelt	open	shelt	open	shelt	open	shelt	open	shelt	open	shelt	open	shelt	open	shelt	open	shelt	freq %	cages	Constancy
Empe nigr					15														15	1	I
Vacc myrt	20		30	15	25	20	25	20	10		0.5	0.5	40	25	40	20	30	50	23	16	V
Vacc vitis-ida	5				3	1	3	2					5				5	2	3	8	III
Agro canin	5		2	2	3	5	7	5	5		7	5	2	7	5	6	1	7	5	16	V
Anth odor						2		2	1	1	15	25	5					2	7	8	III
Desc flex	7		5	5	7	10	3	5	1		5	3	8	1	2	4	1	5	5	16	V
Fest vivi	5		2	7			3	7	9	8			7	3	3		5		5	11	IV
Mol caeru						1			7		10	5	3			3			5	6	II
Nard stri	10		6	20	10	7	15	5	5	15	10	20	15	25		20	5	20	13	16	V
Care bige							3	1					2				1		2	4	II
Care bine				3				7	2								5		4	4	II
Care hostia									7										7	1	I
Care panice									3	5			1						3	3	II
Care pilu							1	12			0.1		10	3		7	3		5	7	III
Care pulic									4	2									3	2	I
Junc squa	7		15	20	7	10	5				15	15		10	7	5	7	10	10	13	IV
Luz multi						3		3		1	3	2				1	2	1	2	8	III
Luz sylvat					3														3	1	I
Gali saxa	1		5	5	1	5	2	7	1		30	30	5	1	1	2	1	0.5	6	16	V
Pote erec								2	3	5	5	5		1			3		3	7	III
Dicran scop	0.5														2				1	2	I
Hylo sple	20		15	5	2	25	30	12	25	7	1	0.5	40	6	20	20	40	25	17	17	V
Hypn jutl	10																	8	9	2	I
Pleu schr	5		1	1		2		1					1						2	6	II
Poly comm	1		6	15	10	7	7	10	1				1		30	25	1	3	9	13	IV
Rhyt lore	1		1	1	1		1	0.5					1	2			0.5	1	1	10	III
Rhyt squar			1		1	3		5	1		1	0.5				1	0.5	1	2	10	III
Liverwort	0.5		0.5	0.5		0.5					0.5	5	0.5						1	7	III
Alch alpi										7			0.1						4	2	I
Alch glab										5									5	1	I
Camp rotun									1	0.5									1	2	I
Care spp			2																2	1	I
Cerast spp							3	2					2						2	3	II
Euphras spp										2									2	1	I
Leont autum										1									1	1	I
Linu cathar										1									1	1	I
Mela prat													1						1	1	I
Oxal acetos													1			7			4	2	I
Persic vivip									2	3									3	2	I
Rum acetosel								3											3	1	I
Tarax offic										0.5									1	1	I
Thali alp										1									1	1	I
Thym prae										15									15	1	I
Trich cesp					10	15													13	2	I
Trifol repe									5	5									5	2	I
Viol rivin										3									3	1	I
Poa sp									1	20						1			7	3	II
Aula palu																		1	1	1	I
Clad arbu	5												1	7			0.5		3	4	II
Clad porten	1												0.5	2					1	3	II
Clad rang								0.5						1	1				1	3	II
Clad unci	1												0.5	3					2	3	II
Clad spp	0.5												0.5		0.5				1	3	II
Lopho biden				0.5		1													1	2	I

Table A3.2 Soil pH and available nutrient content (mg kg^{-1}) from samples collected at experimental cage sites.

	Betula nana						*Salix myrsinites*						*Juniperus communis*					
	High expos		Mid-expos		Low expos		High expos		Mid-expos		Low expos		High expos		Mid-expos		Low expos	
Soil property	open	shelt	open	shelt	open	shelt	open	shelt	open	shelt	open	shelt	open	shelt	open	shelt	open	shelt
pH $CaCl_2$	3.41	3.85	3.21	3.30	3.22	3.31	3.72	3.67	4.74	5.36	3.43	3.26	3.90	3.38	3.65	3.68	3.44	3.37
Ca mg/kg	143	987	621	433	909	723	298	365	1150	3440	622	550	211	193	203	208	560	604
K mg/kg	121	209	464	406	283	450	233	230	91	127	475	301	127	159	292	264	366	438
Mg mg/kg	128	346	554	416	720	484	239	265	121	190	378	285	106	181	269	229	459	564
P mg/kg	17.9	15.6	141	75.2	88.4	230	26.5	35.2	6.89	15.0	119	115	10.86	34.0	51.2	38.7	104	109

Table A3.3 Site characteristic recorded at each experimental cage site as part of the cage habitat assessment.

2nd / 3rd August 2007						Field heights					Inflorescnet heights					Litter depth					Moss								
			Aspect deg N	Altitude m asl	Slope deg	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	Sheep	Deer	Voles	Comments
Betula nana	High expos	open	258	715	30	190	100	160	130	130	360	280	270	540	300	10	30	40			95	55	60	50	60	L	L	L	no dung
		shelt																											
	Mid-expos	open	240	662	17	160	50	160	220	240	300	520	310	380	320	40	20	30	40	40	35	40	25	40	45	L	L	L	2 dung groups within 1 m
		shelt	352	662	5	220	120	230	110	150	285	350	365	280	400	15	30	25	30	50	70	60	65	50	75	L	L	L	4 dung groups within 1 m
	Low expos	open	238	738	4	100	90	110	270	110	360	320	360	400	350						55	50	40	60	50	L	L	L	no dung
		shelt	0	734	0	270	210	130	90	140	300	430	365	410	305						60	70	60	75	40	L	L	L	2 dung groups within 1 m
Salix myrsinites	High expos	open	270	726	25	140	150	130	390	240	390	330	360	310	360	50	25				130	90	70	90	80	M	L	H ?	3 dung groups within a metre
		shelt	254	734	24	160	130	160	140	200	300	365	260	315	275	20	40	30	40	45	110	100	45	60	90	M	L	L+	6 dung groups within 1 m
	Mid-expos	open	250	649	18	210	150	180	190	210	760	39	470	430	380	50	25	15	20	60	40	45	35	25		M	L	L	3 dung groups within a metre
		shelt	268	667	17	170	175	150	110	140	280	340	315	210	175	17	10	10	30	20	60	40	40	30	30	L	L	L	2 dung groups within 1 m
	Low expos	open	111	732	8	150	70	170	210	180	355	398	350	291	301	25	30	20	20	12						M	M	L	15% grazed - could be sheep or deer, sheep more continuous use of the ground
		shelt	143	738	12	130	250	120	150	125	510	390	290	410	370	30	24	20	25	15						M	L	L	7 groups of sheep droppings within 1 m of cage
Juniperus communis	High expos	open	244	718	25	260	150	190	110	260	420	385	390	380	300	25	15	20	30	40	50	55	70	40	60	M	L	L	no dung
		shelt	282	713	26	170	110	120	230	180	350	250	360	280	380	30	30	30	50	50	60					L	L	L	no dung
	Mid-expos	open	262	656	16	95	110	120	110	210	385	350	470	370	200	25	20	10	25		85	60	90	85	75	L	L	L	4 dung groups within 1 m
		shelt	264	658	14	130	180	170	210	160	300	315	305	420	360	30	45				100	95	60	115	60	L	L	L	2 dung groups within 1 m
	Low expos	open	101	734	11.5	150	110	130	125	140	260	270	280	240	255						55	50	75	35	35	L	L	L	1 sheep dung group present
		shelt	101	743	8	130	170	110	120	170	270	300	245	305	220	25	20	28	20		30	50	40	40		L	L	L	3 dung groups within a metre

Chapter four: TREELINE ECOTONE SCRUB AND SNOW

4.1 INTRODUCTION

Snow is a characteristic component of winter weather for many arctic and alpine plants (Canaday and Fonda 1974, Payette et *al.* 1996, Odland & Munkejord 2007, Crawford 2008, Jonas et *al.* 2008). There has been extensive work to explore the relationships between snow cover and arctic / sub-arctic or alpine plant development (authors include those quoted above and Kudo *et al.* 1996, Grippa *et al*. 2005, Höller *et al*. 2009, and manipulative snow experiment methodology has been reviewed by Wipf and Rixen 2010). The factors which determine where snow collects and how deeply are well understood (Holtmeier and Broll 2005, Payette *et al*. 1996, Scott *et al*. 1993, Canaday and Fonda 1974) and predictions of changes in snow patterns in the UK are now available (Harrison *et al.* 1999, Murphy *et al.* 2009). There is growing understanding of a two-way relationship between shrub cover and snow bank development in northern North America (McFadden *et al*. 2001, Sturm *et al.* 2001, Myers-Smith 2010). Treeline tall-shrubs found in the UK generally have sub-arctic and arctic global distributions (Jalas and Suominen 1996) and in the UK they are limited in their distribution and snow cover tends to be erratic and it is not known whether an interactive relationship exists here.

This chapter provides a brief review of the characteristics of snow cover in Scotland, UK, and of the benefits and dis-benefits of winter snow cover considered relevant to UK treeline tall-shrubs. It also reports the results of an experiment to explore the effect of winter snow cover on the growth of three UK tall-shrubs *Betula nana*, *Salix myrsinites* and *Juniperus communis.* Literature cited in this chapter about snow / no snow cover – plant interaction research comes primarily from Arctic or Alpine areas (North American, Scandinavia, Europe or New Zealand) not the UK.

4.1.1 Snow cover in Scotland, UK

Scotland has a markedly varied climate across the length and breadth of the country. The largely westerly oceanic influence is compounded by a complex, relatively small-scale topography (Harrison 1997). Snow cover during winter is variable on an inter-annual scale and Harrison *et al*. (2001) reported no discernable trend in the duration of snow cover from data gathered at thirty-six weather stations in Scotland over a forty year period between 1960/61 and 1999/2000. The majority of climate predictions up to 2100 for the UK generally give a mean daily temperature rise year round, although the scale of the predicted increase varies (Harrison 1997, Harrison *et al.* 2001, Murphy *et al*. 2009). Despite Harrison *et al*. (2001) suggesting that wind and snow cover were difficult to predict, they modelled scenarios, using their predicted winter temperature increases of between 1.8°C and 2.7°C by the 2080s, which predicted a reduction in snow cover of approximately 50% over Scotland as a whole. More recently, as part of the UK climate projection programme, Murphy *et al.* (2009) have predicted temperature rises of at least 0.8°C in Scotland, and although also acknowledging the difficulties involved, a reduction in snow fall rate of 65 – 80% in the main Scottish mountain areas by the 2080s.

These predictions made by Harrison *et al.* (2001) are based on snow cover duration while those of Murphy *et al.* (2009) are based on snowfall rate, and so are not readily comparable. Snow cover duration measures the time snow remains at a given location and is dependent, among other factors, on local topography and ambient weather at the time of the fall and so may be a less reliable measure of long term trends (Marsh 1999). At a given site it may provide valuable information in relation to interpreting vegetation cover. However, as a measure of trends at a regional or national scale it may be less useful. Snowfall rate relates to the volume of snow falling over a given period of time and to some extent is independent of local site factors. It may provide useful information for national trends but would be less useful for determining the implications for vegetation.

There is no documented evidence of a particular trend in snow melt date. When in 1996 all the snow patches in the UK melted for the first time since 1959 there was no information about previous events from which to draw any serious conclusions (Watson *et al.* 2002). Treeline scrub in the UK is not directly associated with snow patches and its distribution seems determined by a range of factors of which snow cover may be only one. If snow cover is predicted to reduce and become more erratic, it is important to determine how treeline scrub is affected by snow in order to clarify the implications for its future.

4.1.2 Snow and treeline ecotone tall-shrubs

Physical factors

Deep snow insulates plants from an otherwise extreme physical environment in mid winter by burying them. A buried plant is not only protected from freezing temperatures and strong winds but also browsing by large mammals (Torp 2010, Rixen *et al.* 2008, Brooks and Williams 1999). Conversely, snow cover may protect small barking-eating mammals from predators while allowing sheltered access to the lower stems of woody plants (Torp 2010) and young shrubs may be particularly vulnerable to damage from this source.

In the absence of snow cover, or following early snowmelt, small or young plants may be vulnerable to the phenomenon of ice-capping (Bliss 19971, Crawford 2008), when a layer of water over the surface of a plant freezes, creating an air-tight ice-container and restricting access to free water and oxygen (Bertrand and Castonguay 2003). Ice can also cause stems to fracture. Without snow protection on a sunny day in winter, plants may desiccate because they are unable to replace the water lost through transpiration due to frozen ground water (Bliss 1971, Grace 1989). Bannister *et al.* (2005) showed that New Zealand alpine plants inundated with snow early in winter developed low frost resistance, suggesting that subsequent early loss of snow cover, as can occur in the UK, may leave plants vulnerable to late frosts.

Lack of snow cover may expose plants to cold ambient air temperatures and, in the UK, strong winds, damage due to ice or particle abrasion and wind (Grace and James 1993). This may be exaggerated immediately above deep snow (Geiger 1966, Payette *et al.*1996) due to the reduced friction of the surface, compared to summer vegetation cover (Grace 1990, Scott *et al.* 1993, Payette *et al.* 1996, Smith *et al.* 2003). In clear weather exposed plants may be stressed by heightened day temperatures oscillating with a drammatic drop at the snow surface at night (Geiger 1966, Stoutjesdijk and Barkman 1992). Exposed plants may be targeted by browsers, which in the UK include *Lepidus timidus* and *Cervus elaphus.*

Snow depth and temperatures

Snow depth determines the temperature regime at ground level (Sturm *et al.* 1997, Brooks and Williams 1999, Mellander *et al.* 2005, Rixen *et al.* 2008). But the depth-temperature relationship is determined by the characteristics of the snow including compaction, air content and density (Sturm *et al.* 1997, Rixen *et al.* 2008, Torp 2010). A snow depth which is beneficial to plants provides temperatures that tend to 0°C and are stable (Mellander *et al.* 2005), as demonstrated by the daily snow data gathered by the Scottish Avalanche Investigation Service (SAIS no date).

Snowmelt date and phenology

Bliss (1971) reported that a long season of snow cover can protect plants from the rapid temperature changes that can occur in autumn and spring. Conversely, late snowmelt has been associated with delayed soil warming in spring and subsequent poor growth by plants (in some bryophytes and graminoids in Scotland, Welch *et al.* 2005, although these results were compounded by grazing), particularly if associated with dry summers (in *Juniperus communis* in southern Europe, García *et al.* 2000).

Wipf *et al.* (2009) showed that the winter hardy *Loisleuria procumbens* responded to an early snowmelt date by showing increased shoot and leaf lengths the following summer. Less winter-hardy shrubs *Vaccinium* spp., and *Empetrumm nigrum* were sensitive to post snowmelt frosts and Wipf *et al.* (2009) proposed that successive premature snowmelt winters could increase plant mortality.

Snow and microbes

In their study in Colorado, Brooks and Williams (1999) demonstrated, on different sites with similar vegetation, that there was increased microbial (primarily bacterial) biomass under snow of at least 0.4 m depth. In sub-arctic Canada a feed-back loop has been proposed of scrub cover expansion in response to higher air temperatures (attributed to climate change) which now collects more snow, raising winter ground temperatures, promoting microbial activity and facilitating enhanced scrub growth (Sturm *et al.* 2001, Myers-Smith 2007).

Late, unusually deep, spring snow has been associated with increased fungal activity including the growth of "snow fungi". In the UK these can affect over wintering crops negatively (Gray 1963). But no published literature was found regarding their presence on woody plants in the UK, and so it is not known whether this is a problem. In other parts of Europe damage to conifers from two fungi, *Phacidium infestans* and *Herpotrichia juniperi*, (and other *Herpotrichia* spp) has been reported (Hansson 2006, Schneider *et al.* 2009). These fungi use *Pinus sylvestris*, and the latter also uses *Juniperus communis*, as hosts.

Seedling survival

Chambers *et al.* (1990) reviewed the literature on seedling establishment in arctic and alpine ecosystems and cite a number of authors who attribute high seedling mortality to the development of intra-cellular needle ice and seedling drought. Seedlings in an open well-drained substrate may be exposed to summer drought, but, if not covered in snow over winter may suffer frost heave and be lifted from the ground, exacerbating the drought stress (Chambers *et al.* 1990, Rosén 1998, Crawford, 2008).

UK treeline ecotone tall-shrub responses to snow cover

There is virtually no literature available about the reactions of UK treeline scrub to snow cover and the following discussion is based on information from studies in other countries which relate to species that occur in the UK (Thompson and Brown 1992). Odland and Munkejord (2008) classified both *Betula nana* and *Juniperus communis* as moderate snow avoiders (chionophobous) in their study of the sensitivity of 126 alpine plant species to snow cover. The classification may was primarily based on snow melt date rather than snow cover. Wahren *et al.* (2005) showed *Betula nana* can tolerate snow cover by recording its expansion, in spread and height, in three different snow depths (2-3 m, 0.5 – 2 m, and up to 0.5 m) over an eight year period.

De Groot *et al.* (1997) report that *B. nana* is more tolerant of avalanche than tree birch because it does not break. Kallio & Mäkinen (1978) reported that on exposed summits branches can be damaged if not protected by snow over winter, while populations growing in wetter locations were "more sensitive" to low temperatures in shallow snow cover. This might suggest that different growing conditions affect the development of frost hardiness.

Rodwell (1991) characterised *Juniperus communis* sites in Scotland as those which have "the lowest February minima", and "moderate morning snow-lie on 60 days year^{-1}", which suggests that *J. communis* is frost hardy and at least tolerates snow cover. Thomas *et al.* (2007) reported that heavy wet snow can break branches and may explain the lower stature of these shrubs at higher altitudes.

Snow manipulation experiments and their relevance to the UK

A natural snow bank has quite a different topography and vegetation from an area which tends to be blown free of snow (Canaday and Fonda, 1974, Thomspon and Brown 1992, Odland and Munkejord 2008) and so has different soils and soil moisture properties (Brooks and Williams 1999, Rixen *et al.* 2008). When studying snow – plant relationships it may be desirable to compare plant responses with snow to those without it, which often requires the manipulation of snow cover in order to isolate the snow effect from other environmental factors.

Wipf and Rixen (2010) have reviewed the considerable body of literature on different snow manipulation experiments. All the experiments reviewed were carried out in sub-arctic, arctic, or alpine zones where annual winter snow cover is more reliable than in the treeline ecotone in the UK.

In reviewing experimental techniques Wipf & Rixen (2010) suggest several disadvantages to the use of snow fences to accumulate snow including the delay of snowmelt date and a tendency to collect litter with the potential to artificially increase the nutrient content of the experiment area. However, they can provide for the development of snow banks on ground which has similar vegetation and topography to areas which remain blown free of snow (Walker *et al.* 1999). Open-topped chambers or the manipulation of snow cover are alternative, but each has its own disadvantages. The former might affect the microclimate around the experimental plants and the latter will change the nature of the snow cover over the plants.

4.1.3 Research need

Plant – snow research in the UK has been focussed above the treeline on open ground plants of snow bed communities (Welch *et al.* 2005) and little is known about the relationship between winter snow cover and the distribution of treeline scrub in Scotland, in particular how snow cover affects the growth and development of young tall-shrub plants. This project tested the hypotheses that winter snow cover enhances summer growth in young treeline tall-shrubs and that altitude exaggerates the response by setting up a manipulative experiment to answer the following questions:

- Does deeper, consistent snow cover have a different effect on the amount of new growth on young plants in the following growing season than snow cover which is shallower and inconsistent, leaving plants intermittently exposed?
- Does this growth response change with altitude?

The experiment used eight month old, rooted cuttings collected from semi-natural Scottish populations of three treeline tall-shrubs *Betula nana* L., *Salix myrsinites* L., and *Juniperus communis* ssp. *communis* L.. The study site selected for the experiment was in the Cairngorm Mountains, Scotland, UK. Two of the three species are deciduous angiosperms, one of which is dioecious, and the third is a dioecious evergreen gymnosperm. They are found on different site types and each is representative of a treeline scrub type in the UK. Their choice is fully explained in Chapter Two.

4.2 METHODS

4.2.1 Location description

A fundamental consideration in selecting a location for this experiment was the need for snow banks that persist through the winter, and adjacent areas with similar vegetation and topography but less consistent snow cover. Snow fences at ski resorts are normally set out irrespective of the vegetation making it possible to pair snow banks close to a fence with relatively close areas that are normally blown free of snow. Cairngorm Mountain Ltd. ski resort, on the north side of the Cairngorm massif is the highest and has the most reliable winter snow cover in Scotland. The ski resort staff were very helpful, interested, and willing to assist with the experiment and it was chosen for these reasons.

The resort (57 ° 1'N, 3° 8'W) has a generally northern aspect spanning two open corries with an intervening ridge. The underlying geology is granite (Institute of Geological Sciences 1964) and the vegetation cover is relatively species poor, dominated by *Calluna vulgaris* with different associations of herbs, dwarf shrubs and graminoids depending on altitude and exposure (Appendix 4.1). The resort ranges from 660 to 1150 m asl. Snow fences have been distributed around the resort below 1120 m asl to collect snow which normally comes from a north or north-easterly direction. Wild *B. nana* is not present at the location but has been recorded from the wider area, *S. myrsinites* is not present in the area and individuals of *Juniperus communis* are widely scattered around the location.

4.2.2 Young plant propagation and use

Betula nana, *Salix myrsinites* and *Juniperus communis* cuttings for this experiment were collected, along with those mentioned in Chapter three, between October 2006 and January 2007 from naturally growing adult plants at three geographically spread sites for each species (see Table 3.1, page 136). The cuttings were propagated as described in Chapter three over an eight to ten month period either in pure perlite and initially left outside over winter, or in a peat / perlite mix and placed in a controlled atmosphere growth room at fixed 16 hour day (350 – 370 µ mol. m^{-2} s^{-1}) at 12°C, and 8 hour night at 8°C, with relative humidity set at 75% (actual reading approximately 80%). At the end of January 2007 the perlite based cuttings were also brought into the growth room. At the end of March they were all transferred to an outdoor location close to the experimental site (at 250 m asl in Strath Spey), to acclimatise before planting out. While in Rootrainers the cuttings were watered once a week prior to showing signs of growth and once every three days as soon as green leaves were visible. Two weeks after the first green leaves appeared each cutting was fed weekly with a 10% solution of N:P:K fertiliser (14:10:27, plus 2.5% MgO and 7.5% SO_3) in liquid form. This was in order to sustain the cutting until planting out but also ensure only a minimum residue of fertiliser was transferred to the planting site. Further details of the propagation process are given in Appendix 3.1 (page 176). There was low propagation success of *S. myrsinites* plants and to complete the complement of this species in the experiment three potted mature plants, which had been heavily pruned, were used.

At the end of the first experimental growing season, any fatalities were replaced. For *Betula nana* the plants were 2nd season seedlings from seed collected at Port Clair (57° 12’N 4° 4’W, 428 m asl). For *Salix myrsinites* rooted cuttings taken from the three mature plants in summer 2007 were used. New nursery-reared three year old *Juniperus communis* seedlings were used. The seed had been collected from high altitude wild populations in Coire Etchachan, Cairngorm massif (57° 6’N 3° 3’W, 437 m asl).

4.2.3 Site selection and experimental design

Around the Cairngorm Mountain Ltd. ski resort eight separate sites, ranging in altitude from 758 m asl to 1036 m asl, were identified with the aid of ski resort staff. At each site a snow fence facilitated the creation of a snow bank over winter in close proximity to an exposed area that did not normally hold snow, but was on similar vegetation. These paired situations represented the “snow treatment” and “controls” respectively and their details are given in

Table 4.1. At each site two large-mammal-proof cages (against *Cervus elaphus, Lepidus timidus* and domesticated *Rangifera tarandus* L.) 1.3 m long by 0.8 m wide and 0.5 m high (for full cage details see Chap 3.2) were set up in the snow treatment and control positions in September 2007. In each cage five rooted-cuttings each of *Betula nana, Salix myrsinites* and *Juniperus communis*, were randomly positioned in one of five rows. In order to aid survival (to counter the acid nature of the site) the willow and juniper were planted into small excavated holes, approximately 2.5 cm larger in diameter and depth than the root trainer plug, which had been lined with John Innes No 1 potting compost.

Table 4.1 Location details for sites and cages

Site no	Cage no	Treatment[1]	Grid Ref	Aspect (deg)	Cage Orientation (deg)	Alt (m a.s.l.)[2]	Altitude class[3]
1	1	Snow	299391 806271	270°	270°	744	1
	2	Ctrl	299391 806195	240°	240°	740	
2	3	Snow	299779 805998	30°	300°	859	2
	4	Ctrl	299777 805994	356°	356°	859	
3	5	Snow	299842 805923	20°	302°	876	2
	6	Ctrl	299845 805938	20°	20°	873	
4	7	Snow	300151 805507	246°	246°	976	3
	8	Ctrl	300114 805535	240°	240°	970	
5	9	Snow	300347 805644	50°	45°	975	3
	10	Ctrl	300361 805655	46°	2°	970	
6	11	Snow	300617 805342	284°	284°	1027	4
	12	Ctrl	300597 805353	270°	270°	1022	
7	13	Snow	300209 804873	276°	276°	1027	4
	14	Ctrl	300169 804876	280°	280°	1015	
8	15	Snow	299897 804993	300°	300°	911	2
	16	Ctrl	299881 804963	300°	250°	912	

[1]Treatments: Snow = sited close to a snow fence or other area that gathers snow; Ctrl = control (see text for more details). [2]All the altitudes were taken from 1:25,000 OS electronic map using ArcMap 9. [3]Sites were assigned to one of four altitude classes created to reflect the natural grouping of the cages, where juniper fatalities were too high, see text, the highest two classes were amalgamated.

The five cuttings were randomly selected from the three origins of cutting material (Table 3.1, page 136), where possible ensuring an even spread of available origins in each cage . This gave a set up of five replicates for each species in each half of the paired snow treatments of consistent or erratic winter snow cover, at eight sites within four altitude classes (Table 4.1). The experiment ran for two years, from late summer 2007 to late summer 2009.

4.2.4 Data capture and handling

Site habitat assessment

A habitat assessment form (Appendix 3.2, page 179) was completed for each cage position. General site information was recorded on: aspect, measured with a magnetic compass; slope with a clinometer; location, with a geographical positioning system (Garmin© Summit); estimate of the extent of the vegetation community; evidence of presence and impact of grazing. Altitude was subsequently confirmed using ArcMap (ESRI ArcGis© 9.1) from OS 1:25,000 maps. More detailed data were recorded on the form using a 2 m x 2 m quadrat. The cages were in position when the forms were completed and so the quadrat was placed along the length of the cage where the vegetation was most similar to that in the cage. Within the quadrat all the vascular plant species, the most prevalent bryophytes, bare rock and soil were recorded with percentage cover estimations. In the middle of each quarter of the quadrat the heights of the field and moss layers, and the depth of the litter and soil were recorded, giving four recordings of each measure per cage location. Soil samples were collected from each quarter quadrat for measurement of pH and plant-available calcium, potassium, phosphorus and magnesium. Details of the soil assessment methodology are given in Chap. 2.3.2 (page 77).

Site weather data

Collated seasonal weather data, and comparisons with 30 year averages, for Cairngorm Mountain was taken from the Meteorological Office climate summaries actual and anomalies web-page (Meteorological Office, web-based, accessed August 2010) for the period autumn 2007 to summer 2009. The mean range of values (for example, rainfall may be from 300 – 400 mm, or sunshine 100 – 120 hours) provided on the 1 km resolution map by the Meteorological Office have been presented in the results as the middle of the range. The size of the data map on the website was small so that the exact value for highly variable data, such as the actual data, was difficult to identify. Where there was any doubt the extracted figures spanned both classes of value. The seasons were defined as - spring: March to May, summer: June to August, autumn: September to November and winter: December to February. The data collected were mean daily maximum temperature, mean daily minimum temperature, rainfall and sunshine. There was no data available on snow cover or frost days. Site weather data from remote sources was complemented by selected on-site monitoring, as described below.

Snow-cover monitoring

Snow depth was measured using a vertical 1.8 m or 2 m pole marked in 10 cm segments attached to each cage. From the first snow fall until the sites were free of snow the following spring, monthly photographs of each pole and cage, if visible, were taken by the author, and approximately once a week by Cairngorm Mountain Ltd. staff. The depth of snow was calculated and recorded per week (and a record kept of the weeks snow was recorded). Where measuring poles were over topped the snow depth was recorded as > 1.5 m. If the poles were dislodged snow depth was measured by counting the number of holes in the netting (each hole was 45 mm), or it was recorded as > 0.5 m when above the height of the cage.

Temperature measurements

Over the first winter 2007/08, three temperature loggers (Thermachron ibuttons, Maxim Integrated Products, Inc., Sunnyvale, CA, USA) were installed in each cage in the soil (s) at a depth of 10 cm, at ground level (g) and at canopy height (15 cm) (c). Due to failure of a high percentage of the loggers there was incomplete recording of temperature data (Table 4.5). In the second winter, 2008/09, loggers were installed on the five sites where a good contrast of snow cover between the paired cages had been demonstrated in the first winter.

The temperature loggers were set to record the average temperature every 2 hours. The temperatures used in the analysis were those recorded during the period between first and last snow cover dates 19th November 2007 to 28th April 2008, and 29th September 2008 to 11th May 2009 respectively.

Altitude classes

To take account of altitude in the analysis, the locations of the cages were grouped into four altitude classes (Table 4.1). *J. communis* suffered high levels of mortality at the highest altitude class and for some analyses (see below) *J. communis* growth from altitude classes 3 and 4 were amalgamated to ensure sufficient data for analysis.

Plant growth parameters

In all cases plants used in the experiments were measured prior to planting out. Subsequently, they were re-measured in late summer in 2008 and again in 2009. Above ground measurements were made of the following parameters (Fig. 3.7, page 145): vertical plant height, overall plant length, maximum horizontal crown diameter (longest canopy diameter) and the diameter measured perpendicular to it, basal diameter using callipers, the length of all new growth, and the length and breadth of the five largest leaves. The new growth was recorded by shoots, which were numbered starting at the apex of the main stem, including secondary and tertiary level shoots (Fig. 3.7). Whether shoots were alive or dead, or new in the measurement year was also recorded. In 2009 the number of buds was also counted.

4.2.5 Statistical analysis

Snow cover

The full snow depth datasets for each cage were analysed across each site pair by repeated measures Analysis of Variance (ANOVA) in GenStat, to assess difference between the snow cage and its control.

Temperature measurements

The difference between temperatures in snow cages and their paired controls were separately analysed by repeated measures ANOVA for each site. The data used were logarithm-transformed (to achieve normality), two hour means recorded from the same logger position (canopy, ground or soil) during the same winter period.

Plant growth parameters

Dimensional parameters, vertical height, the two canopy measures and basal diameter, were analysed as proportional growth relative to the original size of the plant. For one year incremental data the growth from one year was divided by that from the previous year, and for two year increments 2009 data was divided by those collected in 2007. New growth parameters, leader and total new growth were expressed as either the annual measurement, or for the two year assessment, the sum of both years growth, while the longest shoot was always the measure for a particular year (for the 2 year analysis 2009 measures were used). Both dimensional and new growth parameters datasets were checked for normality using histograms before analysis, and all were subsequently transformed to natural logarithm. Where new growth parameter datasets included zeros the transformation $\log_e$ (x+1 mm) was used.

Most *Betula nana* and *Salix myrsinites* plants survived the two years of the experiment (nine and seven individuals were lost, respectively). For each of these species the response of the different growth parameters to the snow treatment and altitude, and their interactions, was analysed using linear residual maximum likelihood (REML) (GenStat 10 © 2007 Lawes Agricultural Trust). To allow for the possibility that the first year was an establishment year two models were used. The first model analysed annual growth responses using the fixed effect combination: snow treatment*altitude class*year (year was the recording year, either 2008 or 2009) and a nested random effect combination: site/cage/cutting number. The second model analysed growth over two years for all the plants surviving until 2009, using the fixed effect combination: snow treatment*altitude class, with nested random effects site/cage. The 2008 replacements plants were excluded from the analyses and, in the case of willow, so were the three mature plants, in order to avoid compounding the results due to variation in ages and origin.

The levels of mortality were high in *Juniperus communis* (37 out of 80 plants over two years). For this reason a third REML model was used, in addition to the two described above, which examined growth in the second year (2008 to 2009) for all the plants, including 2008 replacements. In this scenario the top two altitude classes were amalgamated due to a lack of data in the highest altitude class. The fixed model used was snow treatment*altitude class*planting year (either 2007 or 2008), and a random model: site/cage.

Table 4.2 Numbers of *Betula nana* (Bn), *Salix myrsinites* (Sm) and *Juniperus communis* (Jc) plants per altitude class and snow treatment used in analysis

	Altitude classes	1			2			3			4		
	Species	Bn	Sm	Jc	Bn	Sm	Jc	Bn	Sm	Jc	Bn	Sm	Jc
	Total possible number per treatment[1]	5	5	5	15	15	15	10	10	10	10	10	10
Growth increment	Snow treatments[2]												
07-08	Snow	5	5	4	15	14	13	9	9	7	9	9	10
	Control	4	3	3	14	15	12	9	10	6	8	8	7
07-09	Snow	5	5	4	15	14	12	9	9	7	9	9	8
	Control	4	3	3	14	15	12	9	10	3	8	8	5
08-09	Snow	5	5	5	15	15	14	10	10	10	9	10	8
	Control	5	5	5	15	15	15	10	10	5	10	10	7

[1] This gives the maximum number of plants (replicates) per species per altitude class and snow treatment. The body of the table gives the number of survivors at each stage, which is the number used in analysis.
[2] Snow = plants that spent the winter in a snow bank, Control = plants in a more exposed location with less consistent snow cover.

Table 4.2 gives the numbers of replicates included in each of the analyses given above. The effect of treatments on the mortality of each species was analysed using the Generalised Linear Model (GLM, GenStat 10©) Altitude+snow, across four altitude classes and the two snow treatments.

4.3 RESULTS

4.3.1 Habitat assessments

Ericaceous species dominated the quadrats with upland graminoids such as *Nardus stricta* and *Trichophorum cespitosum* as primary co-dominants. Site 3 shows the greatest contrast between the snow treatment and control cage with the snow cage vegetation being dominated by *Nardus stricta* and *Trichophorum cespitosum* and the control cage dominated by *Calluna vulgaris*. Across the ski resort there was very limited evidence of impact by herbivores, but there was consitstent presence of *Lepidus timidus* and *Lagopus mutus* droppings at all cage locations. The soil analysis identified that, compared to the others, sites 1, 4 and 5 had unusually high magnesium contents (Appendix 4.1 provides the habitat assessment data).

4.3.2 Site weather data

Table 4.3 gives the mean seasonal weather data for Cairngorm Mountain (Meteorological Office, web-based accessed August 2010) and their "anomalies" or variation from the 1971 to 2000 averages. These data show that between the two years there were higher than normal maximum and minimum temperatures in autumn and higher, above freezing maximums in winter 2007 / 08 (by 1.25° C, and 1.75° C respectively, Table 4.3), compared to corresponding temperatures in 2008/2009, which were all normal. Maximum and minimum spring temperatures in 2009 were 0.75° C higher than those of 2008 and whereas both maximum temperatures were marginally higher than normal (by 0.75° C), 2009 minimums were normal. Minimum summer temperatures in both years were higher than normal by 0.75° C.

There were approximately 30% more hours of winter sunshine in 2007/08 than in 2008/2009 or the normal levels. Both spring 2008 and 2009 had more sunshine hours than normal (120% and 130%, respectively). However, in summer 2008 there was 10% less sunshine hours than normal, while in 2009 there were 10% more hours. In autumn 2007 rainfall was 20% less than in 2008 and the average. In winter 2007/08 it was 40% wetter than normal,

Table 4.3 Mean weather data for Cairngorm from September 2007 to August 2009 (Meteorological Office, 2010 web-based)

	2007		2008		2009	
	Actual	Variation[1]	Actual	Variation	Actual	Variation
Daily Max Temp °C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
spring			<4 to 6	0.5 to 1.0	4 to 8	1.5 to 2.0
summer			14 to 16	-0.5 to 0.5	12 to 14	-0.5 to 0.5
autumn	6 to 8	1.0 to 1.5	4 to 6	-0.5 to 0.5		
winter	0 to 4	1.5 to 2.0	-2 to 2	-0.5 to 0.5		
Daily Min Temp °C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
spring			-2 to 2	-0.5 to 0.5	-2.0 to 0	0.5 to 1.0
summer			6 to 10	0.5 to 1.0	6 to 8	0.5 to 1.0
autumn	2 to 4	0.5 to 1.0	0 to 4	-0.5 to 0.5		
winter	-4 to -2	-0.5 to 0.5	-4 to -2	-0.5 to 0.5		
Hours of sunshine	**hr**	**%**	**hr**	**%**	**hr**	**%**
spring			400 to 450	115 to 125	450 to 500	125 to 135
summer			320 to 380	85 to 95	440 to 500	105 to 115
autumn	200 to 240	95 to 105	200 to 240	95 to 105		
winter	120 to 140	125 to 135	100 to 120	95 to 105		
Rain mm	**mm**	**%**	**mm**	**%**	**mm**	**%**
spring			300 to 600	90 to 110	300 to 400	70 to 90
summer			300 to 400	130 to 150	400 to 600	110 to 130
autumn	400 to 600	70 to 90	400 to 800	90 to 110		
winter	600 to 800	130 to 150	400 to 600	70 to 90		

[1]Variation is the difference between the actual and thirty year averages for the period 1971 to 2000

but in 2008/09 it was 20% drier than normal. Spring in 2008 had average rainfall while in 2009 it was 20% drier than normal. In both years the summer was wetter than normal (40%, and 20% above normal, respectively).

4.3.3 Cage snow cover

In year one (2007/2008) snow depths were measured between the week beginning (w. b.) 19th November 2007 until w. b. 5th May 2008 (25 weeks). In year two (2008/2009) recordings were made from 29th September 2008 until w. b. 11th May 2009 (33 weeks). The ANOVA confirmed that snow cages at six sites had significantly deeper snow than the controls (*P* < 0.05, Table 4.4). In addition, there were at least four weeks less snow cover in the control cage at each site than the snow cage (except site 7). Figure 4.1 provides graphs of the snow depths in the snow treatment and control cages for each site over the two winters, grouped into altitude class. It was not possible for the Cairngorm Rangers to photograph the cages every week and the gaps in the photograph sequences may mask complete loss of snow cover in some cages during periods when the snow cover was thin. Despite this the results confirm that the position of paired cages provided consistently greater depths of snow in the snow treatment cages compared to control cages.

Table 4.4 Analysis of Variance (ANOVA) of snow depths (cm) between paired snow treatment cages (control of snow) over two winters

	Mean snow depth (cm) (+/- S.E.)					
Site	control	*N*[1]	snow	*N*	v.r.	F pr.
1	0.09 (+/- 0.03)	*35*	0.15 (+/- 0.03)	*35*	2.1	0.152
2	0.14 (+/- 0.05)	*35*	0.72 (+/- 0.06)	*34*	45.75	<.001
3	0.15 (+/- 0.06)	*34*	0.98 (+/- 0. 06)	*33*	96.93	<.001
4	0.10 (+/-0.04)	*35*	0.23 (+/-0.04)	*35*	5.5	0.022
5	0.24 (+/- 0.05)	*36*	0.52 (+/- 0. 05)	*37*	18.77	<.001
6	0.27 (+/-0.07)	*27*	0.70 (+/-0.07)	*27*	22.04	<.001
7	0.15 (+/-0.07)	*22*	0.33 (+/-0.07)	*22*	3.49	0.069
8	0.12 (+/-0.05)	*22*	0.55 (+/-0.05)	*22*	41.67	<.001

[1]The sample numbers were dependent on the availability of Cairngorm Mountain staff to take photographs and was not consistent across cages.

4.3.4 Cage temperature

Eight pairs of snow treatment and control cage temperature datasets, from the same site and position in the cage, were directly comparable (three from 2007/08 winter, and five from 2008/09) and were spread across altitude classes 2, 3 and 4. Six sets were from the soil (10 cm depth) and two from canopy height (15 cm). Figure 4.2 shows the temperature variations over time. Temperatures in snow cages were generally more stable and closer to zero than those in control cages. Snow cage soil temperatures at sites 2, 6, 7 & 8 were significantly higher than the controls (P<0.001, Table 4.5). Snow cage canopy temperatures at site 6 were

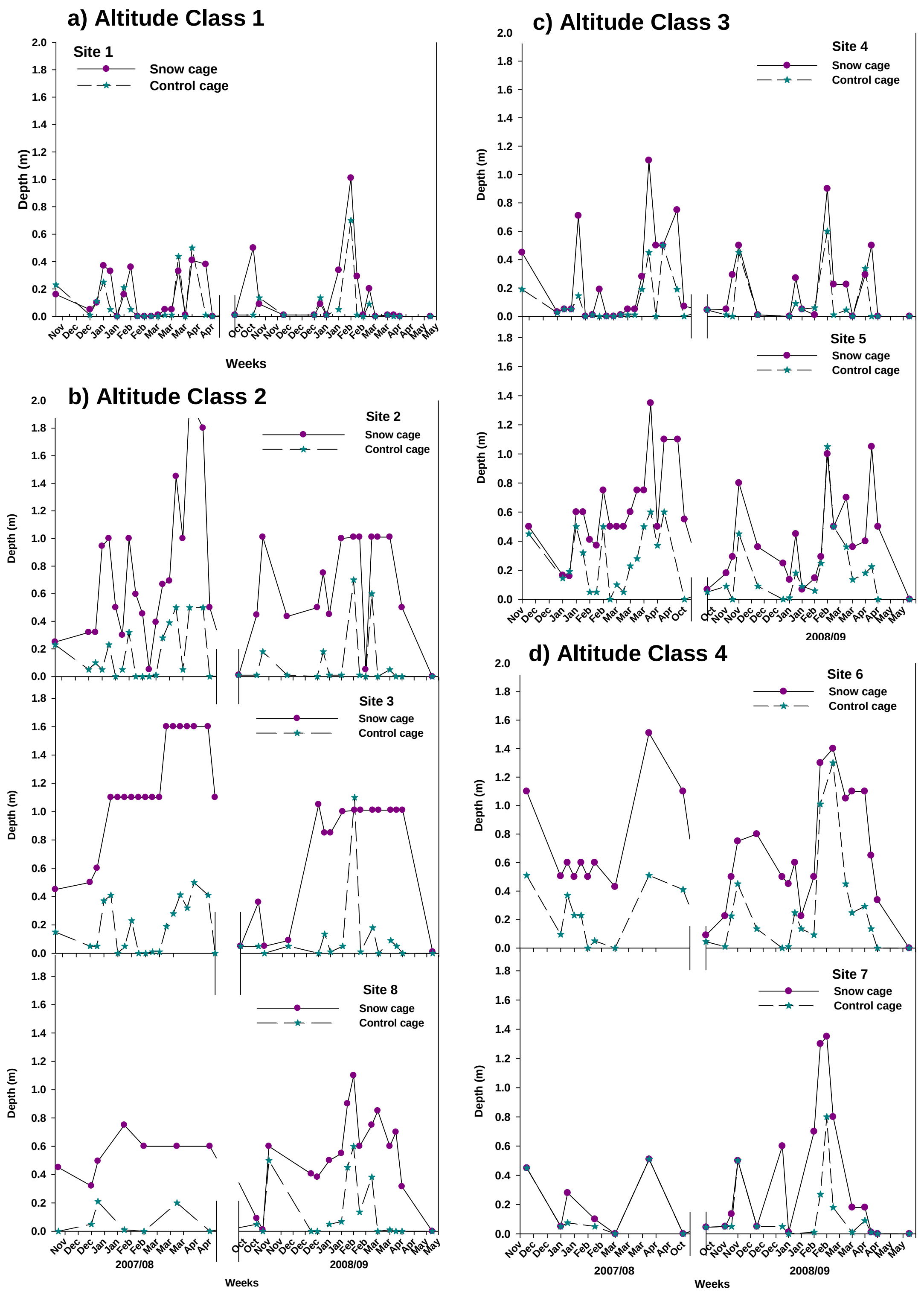

Figure 4.1 Snow depths (cm) over two winters at each site. **a)** Altitude class 1; **b)** Altitude class 2; **c)** Altitude class 3; **d)** Altitude class 4. 2007/08 snow cover extended from 19.11.07 to 28.04.08; 2008/09 from 29.09.08 to 11.05.09.

significantly higher than control cages (P<0.001), but at site 8 they were significantly lower than the controls (P<0.001, Table 4.5).

Table 4.5 Analysis of Variance (ANOVA) between temperatures (°C) in paired snow treatment cages (snow or control) over two winters. Means are presented as natural logarithms. Temperatures were recorded each winter between: 30.10.07 & 17.04.08 and 30.12.08 & 11.05.09.

Site & position of temperature logger[1]	Winter period	Cage type mean temperatures (°C log_e) control	snow	v.r.	F pr.	s.e.d.	*n*
6 soil (+0.5° loge)	07/08	-0.19	-0.083	27.1	<.001	0.0206	2048
7 soil (+1° loge)	07/08	0.1062	0.2894	115.84	<.001	0.01703	2048
8 soil (+1.1° loge)	07/08	0.3428	0.579	243.54	<.001	0.01513	2048
2 soil (+1° loge)	08/09	0.065	0.312	75.54	<.001	0.0284	1587
5 soil (+4° loge)	08/09	1.3418	1.3386	0.06	0.801	0.01262	1587
6 canopy (+11° loge)	08/09	2.2428	2.495	451.32	<.001	0.01187	1002
8 soil (+5° loge)	08/09	1.7092	1.7206	0.86	0.353	0.01232	1587
8 canopy (+10° loge)	08/09	2.3417	2.3078	12.2	<.001	0.01904	1587
8 soil (+5 loge)	07/09	1.703	1.7417	38.14	<.001	0.00627	3635

[1] soil = 10cm depth in soil; canopy = 15 cm above ground level at height of plants. Figures in brackets are the degrees added to the temperatures to ensure logarithms were calculated on a positive number.

4.3.5 Plant growth parameters

Growth responses differed between the two years (2007 to 2008, and 2008 to 2009) and so annual change and two year analyses are presented here. For all three species Table 4.6 presents the mean for each growth parameter prior to the start of the experiment in 2007. Between-year differences were consistently significant in the REML analysis of annual growth and Table 4.7 provides a summary of the mean growth of each species in each year. Table 4.8 presents the main effects identified from the different REML models where these had a probability of less than 0.1. The individual species sub-sections that follow focus on the significant main effects where P<0.05.

Mortality of species

The ANOVA for *B. nana* and *S. myrsinites* did not identify any significant relationship between plant deaths and treatments (not shown). For *J. communis* snow cover appears to have a negative effect on mortality (or positive effect on survival) although it was not significant (logit transformed GLM estimated mean is -1, Standard Error, S.E. was 0.52, P=0.05).

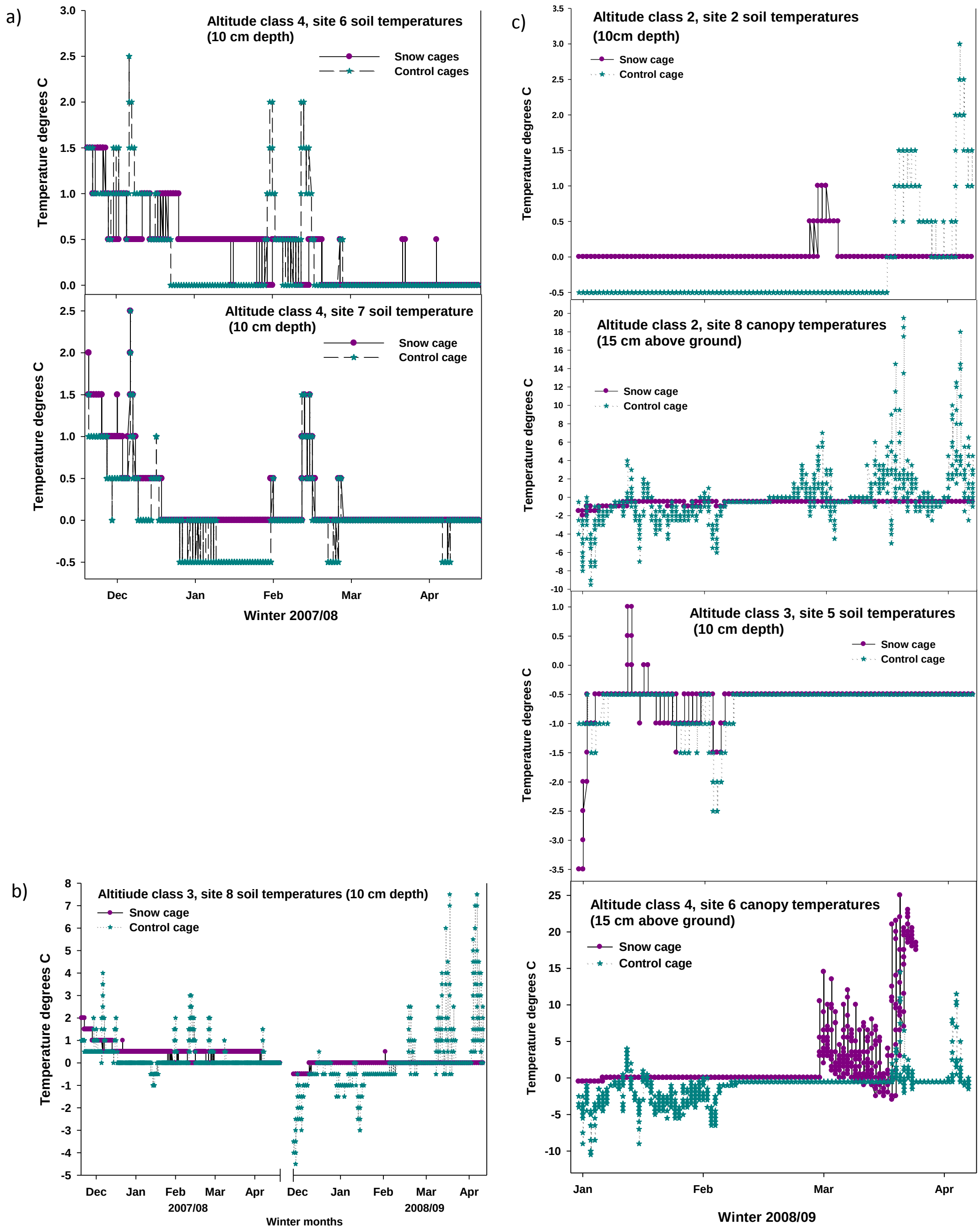

Figure 4.2 Winter temperatures over **a)** 2007/08 for sites 6 and 7 (19.11.07 to 28.04.08) at 10 cm depth in soil; **b)** 2007/08 and 2008/09 for site 8 (19.11.07 to 28.04.08 & 09.08 to 11.05.09) in the soil at 10 cm depth; and **c)** 2008/09 at sites 2, 5, in soil (10 cm depth) and sites 6 and 8 at canopy level 15 cm above ground.

Table 4.6 Mean size of different growth parameters prior to the start of the experiment in 2007. Refer to figure 3.6, page 149 for definition of different parameters.

Species	*Betula nana*		*Salix myrsinites*		*Juniperus communis*	
n=	80		77		80	
Growth parameter	mean	SE	mean	SE	mean	SE
Vertical height (mm)	72.3	3.4	51.0	2.4	48.2	2.1
Longest Canopy diameter (mm)	28.7	3.1	15.8	1.3	22.7	1.1
Canopy Area (cm^2)	5	1.2	1.4	0.2	2.5	0.2
Basal Diameter (mm)	1.6	0.1	2.2	0.1	1.2	0.0
Leader (mm)	18.4	3.1	6.2	0.8	6.0	0.5
Longest shoot (mm)	22.6	3.1	11.8	1.0	8.3	0.5
Total New Growth (mm)	37.1	4.5	17.3	1.5	46.8	4.3

Table 4.7 Relative mean annual growth measurements from 2008 and 2009 for different growth parameters. *P* gives the level of probability for the difference between years: * < 0.05; ** < 0.01; *** <0.001.

	Betula nana			*Salix myrsinites*			*Juniperus communis*		
Growth parameters	2008	2009	*P*	2008	2009	*P*	2008	2009	*P*
Vertical height proportional increase	1.26	1.06	**	2.23	1.89	***	0.95	0.93	*
Longest canopy diameter proportional increase	2.63	1.33	***	4.62	1.92	***	1.88	0.97	***
Canopy area proportional increase	9.64	1.48	***	19.87	1.74	***	3.74	0.83	***
Basal diameter proportional increase	1.48	1.09	***	2.33	2.04	***	1.38	0.81	***
Leader length mm	12.5	14.4		17.0	7.6	***	10.5	7.3	***
Longest shoot mm	27.6	27.8		20.7	9.7	***	11.9	8.8	***
Total New Growth mm	62.6	72.2		56.1	30.5	***	59.3	26.9	***

Betula nana

Generally *B. nana* showed a weak response to the treatments. The strongest effect was the difference in dimensional increments (vertical height, longest canopy diameter, canopy area and basal diameter) between the two growing years (Table 4.8), with 2008 having significantly larger proportional increments than in 2009 (Table 4.7). This effect is not found in any new growth (leader length, longest shoot and total new growth) parameter and it likely to result from the use of proportional increments to record dimensional growth change, as explained in chapter three.

Table 4.8 Significant main effects from REML models for all three species 1 and 2 years' growth. Only effects with *P* <0.1 are shown. Effects significant at *P*<0.5 are in bold.

Main Effects [1]	Vertical Height Increment	Long Canopy diameter increment	Canopy Area increment	Basal Diameter increment	Leader length (mm)	Longest shoot (mm)	Total shoot growth (mm)
Betula nana 1 yr incr over 07 09							
Snow							
Altitude (x4)		**0.038**					
Year	**0.002**	**<0.001**	**<0.001**	**<0.001**			
Snow.Altitude (x4)							
Snow.Year		**0.011**	0.098		0.066		
Altitude (x4).Year					0.055		
Snow.Altitude (x4).Year			0.073		0.063		
Betula nana 2 yr incr over 07 09							
Snow							
Altitude (x4)		0.076					
Snow.Altitude (x4)							
Salix myrsinites 1 yr incr over 07 09							
Snow		0.055			0.05	**0.044**	
Altitude (x4)			**0.003**				
Year	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Snow.Altitude (x4)							
Snow.Year					0.099		
Altitude (x4).Year			0.077		**0.012**	**0.001**	**0.018**
Snow.Altitude (x4).Year					0.069	**0.001**	**0.008**
Salix myrsinites 2 yr incr 07 09							
Snow		**0.037**	**0.04**		0.063		
Altitude (x4)			**<0.001**				
Snow.Altitude (x4)						0.075	
Juniperus communis 1yr incr 0709							
Snow						0.052	
Altitude (x4)							
Year	**0.026**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Snow.Altitude (x4)							
Snow.Year							
Altitude (x4).Year	**0.036**						0.059
Snow.Altitude (x4).Year							
Juniperus communis 2yr incr 0709							
Snow		**0.023**	**0.028**				
Altitude (x4)				0.073			
Snow.Altitude (x4)			0.051		0.081		
Juniperus communis 1yr incr 0809							
Snow							
Altitude (x3)				0.059			
Pyear	**0.033**			**<0.001**			**<0.001**
Snow.Altitude (x3)							
Snow.Pyear					**0.016**		
Altitude (x3).Pyear					**0.04**		**0.049**
Snow.Altitude (x3).Pyear							**0.006**

[1] Effects are Snow: snow or control cage; Altitude: Altitude classes, either 4 or 3; Year: growth year (2008 or 2009; or Pyear: planting year (2007 or 2008). See text for more details.

Altitude had a significant effect on longest canopy diameter proportional increments. Diameters at altitude class 3 were significantly smaller than those at class 4 and both were significantly smaller than those at class 2 (back-transformed proportional increments are 1.6, 1.7, 2.2 times baseline respectively, $P<0.05$). Longest canopy diameter increments also showed a significant response to the snow-year interaction. Diameters in 2008 were all larger than those in 2009 and those in snow cages were larger than those in control cages ($P<0.05$), while in 2009 there was no snow effect (Fig. 4.3)

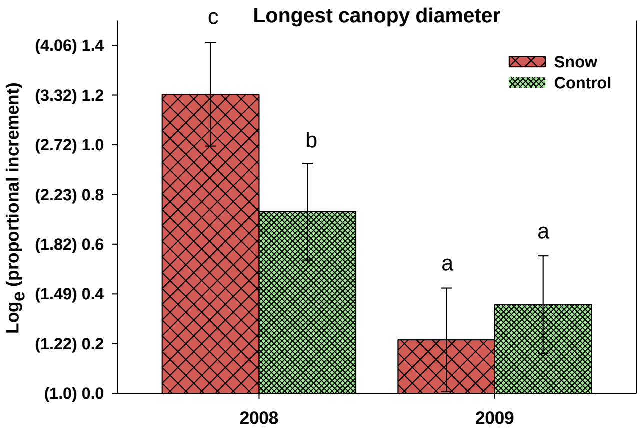

Figure 4.3 *Betula nana* REML-estimated longest canopy diameter mean annual proportional increments from 2008 and 2009 for snow and control cages. Growth is shown in natural logarithms with 95% confidence intervals. Back transformed values are in brackets. Columns sharing the same letter are not significantly different at $P<0.05$.

There were no other significant effects for either the annual or two year increments. However leader lengths showed a strong trend of shorter length with increasing altitude (Fig. 4.4), particularly in 2009, and this was echoed by shorter longest canopy diameter two year proportional increments at altitude classes 3 and 4 than at the lower two altitudes (not shown).

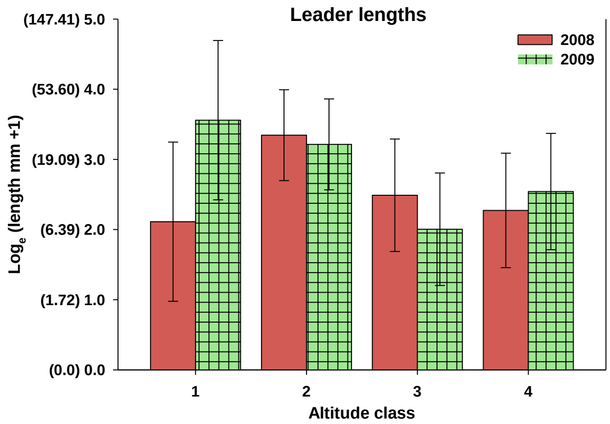

Figure 4.4 Trend in *Betula nana* REML-estimated mean annual leader lengths (mm) for 2008 and 2009 at different altitude classes. Growth is shown as natural logarithm of the lengths +1 mm, with 95% confidence intervals. Back-transformed values are in brackets on the Y-axis. Altitude classes, 1 = lowest, 4 = highest.

Salix myrsinites

Significantly greater growth was recorded across all the parameters in 2008 than 2009 (*P* <0.001, Table 4.7, above). Despite this *S. myrsinites* responded more consistently to the treatments than *B. nana*.

In particular, longest shoots showed a significant positive effect of snow with a back-transformed mean in snow cages of 16 mm, compared to a control cage mean of 13 mm (least significant difference, L.S.D. of logarithm values 0.27, *P*<0.05). There was also a positive effect of snow evident in the snow-altitude-year interaction in longest shoots and total new growth. Any altitude effect was masked in snow cages in both years but not in control cages, where it was inconsistent between years (Fig. 4.5), with altitude class 1 growth significantly longer than other classes in 2008 and significantly shorter than other classes in 2009 (*P*<0.05). When change was measured over two years both longest canopy diameter and canopy area proportional increments were significantly longer in snow cages than in controls (back-transformed mean for canopy areas were 16 times the base size in snow cages compared to 10 times in control cages, L.S.D. of logarithm values 0.43, *P*<0.05).

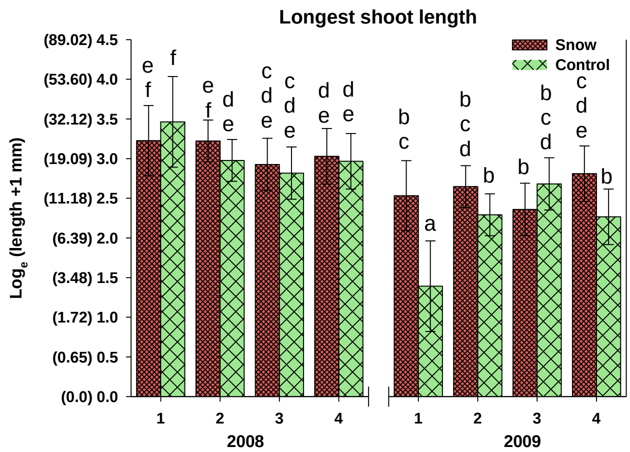

Figure 4.5 *Salix myrsinites* REML-estimated mean longest shoots in 2008 and 2009 across altitude and snow treatment. Growth is presented as the natural logarithm (x+1 mm) (back-transformed values in brackets on the Y-axis), with 95 % confidence intervals. Altitude classes: 1 = lowest, 4 = highest. Columns sharing the same letter are not significantly different at *P* < 0.05.

Altitude had a significant effect on canopy area, both over annual and two year, proportional increments. In both cases the shortest increments were at altitude class 3 (*P*<0.05, Table 4.9).

There was a significant response to the altitude-year interaction across annual growth for all three new growth parameters. In 2008 leader lengths and longest shoot lengths at altitude class 1were significantly longer than at altitude class 4, while in 2009 altitude class 1 was always significantly shorter than at other classes in all three parameters, (*P*<0.05, Fig. 4.6).

Table 4.9 *Salix myrsinites* canopy area back-transformed proportional increments for one or two years across altitude classes (1 is low, 4 is high). For each increment columns with the same letter are not significantly different at *P*<0.05. Least significant differences (L.S.D.) are for logarithms.

	Altitude class				L.S.D. for
	1	2	3	4	Log values
Annual increment	6.5 b	7.2 b	4.5 a	5.6 a,b	0.3
Two year increment	18.2 b	20.9 b	6.0 a	11.5 b	0.6

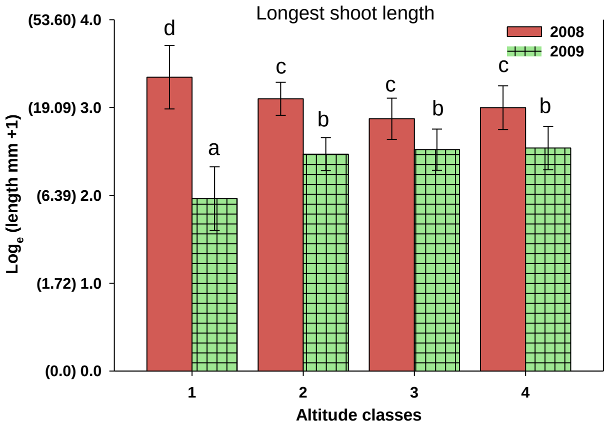

Figure 4.6 *Salix myrsinites* REML-estimated mean longest shoots for 2008 and 2009 across altitude classes. Growth is expressed as natural logarithm with 95% confidence intervals. Back–transformed values are in brackets on the Y-axis. Altitude classes: 1 = lowest, 4 = highest (see table 4.1 for detail). Columns sharing the same letter are not significantly different at *P*<0.05.

Juniperus communis

The most consistent response from *J. communis* arising from the REML analysis of annual growth over two years was the greater growth in 2008 than in 2009 (Table 4.7 & 4.8) which, similar to *S. myrsinites*, was apparent in both proportional increments for dimensional parameters and in all new growth parameters. In the analysis of 2009 growth across *J. communis* planted in 2007 and that planted in 2008, the latter plants showed significantly larger growth increments in vertical height, basal diameters and in total new growth (*P*<0.05, Table 4.10).

Table 4.10 Effect of planting year on different *J. communis* growth parameters in 2009. Figures are back-transformed REML generated means. Least significant differences (L.S.D.) are for logarithm values. Columns with the same letter are not significantly different at *P*<0.05.

	Planting year		**L.S.D for**
	2007	**2008**	**Log$_e$ values**
Vertical height proportional growth	0.92 a	1.11 b	0.15
Basal Diameter proportional growth	0.83 a	1.19 b	0.11
Total New Growth (mm)	37.30 a	141.17 b	0.39

J. communis suffered high levels of mortality which were relatively evenly spread across the different altitudes, but showed a strong trend of less mortality in snow compared to control cages (*P*=0.05). This suggested positive effect of snow was weakly supported by some REML results. Two year increments for longest canopy diameter and canopy area proportional increments were significantly larger in snow cages than controls (back-transformed proportional increments were 3.2 and 5.4 in snow cages, compared to 2.8 and 4.1 in controls, respectively, L.S.D. for logarithm values are 0.15 and 0.27, *P*<0.05). In the annual growth over two years longest shoots tended to be longer in snow cages than controls (*P*=0.052). In contrast 2009 growth across planting years (2007 and 2008) and snow treatments showed no difference between snow and control cages in 2007 plant leader lengths, while 2008 control cage plants had longer leaders than snow cage plants (back-transformed lengths 2.4 mm and 1.8 mm, respectively, L.S.D. for logarithms 0.14, *P*<0.05). Leader lengths in snow cages were significantly longer on 2007 plants than on those planted in 2008 (back-transformed mean is 2.3 mm, compared to 1.8 mm, L.S.D. for logarithms is 0.14, *P*<0.05).

Altitude had a relatively weak, inconsistent effect. The two year basal diameter proportional increments showed a non-significant trend of shorter increments at altitude class 3 than at class 2 or 4. In the interaction with snow canopy area proportional increments showed a strong (non-significant) trend of larger growth in snow cages than controls at both altitude class 2 and 3. Similarly leader lengths tended to be longer in snow cages, than controls, at altitude class 3 and 4. In the annual increments over two years the vertical height proportional increments in 2008 were only significantly longer than 2009 at altitude class 2 (*P*<0.05), and there was no altitude effect in 2008. In 2009, altitude class 2 increments were the shortest but class 1 increments were significantly longer than either class 2 or 4 (*P*<0.05, Fig. 4.7). Total new growth was significantly shorter in 2009 at altitude class 4 than growth in 2008 at altitude class 1(back-transformed values 15 mm and 8 mm respectively, L.S.D. for logarithms 0.52, *P*<0.05), otherwise there were no differences. In the analysis of 2009 growth juniper planted in 2008 had generally larger growth increments, than those planted in 2007, but the total new growth means in the control cage at the highest altitude were significantly shorter than all others in the 2008 plants (*P*<0.05) and similar to growth in 2007 plants at all altitudes (Fig. 4.8).

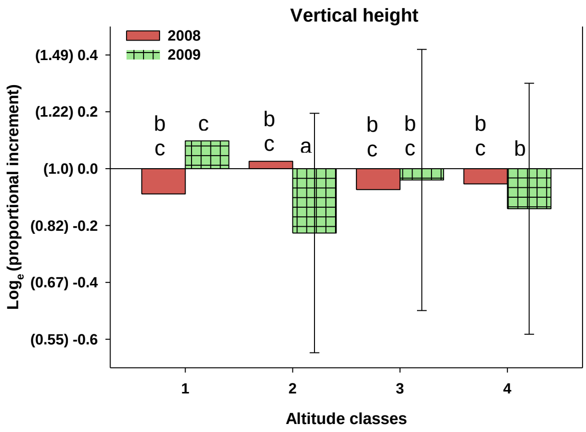

Figure 4.7 *Juniperus. communis* REML-estimated mean vertical height proportional increments for 2008 and 2009 across altitude classes. Growth is presented as natural logarithms with back-transformed values in brackets. Altitude classes: 1 is low and 4 is high. Columns sharing the same letter are not significantly different at *P* < 0.05.

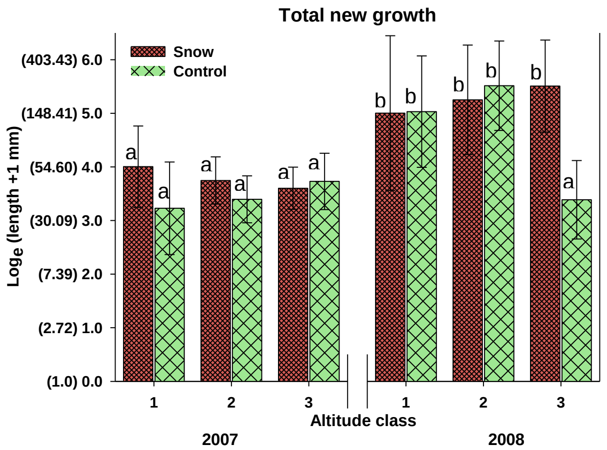

Figure 4.8 *Juniperus communis* REML-estimated 2009 total new growth means for different planting years (2007 & 2008), altitude classes and snow treatment. Growth is presented as the natural logarithm of new growth +1 mm (back-transformed values in brackets on the Y-axis), with 95 % confidence intervals. Altitude classes: 1 is low, 3 is high. Columns sharing the same letter are not significantly different at *P* < 0.05.

4.4 DISCUSSION

4.4.1 Growth responses

The effects of snow, as supported by the literature (Wipf *et al*. 2010, Odland & Munkejord 2008, Wahren *et al.* 2005) were complex for all of the three species studied and interacted with other factors in different ways, as described below. For *S. myrsinites* and *J. communis* there was a strong between-year effect apparent from the analysis of annual increments. Between the two years the snow depths were similar in the majority of cages, although maximum depths were greater in 2007/08 at site 2 and 3, in altitude class 2. It was not possible to compare the cage temperatures between the two years due to the failure of the temperature loggers, but generally the between-year weather differences do not appear to be sufficient to explain the growth differences. It is possible that in 2008 there was residual fertilizer around the roots of the plants which will have been exhausted by 2009. Linked to that it is possible that the acid nature of the sitewas beginning to effect growth in 2009, particularly on the willow. There was some suggestion that the reduced growth in 2009 was more responsive to treatments which might support the theory that the greater growth in 2008 resulted from residual fertiliser in the growing medium around the young plants.

Betula nana

Overall *Betula nana* dimensions showed a relatively neutral response to winter snow cover in the first year. In the second year there was some suggestion that a positive response to snow cover may be coupled to altitude, but none of the responses were significant. Actual new growth was generally longer in the second year and there was some evidence that the longest growth was at lower altitudes, independent of snow cover. Generally, from these results, young *B. nana* would appear to be relatively tolerant of snow cover and of relatively exposed conditions. There were very few fatalities, approximately 10%, and at the end of the experiment the plants remained healthy. Evidence from literature suggests that mature *B. nana* is tolerant of snow (Sturm *et al.* 2001). The suggestion from Odland and Munkejord (2008) that *B. nana* tended to avoid snow cover in the southern Norwegian mountains primarily related to areas with late snowmelt dates, rather than snow cover more generally. The results from this experiment tend to complement the reported tolerance by mature *B. nana* of a range of snow depths by Wahren *et al.* (2005). The suggested tolerance of higher altitude shown would concur with the reports from Kallio and Mäkinen (1978) of the presence of *B. nana* on exposed mountain ridges. These factors complement the findings of chapter three on the response of *B. nana* to exposure and support questions about the perceived habitat preferences of this plant in the UK, which are discussed in further detail in chapter six.

Salix myrsinites

Generally *Salix myrsinites* showed a positive growth response to winter snow cover. Although not consistent across all parameters it was evident in both the annual and two year increment analyses. The effect of altitude was inconsistent with both poor and good growth recorded at altitude classes 3 and 1, and positive effects in 2008 becoming significantly negative in 2009. The range of pH's (3.14 – 3.85, Appendix 4.1) at the site are at the lower end of those tolerated by *S. myrsinites*, and the minimum was found at site 1 (altitude class 1), with site 4 (altitude class 3) also below pH 3.2. In the survey reported in Chapter 2 the pH values ranged from a minimum of 3.85 upwards. However, the loss of plants over the two years of the experiment was low, and there was greater variation in growth in control cages across the altitude classes in the second year compared to the snow cages. This would support the hypothesis that snow did provide protection and generally insulated the plants from the less hospitable winter weather at higher altitude but the results were not significant. Only very limited literature was found relating specifically to *S. myrsinites* and nothing regarding the growth response of young willows to snow cover. Generally, in arctic habitats, *Salix* species appear to respond positively to snow cover and there is now growing evidence of a deciduous shrub expansion-snow cover distribution feedback loop (Myers-Smith, 2007). However this is in a region where winter temperatures are generally lower than in the UK and the processes may be different.

Juniperus communis

Across several growth parameters, both dimensional and new growth, snow benefited *J. communis* plants compared with controls through reduced mortality and enhanced growth. Altitude did not have a clear effect on this result. In the second year there was no clear evidence of a snow effect or altitude effect on annual growth. Planting year had a large effect on the 2009 data analysis indicating that the high number of mortality-replacements may have masked any annual treatment effects. There is little information available on the production and establishment of young plants from cuttings (Sullivan 2001) but Ward (1982) suggests that, like spruce, *J. communis* has a fixed growth pattern which may be determined during early life by environmental factors which set the growth rate. The plants with slower growth rates may achieve greater age and tend to occur in less hospitable situations. The consequence of this is that cuttings taken from mature plants of this nature may produce physiologically old plants which struggle to establish. This may be a factor in the high levels of mortality in the cuttings, and in the subsequent slow growth. In long term studies of the response of arctic plants to increased snow cover with delayed snowmelt (Wahren *et al.* 2005, Sturm *et al.* 2001) evergreen shrubs tended to give way to graminoids and deciduous tall-shrubs. However *Juniperus communis* is sub-arctic and was not one of the species studied so it is not known whether it would respond in the same way. The results from the browsing-exposure experiment reported in Chapter 3 suggested that *J. communis* may not share the same pre-formed growth traits with other conifers (Hester *et al* 2004) and it may have the capacity to respond more flexibly to damage. This would require further study to confirm. *J. communis* grows up to high altitudes in the UK (over 900 m asl, MacKenzie 2000) and there is evidence that at higher altitudes the growth form tends to be more prostrate (Thomas *et al.* 2007). This could be in response to either or both snow cover and greater exposure. The results for this experiment showed that leader lengths at the higher altitude classes were short but the values for total new growth were similar across all altitude classes. This suggests that the plants may have been developing a more prostrate growth form.

4.4.2 Conclusions

In conclusion, there is no clear evidence from this experiment that the loss of snow in the future in Scotland will adversely affect the growth of young *Betula nana*, *Salix myrsinites* or *Juniperus communis*, although it may restrict the altitude and levels of exposure at which *J. communis* is likely to establish successfully. The possible wider implications of this are discussed in chapter six.

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APPENDIX 4.1 CAGE HABITAT ASSESSMENT

Below are tables providing the results of habitat assessments of each cage location at Cairngorm Mountain. The cage survey forms are given in Appendix 3.2, Fig. A3.2, on page 126.

Table A4.1 Species and values for pH and available nutrients extracted from soil samples recorded at each experimental cage sites as part of habitat assessment.

Site	1		2		3		4		5		6		7		8			
spp code	snow	control	snow	control	snow	control	snow	control	snow	control	snow	control	snow	control	snow	control	mean % and range	Constancy across site
Call vulg	55	55	25	85		85									2	25	47 (2-85)	III
Empe nigr	15	3	5	2	5		20	40	10	30	3	20	2	35	5	7	13 (2-40)	IV
Vacc myrt	15	2	3	2	15	4	7	5	7	2	7	2	7	5	2	4	5 (2-15)	V
Vacc ulig	7		7		7	7	45	20	40	45	10	40	3	30	40		23 (3 -45)	IV
Nard stri			25		30				30	30	60		50	2	25		31 (2-60)	III
Trich cesp		15	20		20				2	2					15	3	11 (2-20)	III
Desc flex	5		2		3		2	15	7	7		4	10	5		2	6 (2-15)	IV
Junc trif								7	2		2	6	1	3		4	4 (1-7)	III
Care bige			1			5	30	8	5	15	3	10	15	7		10	10 (1-30)	IV
Hylo sple	5	3	1			20		60	4	2				15	10		13 (1-60)	III
Raco lanu		3					30			10		7	3	20	20	1	12 (3-30)	III
Clad arbu		1		5				1		1		3		2	1	1	2 (1-5)	III
Clad rang	2	5	1									2					2 (1-5)	II
Clad unci	1	1	1	3				1		3		2		5	1	1	2 (1-5)	III
Cetr isla			7	2						2		2	2	1	3		3 (1-7)	II
Alch alpi								25					5				15 (5-25)	I
Aula palu		1					1				1						1	II
Gali saxa	1				3				3		1		2		2		2 (1-3)	II
Diph alpi											1	5				2	3 (1-5)	II
Hupe sela			2						1	2		1		1		1	1 (1-2)	I
Dicr scop	2														0.5		1 (0.5 - 1)	I
Dicr sp					5	1			4		3						3(1-5)	II
Liverwort	0.5								20	1	1						6 (0.5-20)	II
Pleu schr	5	2						5	2		1		5		7		4 (1-7)	III
Poly comm					4				2	1	1		5		1		2 (1-5)	II
Rhyt squa	1				2					1	1				1		1 (1-2)	II
Corn suec	5																5	I
Lois proc																3	3	I
Eric tetr		2															2	I
Sali herb								2					2				2	I
Vacc viti	5					2		2									3 (2-5)	II
Rubu cham	2	1															1.5	I
Mela prat					2					1							1.5	I
Nart ossi		2	6												10		6 (2-10)	II
Gnap supi													2				2	I
Pote erec					5										5		5	I
Anth odor														1			1	I
Fest vivi								5					10				7 (5-10)	I
Junc squa		10															10	I
Care bine				2													2	I
Care pilu																2	2	I
Care vag											2						2	I
Erio angu		5															5	I
Blec spic	1																1	I
Lyco annot	2		1														1.5	I
Pseu puru	2				1												1.5	I
Ptil cili	2		2														2	I
Plag undu	2					0.5											1.25	I
Rhyt lore						20			1		1						7 (1-20)	II
Spha cap1.					30												30	I
Spha spp.			3														3	I
pH $CaCl_2$	3.14	3.14	3.32	3.24	3.40	3.29	3.19	3.85	3.37	3.31	3.37	3.55	3.80	3.34	3.39	3.63		
Ca mg/kg	686.25	499.45	119.46	214.53	87.06	301.59	441.10	376.65	644.50	479.22	175.61	76.27	75.99	207.16	188.51	165.72		
K mg/kg	348.55	588.92	140.23	162.18	118.43	174.73	246.86	194.42	351.57	234.80	173.01	74.83	79.08	138.95	130.27	75.15		
Mg mg/kg	727.62	620.19	86.25	119.06	71.44	217.33	325.30	196.07	488.16	213.37	121.13	50.83	42.18	120.19	98.35	58.37		
P mg/kg	89.88	92.46	20.32	21.60	9.44	31.34	56.57	41.89	52.85	68.82	15.07	18.64	6.01	24.31	14.35	8.24		

Key to constancy values in right hand column

v = 15 - 16 cages
IV = 11 - 14
III = 7-10
II = 3-6
I = 1-2

Table A4.2 Site characteristic recorded at each experimental cage site as part of the cage habitat assessment.

13th to 20th July 2009		Aspect deg N	Altitude m asl	Slope deg	field heights (cm) 1	2	3	4	Inflorescent heights (cm) 1	2	3	4	Litter depth (cm) 1	2	3	4	Moss (cm) 1	2	3	4	Soil depth (cm) 1	2	3	4	Hebivore impacts Hares	Deer	Reindeer	Voles
1	snow	270	744	21	28	27	48	46	28	27	48	46	0.5	2	2	1	2	7	4	3	21	15	24	29	L	L	L	no dung
	control	240	740	12	28	26	33	36	28	26	33	36	5	2	2	4	6	5	4	7	24	16	27	38	L	L	L	no dung
2	snow	30	859	12	17	16	18	15	17	16	18	15	0.5	0.5	0.5	2	0.5	0.5	1	1	26	22	12	14	L	L	L	no dung
	control	356	859	16	15	10	9	7	15	10	9	7	1	1	1	1	2	2	0	0	10	8	9	11	L	L	L	no dung
3	snow	20	876	16	7	8	10	10	16	20	16	23	0.5	0	0	4	3	3	3	4	50	50	39	22	L	L	L	no dung
	control	20	873	15	22	15	14	12	22	15	14	12	2	2	2	2	4	7	8	4	10	11	5	23	L	L	L	no dung
4	snow	246	979	11	6	6	13	6	6	6	13	6	0.5	0.5	0.5	0.5	2	3	2	3	8	11	8	6	L	L	L	no dung
	control	240	970	11	8	7	15	9	26	28	26	24	0.5	1	0.5	0.5	2	3	3	3	8	7	14	15	L	L	L	no dung
5	snow	50	975	14	11	9	14	11	0	15	23	20	1	1	3	2	4	4	7	4	7	13	17	9	L	L	L	no dung
	control	46	970	13	5	3	7	4	0	0	14	0	0.5	0.5	0.5	0.5	4	1	3	0.5	3	9	25	7	L	L	L	no dung
6	snow	284	1027	16	14	10	7	17	0	0	20	1	2	2	2	0.5	1	5	4	5	24	15	16	4	L	L	L	no dung
	control	270	1022	15	8	5	5	4	11	25	3	12	0.5	0.5	1	0.5	1.5	4	2	2	15	19	29	22	L	L	L	no dung
7	snow	276	1027	22	14	9	15	12	0	0	15	0	1	1	4	5	6	0	5	0	12	18	3	4	L	L	L	no dung
	control	280	1015	15	5	5	10	11	0	0	0	0	0.5	0.5	2	0	2	2	5	4	3	10	12	10	L	L	L	no dung
8	snow	300	911	19	10	8	10	8	16	15	0	23	0.5	0.5	0	1	2	2	1	2	5	9	24	2	L	L	L	no dung
	control	300	912	15	2	4	2	5	0	10	0	0	0.5	0	0.5	0	0.5	0	0.5	0.5	17	14	15	2	L	L	L	no dung

Chapter five: UPLAND LAND USE POLICY AND TREELINE ECOTONE SCRUB

5.1 INTRODUCTION

Land use and rural policy, alongside biological and physical factors and management actions, have key influences on the distribution and condition of semi-natural vegetation, in particular in highly mechanised and densely populated areas. This chapter reports on an investigation into the inclusion of treeline ecotone scrub (treeline scrub) in Scottish land use policy and rural policy, and the likelihood that current policy and its implementation may provide for the stewardship of treeline scrub in the future. The investigation followed two strands, a review of policies which affect the way land is managed in Scotland, and a qualitative investigation into how those involved in shaping and implementing Scottish policy view treeline scrub and its future.

Treeline scrub in the UK occurs in the uplands, which is defined as the area of land from above the limit of enclosed farmland up to mountain summits (Ratcliffe 1989) and which, in policy terms, overlaps with marginal land given Less Favoured Area (LFA) status under European Union (EU) legislation (EU Agriculture and Rural Development 2009). This chapter focuses on policies specific to the uplands and those with a more general spread that include the uplands, collectively referred to in this thesis as ‘rural policy’.

5.1.1 Background

Land use in Scotland

In upland areas of Scotland there are three main land uses: agriculture (70-80%) primarily through privately owned enterprises; forestry (17%, FCS 2009) which is divided almost equally between private and state owned land; and privately owned hunting estates (approximately 20%, Bill Slee *pers com*.). Detailed statistics on the relative share of these sectors are not available and these divisions are not exclusive. For example there is often overlap, particularly between agriculture and hunting interests where the agricultural use is tenanted while the estate owner retains the sporting rights. In addition, non-governmental organisations and community groups form a growing land ownership sector, and their land use does not necessarily fit into these conventional sectoral categorisations.

Land use policy since the mid 20th Century

This section outlines a brief history of the development of land use policy in order to set the context for the current policy. Land use policies provide the framework within which support has been provided to those owning and occupying land, and so have been primary drivers for land management. Mowle and Bell (1989) usefully summarised the evolution of these drivers in relation to upland rural policies from the end of World War two to the late 1980s for a conference discussing ecological change in the uplands in 1988. Essentially they demonstrated how, before and after accession to the European Economic Community (EEC), the agricultural policy aim to increase production and improve the viability of agricultural units effected an ongoing reduction in marginal, semi-natural areas. From the end of the 1960's, growing surpluses, increasing financial difficulties and growing environmental concerns at a European level started the evolution away from production subsidies and towards business support. A key aspect for ecological interests was that this evolution effectively ended support for conversion of semi-natural habitats into agricultural land. No similar review of the impacts of agricultural policy specifically relating to the uplands for the last twenty years was found. Changes in European and national policy have continued to take increasing account of environmental concerns through the emphasis in incentive schemes. One exception has been in the north and west of Scotland where most agricultural land has LFA status, is upland and under crofting tenure. Croft land has had its own policies running in parallel to those at the national level, and land conversion was supported into the twenty-first century. Crofting policy was finally brought into alignment with national policy through the recent Scottish Rural Development Programme (SRDP) (Scottish Government 2010a). The SRDP is Scotland's interpretation of the European level Rural Development Policy 2007 – 2013 (EC Agriculture and Rural Development 2008) which arose from the most recent revision of the Common Agricultural Policy (CAP, EC Agriculture and Rural Development, no date). This most recent development represents the biggest step to date away from production subsidies to more holistic support for rural businesses, encompassing measures for natural heritage as well as forestry and agriculture. Already there have been comments, followed by modifications in the incentives, about the negative effects of this policy for natural heritage following the dramatic reduction in sheep numbers, or complete removal, on some hill ground (SAC, no date). Holland *et al.* (no date) reviewed existing literature on the consequences of stock removal from hill ground and recognise there will be winners, most notably treeline scrub and tall herbs, and losers, primarily less common grassland species. They acknowledge that deer, both red (*Cervus elaphus*) and roe (*Capraeolus capraeolus*), may move into areas previously occupied by sheep, but seem to discount the possibility that red deer would use these more productive montane grassland swards and maintain the presence of less common herbs. Averis *et al.* (2004) described some more productive montane grasslands in areas which are only grazed by red deer. The situation is far from simple, and ultimately seems to engender a philosophical debate about the maintenance of anthropogenic grasslands versus reversion towards more climax heath (with an increase in *Calluna vulgaris* cover) (Averis *et al.* 2004).

In parallel with agricultural reforms, forestry policy had sought to develop a strategic timber reserve for the UK through the establishment of plantations, and had often been in competition with agriculture for land, particularly in the uplands (Mowle and Bell 1989). McMorran (2008) comprehensively reviewed the course of forestry policy, particularly in terms of how it relates to upland areas, although not specifically including the treeline ecotone. The following brief policy history highlights the particular aspects which are pertinent to this thesis. Forestry is a reserved matter for Member States within the European Community, and the UK introduction of tax incentives for afforestation in the 1980s stimulated the expansion of plantations onto upland agricultural land with the sanction of the national agricultural authority, the Department of Agriculture and Fisheries Scotland (DAFS, Hansard 1987). Throughout much of the twentieth century, the Forestry Commission's remit was focussed on timber production using whichever species were likely to deliver a resource quickly. Generally, and particularly in Scotland, this meant the use of north American species of conifers planted using techniques which mirrored agricultural crop production.

1988 saw the end of the tax incentive for planting trees, and forestry policy went through a number of major modifications in which existing native woodland gained increasing importance. Incentives were introduced specifically to encourage the positive management of native woodland as a natural heritage resource, including the recognition of "scrub" as a legitimate component of newly planted native woodland. By this time, it was estimated that native woodland occupied no more than 2% of the Scottish land mass (MacKenzie 1999), compared with an overall forest cover (including plantations) of 16%. At the beginning of the twenty-first century the Forestry Commission accepted responsibility for the future of native woodland within the Scottish Forestry Strategy (Anon 2000). The vision for the second half of the twenty-first century in the current Scottish Forestry Strategy (Anon 2006) includes overall forest cover of 25%, 35% of which will be native and extend into the treeline ecotone.

National policy has not tended to be concerned with the management of land reserved for hunting where the primary business activity is recreational shooting of either red deer or red grouse (*Lagopus lagopus*). Following significant red deer population increases over the twentieth century (Callander and MacKenzie 1991, Staines and Balharry, 2002), there has been growing policy involvement in the control of deer populations (see below) particularly with regard to how deer affect land use interests outside hunting estates.

At a local level, but highly relevant, heather burning, as part of grouse-moor management, or grass (*Molinia*) burning in the west to improve pasture, has been preacticed on both agricultural and hunting estate ground. The extensive and in many cases excessive use of this tool led to legislation and codes of practice in the 1980's (Anon 1981, revised in 2008) which have led to a greater care with regard to ground nesting birds and the condition of *Calluna vulgaris* swards. However, muirburn has a continuing direct impact on treeline scrub in some areas and the impact of fire on *Betula nana* was specifically mentioned in the supplement to the Muirburn code (Anon 2001).

Natural heritage policy

Throughout the twentieth century, concerns were raised about the impact of sectoral land use policies on semi-natural vegetation and certain animal and plant species. The first sign of moderation in the production drive was the introduction of a duty for "reasonable balance" into both agricultural and forestry legislation through the Wildlife and Countryside (Amendment) Act 1985 (JNCC 2010a). This was subsequently strengthened through the Nature Conservation (Scotland) Act 2004 which placed a duty on all public bodies to further the conservation of biodiversity generally, but with particular regard to the Scottish Biodiversity Strategy (Scottish Executive 2004) and the UN Convention on Biological Diversity signed in 1992 (CBD, no date).

Natural heritage policy includes any measure relating to the management or control of any feature of native UK fauna or flora, and geology or geomorphology, although aspects specifically relating to animals and earth sciences are not considered in this thesis. The initial focus of policy in the twentieth century was the identification and designation of sites of particular interest, and the establishment of bodies to undertake the work. The National Parks and Access to the Countryside Act 1949, the Nature Conservancy Council Act 1973, and the Wildlife and Countryside Act 1981 were the principal legislative measures (Anon, 1984). Following accession to the EEC and growing pressure for greater consideration of environmental issues in the second half of the century, the focus of UK natural heritage policy began to change through increasingly systematic description and assessment of plant communities (Rodwell 2006, EC DG Environment 2007), and increasing protection for, and regulation of, the use of natural heritage features (EC Habitats Directive from 1992, JNCC 2010b, and the associated Natura 2000 network, Eurosite 2007). The focus of protection was increasingly directed to particular species and habitats through the designation of key areas for each or both. At a European Commission (EC) level, priority species and habitats were collated from Member State lists into the Habitats Directive Annexes (EC DG Environment 2007). At a UK level, the European lists were supplemented by habitats and species of particular national importance (for vascular plants see Cheffings & Farrell 2005), and in Scotland a similar process resulted in the Scottish Biodiversity Strategy (Scottish Executive 2004) and subsequently the Scottish Biodiversity List (Scottish Biodiversity Forum 2004). The Conservation (Natural Habitats &c.) Regulations 1994, (Legislation.gov.uk, no date a) and subsequent update, Habitats and Species Regulation (JNCC 2010c), outlined the UK's commitment to implement the EC's Habitats Directive (JNCC 2010b). It acknowledged the global CBD (2009) and European-level intention to see responsibility for environmental stewardship spread through all public bodies by introducing a duty of care on any "Minister, Government Department, public body or individual holding public office" in relation to how their activities might affect the conservation of European designated sites (JNCC 2010c). The Nature Conservation (Scotland) Act 2004 (legislation.co.uk, no date b) subsequently extended these obligations to biodiversity more widely, particularly those elements included in the Scottish Biodiversity List (Scottish Biodiversity Forum 2004). The strategic activities of public land-use and planning organisations now encompass commitment to these duties (legislation.co.uk, no date b).

The UK Designated Site Network

Within the UK there is a network of sites which were selected on the basis of their uniqueness in UK terms either because they were typical of a more widely spread habitat; the species present were rare, or the presence of a particular assemblage of species (JNCC 1998). Sites are either of regional, national or international importance. Designated sites which contribute to the European Commission's Natura 2000 network (Eurosite 2007) and are of continental importance attract significantly greater protection than nationally important sites (either National Nature Reserves (NNR) or Sites (or Areas, in Northern Ireland) of Special(or Area of) Scientific Interest (S (or A) SSI)), and carry greater obligations for the UK to avoid their degradation. For example Special Areas of Conservation (SACs) for plants and habitats.

The UK Biodiversity Action Planning Process

The UK Biodiversity Strategy was initiated as part of the UK response to the EU Habitats Directive and established national and local level biodiversity action plans (BAPs). At the national level, species (SAP) and habitat (HAP) action plans were generated for the priorities from the lists mentioned above and attract some support and resources at a national-level. The plans include targets relating to monitoring, survey or restoration of populations or habitats. Local-level plans are focussed on species, habitats or environmental projects of local concern and are delivered through a combination of local agency and volunteer activity with local funding. A fundamental review of the UK national SAPs and HAPs was undertaken in 2006 (Maddock 2007, 2008) and has resulted in greater coordination of species and habitat plans from similar localities. At the time of writing this process is ongoing in Scotland.

Other relevant policy

Most recently climate change policy (Scottish Government 2009) has stimulated the development of renewable energy projects. This provides both a potential opportunity and a cause for concern for the future of treeline scrub. For example, there have been wind farm developments in areas where *Betula nana* scrub is present and where its better management might be facilitated with appropriate liaison. There is also potential for overlap between areas supporting *B. nana* and those chosen for water storage in relation to large hydro-electricity schemes. This latter scenario might contribute to a decline in its UK distribution. The Forestry Commission Scotland has developed a strategy (FCS 2009) in response to the Scottish Climate Change Act 2009, which promotes the expansion of woodland for carbon sequestration and treeline scrub could make a contribution to these goals.

5.1.2 Treeline scrub and natural heritage policy

Table 1.1 in chapter one identified the habitats in which treeline scrub species are found. The plants are spread across a number of different vegetation types with no collective identity. As a result, the component vegetation types making up treeline scrub do not feature as a specific group of plant communities (in the same way as mires, or woodlands), in either European or UK environmental or biodiversity policy. Mountain Heaths and Willow Scrub was a new habitat accepted into the revised UK priority list (Maddock 2008) following a review of the UK Biodiversity Action Plan in 2006 (UKBP 2010). At the time of writing, the targeted actions for the plan have not been determined. The willow scrub referred to in it is the treeline ecotone European community sub-arctic *Salix* scrub (H4080, Annex 1 EC DG Environment 2007) which includes *Salix lapponum - Luzula sylvatica* scrub, W20 (NVC, Rodwell 1991a). *Juniperus communis* ssp *nana* is included in the *Calluna vulgaris – J. c.* spp. *nana* heath H15 (NVC, Rodwell 1991b) but upright juniper *Juniperus communis* ssp *communis* is not and nor is *Betula nana*. These latter species are included in the Upland heath and Blanket mire HAP descriptions, respectively (Maddock 2008). *J. communis* L. and *S. lanata* L., two treeline ecotone tall-shrub species, were included in the original UK Biodiversity Action Plan species list (UKBP 2010). *S. myrsinites* L. and *S. lapponum* L. were added to the priority list during the recent review (Maddock 2007), although species action plans have not been developed. As part of this process, specific responsibility for different species and habitat plans has been adopted by different public bodies or non-government organisations (NGOs). The species and habitats with plans are now grouped under ecosystem types and action will be coordinated through these. The Forestry Commission is the lead for the native woodland ecosystem, and has now interpreted this as encompassing treeline woodland (see Chap 1 Introduction for definition) although there are no treeline-specific actions identified in their biodiversity plan (FCS 2008).

5.1.3 Research need

All the tall-shrub species making up treeline scrub are uncommon in the UK and some are declining according to the most recent UK plant atlas (Preston *et al.* 2002). As stated above, there is no specifically defined main habitat or vegetation type that encompasses all the treeline ecotone plant communities. Despite this there has been growing attention from the UK Biodiversity Action Planning process (JNCC 2010d), as outlined above, and many elements of treeline scrub are now included in either broad habitat types or have a species action plan (see Table 5.1). To date, direct action through this process related to treeline scrub has been focused on *Salix lanata*, through Scottish Natural Heritage "Species Action Framework" (Anon 2007) and *Juniperus communis* through Forestry Commission's "Action for Juniper" (Anon 2009).

Incentives for management of land, for agriculture, forestry, nature conservation or other rural business development, are now channelled through the Scottish Rural Development Plan 2007 – 2013 (SRDP, Scottish Government (SG) 2010a). The Rural Priorities or options (SG 2010b) in the plan are tailored to each region through local interpretation of the EC regulation's (EC1698/2005) "three key themes on support for rural development" which are:

Table 5.1 Key treeline scrub species and their status within the UK BAP process (Mattock 2008). New conservation targets and actions are currently being written for all plans and are not available. (UK BP 2010)

Species	Species Action Plan	Scottish Biodiversity List	UK Vascular Plant Red data book	Habitat Action Plan
Betula nana				Indirect: through Blanket bog HAP
Salix arbuscula				
Salix lanata	x	x	x	
Salix lapponum		x	x	Direct: Mountain Heaths and Willow Scrub HAP
Salix myrsinites			x	
Salix phylicifolia				
Salix reticulata				
Juniperus communis ssp *nana*	x	x	x	Direct: Mountain Heaths and Willow Scrub HAP
Juniperus communis ssp *communis*	x	x	x	Indirect: through Upland heath HAP

Axis 1- Improving the competitiveness of the agricultural and forestry sector; Axis 2 - Improving the environment and the countryside; and Axis 3 - Improving the quality of life in rural areas and diversification of the rural economy. Regional priorities are set by cross-sectoral panels, the Regional Proposal Assessment Committees (RPACs) representing agricultural, forestry, nature conservation and economic development interests. The environmental focus for each region is based on the locally important habitats and species from the Scottish Biodiversity List created in 2004 (Scottish Biodiversity Forum 2004).

In order to understand whether or not positive management of treeline scrub is likely to occur in practice, it is necessary to understand the context for its inclusion in current policy and implementation plans. Proving that treeline scrub in included is policy would not in itself guarantee its future. It is necessary to understand how those involved in creating, implementing and influencing policy view these habitats and promote or support their management.

Table 5.2 List of known current projects or management initiatives for treeline scrub across Scotland.

Site	Owner / manager	Plant communities	Main action
Ben Lawers NNR	National Trust for Scotland[1]	Sub-arctic willow scrub, Juniper scrub, Treeline woodland	Existing and new
Carrifran Wildwood	Borders Forest Trust[2]	Sub-arctic willow scrub, Juniper scrub, Treeline woodland	new
Clunes and Glengarry Mountains	Forestry Commission Scotland	Sub-arctic Willow scrub, *Betula nana* scrub,	Existing
Corrie Sharroch	Scottish Natural Heritage	Sub-arctic willow scrub	Existing and new
Dundreggan	Trees for Life[3]	*Betula nana* scrub	Existing and new
Grey Mare's Tail	National Trust for Scotland	Sub-arctic willow scrub	Existing
The Merrick	Forestry Commission Scotland	Sub-arctic willow scrub, Juniper scrub	Existing and new
Scotland-wide, Action for Mountain Woodlands	Highland Birchwoods[4] (HLF funded)	Sub-arctic willow scrub, Juniper scrub, *Betula nana* scrub, Treeline woodland	Existing and new

[1] Mardon (2004), [2] Ashmole and Ashmole (2009), [3] Trees for Life (2010), [4] Action for Mountain Woodlands (2010)

At the time of writing, there have been a number of projects which include land management activity to benefit treeline scrub. Table 5.2 lists them with the main plant communities targeted and indicates whether the management is focused on existing populations or the establishment of new ones. The Heritage Lottery Funded (HLF) project, Action for Mountain Woodlands (2010) promoted the habitats, in particular the management of treeline scrub, on six sites across Scotland. Although the general public was the primary focus for the project land managers and their advisers were specifically targeted with management-orientated events. A feature of the projects listed in table 5.2 is that they are either owned or managed by public bodies or environmental charities.

The conclusion from the above review suggests that the place of treeline scrub in current policy is confused and the safeguard of its future is haphazard and only secure in limited cases. As a result, this study aimed to clarify the situation through investigating the following hypotheses:

- Treeline scrub is largely invisible, but not excluded from national-level policy and legislation.
- Awareness of treeline scrub will vary across sectoral interests from low in agriculture to high in nature conservation sectors.
- Specific management projects for treeline scrub will continue to be uncommon under the current policy provisions.

Assessment of the key rural policies as they are interpreted and implemented in Scotland, with reference to original Global, EU or UK policies where appropriate was undertaken to clarify how treeline scrub currently fits within policy. A complementary qualitative interview-based investigation across three key groups of people involved in Scottish rural policy development and delivery was carried out. These two exercises were devised to address the following research questions:

- How is treeline scrub conceptualised by policy creators, implementers and influencers?
- How does treeline scrub feature in Scottish biodiversity, rural and land use policy?
- Could restoration activity happen within the current policy implementation strategies?
- What type of scheme is likely to deliver the broadest policy objectives?

The objective of the qualitative study was to ascertain the range of views and attitudes to treeline scrub in the different sectors and policy engagement groups, in order to better understand how policy in this field is delivered and the likely outcomes of that delivery. As there was no intention or need for the results of this work to be extrapolated or transferred in any way to a wider group, a qualitative assessment was considered the most appropriate method to gather the information sought (Ritchie and Lewis 2003).

5.2 METHODS

5.2.1 Collection of data

Rural policy desk review

Milne *et al*. (2007) compiled and reviewed key policy documents relating to upland biodiversity up until 2006. Appendix 5.1 was collated from documents covered in this review and subsequently supplemented by newer or additional ones. The focus of the review by Milne *et al.* (2007) was to relate policy to the delivery of biodiversity in the uplands. The review was scanned for mention of treeline scrub or any component plant communities, or a suggestion that a source document might contain details of that nature. Each of the documents listed in Appendix 5.1 was scanned with the same objective. In each case, the intention was to identify whether treeline scrub was i) explicitly included, i.e. specifically targeted, or ii) implicitly included, i.e. where it was included by default and/or not specifically excluded, or iii) explicitly excluded. For those policies or strategies which fell into categories i) or ii) a further search was made for objectives or actions in any implementation or action plans which arose from the policy.

Other policies were identified through references made in strategic documents already known to the author. For example, background documents to the Scottish Forestry Strategy revision (FCS no date) refer to governing legislation which included reference to the Conservation (Natural Habitats &c.) Regulation 1994 and now updated (JNCC 2010). The author was also familiar with the UK BAP review (Maddock 2007) which was ongoing during the course of this study. All documents were sourced from either Scottish Government or other public body websites, and reference has been made to the relevant web pages in Appendix 5.1.

Rural policy interviews

Interviewee selection

Organisations or departments involved in rural or land use policy were selected from three functional groups: **C**) policy creators **-** Departments of the Scottish Government which generate Scottish level policy; **I**) policy implementers – public bodies answerable to Government who develop implementation strategies, and steer their delivery; and **In**) policy influencers – non-governmental, constituted organisations that are representative of particular interests, often through membership, and which influence the work of either or both of the previous groups. Although there was a general aim to interview one individual from five organisations per group, the actual number was determined by the objective to capture a wide range of views across the main land use sectors, particularly agriculture, forestry, hunting and conservation. An initial list of organisations and potential interviewees was developed through discussions with colleagues with knowledge of each sector and advice from existing contacts within target organisations.

In Scotland policy is created in the Scottish Government. This restricted the choice of interviewees to those directorates or departments dealing with land use or rural land policy relevant to the uplands such as those covering agriculture, natural heritage management and biodiversity, and forestry. Strategic land use or rural policy implementation derives from policy and is delivered by the following public bodies, the Crofters Commission (CCS), Deer Commission Scotland (now part of Scottish Natural Heritage, SNH), Forestry Commission Scotland (FCS), Scottish Environmental Protection Agency (SEPA), Scottish Natural Heritage (SNH), Cairngorms National Park Authority (CNPA) and Loch Lomond and Trossachs National Park Authority (LTNPA). One person responsible for strategic implementation of policy for upland land was interviewed from each of the five national bodies, but only one Park Authority officer was included. In addition, a range of non-governmental organisations (NGOs) seek to influence, or lobby, policy creators and implementers in order to further the interests of their members. NGOs were selected on the basis of the sector they represented and a known interest in upland land. The particular interests included were agriculture, hunting interests, game conservation, native woodlands, and habitat conservation for birds. Table 5.3 shows how the range of organisations selected were spread across broad remit categories.

Invitations to interview were made in person, by telephone or through an intermediary such as a personal assistant. It was made clear that the interview was part of a wider research project in support of a Doctorate of Philosophy Degree through the Macaulay Institute and Edinburgh University. When agreement was forthcoming, a letter was sent confirming the key facts that the interview would be no more than 45 minutes long, that it related to vegetation in the zone above plantations but below summit heaths, and particularly the drivers for management in these areas and that the interviews would be semi-structured and reported anonymously. It also provided an outline of the investigation strategy and in which group the respondent was classified. During the initial contact and in the interview, opportunity was given to interviewees to question or raise points of clarification about the interview process and protocol. No points of concern or issues about the nature of the interview or the reporting procedures were raised by any participant. Requests for outputs from the research were made in many cases.

Table 5.3 Categorisation of organisations selected for interview.

	Agriculture	Forestry	Hunting	Land Use[1]	Conser-vation
Creators	2	1			2
Implementers	1	1	1	1	3
Influencers	1		2		2

[1]Remit covered all land uses

By its nature, qualitative research is subjective, and a fundamental element of that subjectivity is the role of the interviewer. It is unlikely that someone who has made a commitment to study a particular semi-natural vegetation type does not develop sympathies with it which influence their outlook and so their approach to the subject. In the case of this investigation, the author (who was the interviewer) has a history of involvement and interest in native woodland management primarily and upland ecology more generally and was known to more than half the interviewees through these interests. In at least two cases the author's specific interest in treeline scrub was known to the interviewee. However aware the author was of her bias, it was not possible to be entirely neutral. As a result, the interviewees may have been aware of any bias that was brought to the interview. Interviewees not known to the author also showed some tendency to assume a level of bias from the author. On one occasion, this was evident before the subject of the interview was clear (it is possible the interviewee had prior knowledge of the author). How this actual or perceived bias affected the responses of the interviewees is difficult to assess. However there was no indication that any interviewee changed their opinion as a result of this knowledge. In some cases their responses may have been exaggerated in order to provoke particular responses, or because they expected a sympathetic ear.

Interviews

The interviews were semi-structured (Ritchie and Lewis 2003). An interview guide was developed from the research questions, each with a number of sub-topics designed to explore the level of familiarity of the interviewee with treeline scrub, how it fitted into existing policy, and what the prospects were for its future stewardship. This framework is set out in Table 5.4. The interviews ran for approximately 45 minutes, but ranged from 30 to 57 minutes. No mention was made of treeline scrub before the interview itself. Interviewees only knew that the subject behind the interview was hill land, above the head dyke, or enclosed land. This approach ensured that their answers to the first question concerning their

Table 5.4 List of key and sub-topics which were the subject of questions at all interviews. The final column gives the nodes used to extract the range of views expressed across each interview under each topic area (see text for explanation).

Research questions/topic areas	Sub-topics / specific research questions	Interview strategy	Nodes used to select text to generate results
Context/ Definitions			
How is montane scrub conceptualised by policy creators/ implementers/ influencers	What is the perception of the Scottish hill landscape?	Ask how interviewee visualises the landscape between forestry plantations and summit heaths?	"Vision"
	To what extent is the interviewee aware of the treeline scrub when considering rural or land use policy?	Show photos of treeline scrub in the UK and Scandinavia	"Vision" AND "montane scrub"; " Vision" AND "treeline" OR "mosaic" OR "scrub"
	What is the attitude to treeline scrub?	Explore where such vegetation might be seen as inappropriate.	"attitude" AND "montane scrub"
	[Where might there be conflicts?]	Explore where it might be seen as appropriate	"montane scrub" AND "policy2practice" AND "constraints"; and "policy constraints" AND "montane scrub"
Land use policy			
How does treeline scrub feature in Scottish rural and land use policy?	What are the rural / land use policies that are in general every day use?	Ask about the policies they normally work with?	"Policies used"
	Does the interviewee take any ownership of this habitat?	Explore how treeline scrub is treated with in the policies.	"policy" AND "attitude" AND "montane scrub"
		Explore any specific issues for treeline scrub	"policy" AND "explicit inclusion" OR "implicit inclusion"
		If there is policy inclusion, explore how that feeds down to implementation.	

Continued next page/

Table 5.4 contd. List of key and sub-topics which were the subject of questions at all interviews. The final column gives the codes used to extract the range of views expressed under each topic area (see text for explanation).

Research questions/topic areas	**Sub-topics / specific research questions**	**Interview strategy**	**Nodes used to select text to generate results:**
Could restoration activity happen within current implementation strategies?	Where are the opportunities for treeline scrub?	Identify any land management projects which include treeline scrub with which the interviewee is familiar.	"policy2practice" AND "explicit inclusion"
	What are the current mechanisms expected to deliver?	Discuss how treeline scrub fits within the wider rural or land use policy context, directly or indirectly.	"policy2practice" AND "montane scrub" AND "policy constraints"
	What are the constraints to schemes involving treeline scrub?	Has there been any implementation activity involving treeline scrub?	"projects" AND "montane scrub"
	Have any mechanisms worked?	Explore any difficulties in including treeline scrub in wider policy.	"policy effects" AND "montane scrub"
	Are there recognised issues with the current mechanisms and these types of vegetation?	What would need to change before such schemes became a likelihood?	"Future expectations" AND "policy constraints" and to "Future expectations" AND "policy constraints" AND "montane scrub"
Cross-sectoral themes			
What type of scheme is likely to deliver the broadest policy objectives?	Where is there potential integration with other interests?	Explore whether treeline scrub could deliver, indirectly, any interviewee's policy objectives.	Text coded to "policy2practice AND integration AND montane scrub" and to "policy2practice AND integration AND inertia"
	Are there areas of specific exclusion?	Explore areas of potential conflict with an expansion of treeline scrub	
	Are there opportunities for multi-objective projects?	Explore areas of potential benefits from encouraging this type of vegetation.	

vision of an ideal hill landscape was not coloured by their knowledge of the interests of the study (except in the case of the two interviewees who knew the author was currently researching this topic). Following the initial question a number of photographs of examples of treeline scrub were shown and discussed with the interviewee. The subsequent questions, although not identical from interview to interview, were based around the series of topics set out in Table 5.4.

Seventeen interviews were undertaken, five each in the functional group of policy creators (**C**) and policy influencers (**In**), and seven in the functional group of policy implementers (**I**). In addition, it was useful to group the interviewees by their work remit. This was carried out by first categorising the main (primary) remit of the section, department or organisation in which they work into one of five groups (land use. agriculture, forestry, hunting or conservation, Table 5.5). This group needed to be flexibly defined in order to take account of the range of structures and sizes across the organisations interviewed. For example a public servant in the Scottish Government was categorised by the Department that they worked in, whereas an NGO employee was categorised by the overall remit of the organisation. Secondly they were categorised by their own job remit into one of three groups (land use, biodiversity, and forestry). This process created eight groups in total which are given in Table 5.5. For example, an employee of a conservation organisation whose job primarily involved working with other land uses was categorised as ‘conservation/land use’.

5.2.2 Data management

Rural policy desk review

Policies, starting at a global level, were scanned for explicit or implicit inclusion of treeline scrub or relevant drivers. Where these were found, the downstream documents were identified and similarly examined. The aim was to identify a trail from higher-level policy to local implementation. However, policy implementation is not necessarily linear and key policies which have modified implementation were also identified.

Rural policy interviews

Each interview was recorded using a dictaphone and subsequently transcribed by the interviewer. Within the transcriptions there were occasional words or phrases which were unintelligible. Where the likely word could be deduced from the surrounding text unambiguously, and without potentially mis-representing the interviewee, it was added between brackets: { }. Where it was not possible to determine the meaning, gaps were left in the text. The transcriptions were imported into NVivo software (NVivo 8.0.332.0 SP4, QSR

International Pty Ltd.© 2008) and analysed using descriptive analysis techniques (Spencer *et al.* 2003). All the text of the interviewee responses was coded. Coding is a means of identifying any text, one word, phrase, sentence or paragraph, across all the interviews to the same "node", i.e. to the same descriptive or analytical category. Essentially, coding assigns labels to pieces of text (similar to storing quantitative data in a particular field in a database). Text can be coded to a number of different nodes but it is fundamental to the process that coding is consistent and strictly relates to the descriptions for each node. This is achieved by regular back-checking. Subsequently, all the text related to a node is collated and examined for an assessment of the range of views expressed.

There are two key strategies for coding text (Spencer *et al.* 2003), establishing a set of nodes based on the research questions, or iteratively allowing the themes or topics to

Table 5.5 Categorisation of seventeen interviewees according to their role in policy development, and the two main land/rural policy functions of their job remit. (see text for further details) Biodiver = biodiversity

Policies regularly used by interviewees

Policy function	Job remit / Primary remit	Land use / Agriculture	Land use / Forestry	Biodiver / Forestry	Land use / Hunting	Land Use	Land use / Conservation	Biodiver / Conservation	Forestry / Conservation	CAP	CBD / Habitats directive	SRDP	SFS	Deer Act	WFD
Policy **C**reators	C1						X					o			
	C2							X			o				
	C3	X								o		o			
	C4						X			o		o			
	C5			X									o		
Policy **I**mplementers	I1		X								o		o		
	I2	X								o		o			
	I3							X			o				
	I4						X				o	o			
	I5					X					o	o		o	
	I6				X						o			o	
	I7						X				o	o			o
Policy **In**fluencers	In1	X								o		o	o		
	In2								X		o		o	o	
	In3				X							o		o	
	In4								X		o		o	o	
	In5				X					o	o			o	

emerge from the text as it is read. In this study a combination of these methods was used. An initial framework of nodes was set up based on the three main themes of the interview, 'vision', 'policies' and 'integration'. Two additional themes were added: 'context', which included information about the job remit of the interviewee, and the policies they regularly used, and 'treeline scrub' to cover any specific mention of the habitats. The whole of the initial response from interviewees prior to the discussion of the photographs was coded to 'vision'. Whilst working through each transcript, additional nodes were added as sub-themes under the main nodes where they elaborated on the five main themes. These were subsequently rationalised into a list of five main and thirteen sub-themes. Figure 5.1 provides an example of how the node 'tree' is set up by the software.

Figure 5.1 An example of the node tree established to code the interviewee text. The sources column gives the number of interviews with text coded to the particular node and the reference column is the total number of text fragments coded to it. The description provides further detail on the type of text coded.

Tree Nodes

Name	Sources	Reference	Description
1. Vision	17	68	Question 1, and overaching node for all items under vision

Name	Sources	References	Description
Attitudes	17	211	Indications of interviewee's attitude to treeline ecotone

Name	Sources	Reference	Description
2. Policy	17	245	Question 2, and overarching for all sub questions under this heac

Name	Sources	References	Description
Future expectations	17	135	Expeced policy developments which would constrain d
Policy constraints	17	154	Policy or strategy areas identified where there are cons
Policy drivers	15	99	Anything that influences the way policy develops inclu

Name	Sources	References	Description
Lobbying	11	32	Interviewee's expressed areas for policy

Name	Sources	References	Description
Policy to practise	17	274	interviewee cited incidence of practical delivery of policy

Name	Sources	References	Description
Policy effects	12	64	Interviewee perception of effects of policy driver
Projects	16	84	Anything interviewees organisation is involved i

Name	Sources	Reference	Description
3. Intergration	17	146	Question 3 and all items relating to integration

Name	Sources	References	Description
Inertia	13	30	Statements from interviewees relating to the difficulties

Name	Sources	Reference	Description
Context	9	23	Back ground about remit and policies interviewee is familiar with,

Name	Sources	References	Description
Policies used	16	28	Policies from above being used to generate new policie
Remit	16	49	Scope of interviewee's job

Name	Sources	Reference	Description
Treeline ecotone scr	16	115	any mention of ro reference to montane scrub, treelines, willow, j

Name	Sources	References	Description
Explicit inclusion	10	27	Whether or not interviewee's policy specifically includes
Implicit inclusion	10	19	indications of interviewee's policy implicitly including or

The answers to the research questions were collated through a process of selecting text which had been coded to a combination of different nodes. NVivo carried this out through queries which used "Boolean" operators (AND, OR, NOT) to expand or limit the results displayed. The resulting collated text produced by NVivo retained links to the full transcripts and allowed cross-checking of a phrase with its context. Cross-checking ensured there was no mis-representation of the views of the interviewee, or revealed the origin of a response. Table 5.4 (above) provides the main breakdown of research questions, topic themes and node combinations used in the analysis.

The interview texts were primarily analysed by the three functional groups (**C1** to **C5, I1** to **I7** and **In1** to **In5)** in order to identify any patterns in responses. Responses across the eight remit groups were also explored and any particular patterns either between or within groups identified. Square brackets have also been used to protect the anonymity of interviewees where interviews included references which might identify them. For example, by replacing a site name with "[interest]". Square brackets have also been used to summarise the meaning of a long phrase within a quote, simply to reduce the volume of text.

5.3 RESULTS

5.3.1 Rural policy desk review

Policy generally tends to be less specific, and consequently less powerful, in relation to implementation the further it is from its target. Global or European level policy, with a number of key exceptions, may set a general framework for UK policy but does not tend to direct what does or does not happen on the ground. For example, the EU Common Agricultural Policy (CAP) establishes a framework for the regulation and support of agriculture within the EU, including the disbursement of incentives for land based rural activities, but the actual mechanisms and details are determined at a UK or Scottish level. This review has confirmed this general trend and the results are summarised in Table 5.6. There is nothing specific about treeline scrub in global biodiversity policy, but treeline scrub could be considered to be implicitly included in the Convention on Biological Diversity (CBD), and the UK interpretation to the national context (Department of Environment, Food and Rural Affairs 2002, CBD 2009). This would be because it is part of the UK's biological diversity and to allow native habitats and species to become endangered or extinct would run counter to that commitment.

At a European level a number of specific habitats and species are included in the habitats and species lists associated with the EU Habitats Directive (JNCC 2010b, Table 5.7). These carry obligations for protection through the EU Natura 2000 network of designated sites but

Table 5.6 Key over-arching policies which either directly or indirectly include or influence the future of treeline scrub.

Policy / Implementation	Date	Level	Mechanism	Explicit (E) or Implicit (I) inclusion
Wildlife and Countryside Act (Scotland)1981 and amendments	1981	UK	NNR and SSSI designations	Partial E, inclusion dependent on interest at time of designation
Convention on Biological Diversity	1992	Global	EU level biodiversity policy	I
COUNCIL DIRECTIVE 92/43/EEC: on the conservation of natural habitats and of wild fauna and flora	1992	European	Natura 2000 Network, Schedules of priority habitats and species	Partial E Some species and habitats included in designated sites, where a designating feature[1].
Scotland's Biodiversity: It's in Your Hands. Strategy for conservation and enhancement of biodiversity in Scotland	2004	Scottish	Habitats and species in agri-environment measures	Partial E LBAPs in some areas include actions for “montane scrub”
The Nature Conservation (Scotland) Act	2004	Scottish	Scottish Biodiversity Lists Biodiversity Duty (BD)	Partial E willow and juniper included. BD essentially relates to all public body staff in their work that impacts on biodiversity.
SRDP 2007 - 2013	2007	Scottish	Rural priority option	E – Scrub and Tall Herb Communities (see Appendix 5.2)
Scottish Climate Change Act	2009	Scottish	Unclear	Unclear, potential unexplored opportunity

Notes: [1] – Inclusion of a treeline ecotone habitat or species as a feature of the designation has tended to depend on the contemporary priorities or focus at the time of designation.

have limited effect in the wider countryside. Similarly, many of the habitats and some species feature in the UK Biodiversity Action Plan (JNCC 2010d, Table 5.7). This process was the UK response to the CBD, but is not statutory, and delivery of actions is largely dependent on voluntary activity. Another aspect of the CBD is the request to “integrate, as far as possible and as appropriate, the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans, programmes and policies” (CBD 2009). As a result, an adjusted list of habitats and species has been developed in Scotland, the Scottish Biodiversity List (Scottish Biodiversity Forum 2004), which is the basis for the biodiversity duty relating to public bodies and included in the Nature Conservation (Scotland) Act 2004. The rural priority options (RPOs) for biodiversity are aimed at supporting and enhancing species and habitats on the Scottish Biodiversity List. RPOs are part of the current agri-environment programme from the Scottish Rural Development Plan (SRDP 2007 – 2013), which is the Scottish plan for delivery of the CAP. As part of this

Table 5.7 Treeline scrub and current policy. The first part of the table shows how the individual species and habitats fit into current policy. The second half sets out other policies which drive land management that is likely to impact on treeline scrub

Treeline Scrub type or species	Plant community	Name in policy document	Policy / Implementation plan	Connection to other policies
Salix lapponum – luzula sylvatica scrub	Sub-arctic *Salix* sp Scrub	H4080	EC Habitats Directive (92/43/EEC)	Annex 1 habitat. Not on priority list but there is an obligation to safeguard
Betula nana scrub	NVC M19	Active blanket bog 7130		Priority habitat, obligation to designate SACs to protect proportion of UK resource
Salix lanata, *S. lapponum,* *S. myrsinites,* *S. arbuscula*	NVC W20, but not exclusively	Mountain heaths and willow scrub HAP	UK Biodiversity Action Plan encompassing Habitat Action Plans (HAP), and Species Action Plans (SAP)	All three HAPs are Included in remit of the UK Biodiversity Research Group Uplands Ecosystem Biodiversity Group, no targets yet available.
Juniperus communis ssp *nana*	NVC H15			
Juniperus communis ssp *communis*	No specific habitat classification	Upland Heathland HAP		
Betula nana	NVC M19	Blanket bog HAP		
Salix lanata, *S. lapponum*			Scottish Biodiversity List	Used to focus delivery of the “biodiversity duty” into the SRDP
Salix lanata, *S. lapponum,* *S. myrsinites,* *S. arbuscula,* *Juniperus communis,* *Betula nana,* Pine treeline woodland	Upland dwarf willow scrub; Upland juniper scrub Upland dwarf birch scrub Dry upland scrub forest zone, including treeline	Rural option 39 Scrub and Tall Herb Communities	Scottish Rural Development Plan (2007 – 2013) (SRDP)	One of a list of 47 rural options available under Axis 2 of the SRDP. Other scrub habitats are included in the option as well as tall herb habitats. Full details of the option are available in Appendix 5.2
Salix lanata		Woolly willow SAP	Scottish Species Framework	Stimulated direct action to propagate and plant out willows in new populations at existing sites

programme there is an option titled "Scrub and Tall Herb Communities" (Appendix 5.1 Table A5.2). The Scottish Government (SG 2010c) reported on its website that 202 projects, totalling £800,043, had been approved under this option by the end of March 2010. There is no information available about which habitats included in the RPO (Table 5.7) were the focus for each of the contracts awarded, where they are based or what operations have been undertaken, so it is not possible to assess whether or not any have included treeline scrub.

5.3.2 Rural policy interviews

The resuts are principally presented by the three functional groups (**C1** to **C5, I1** to **I7** and **In1** to **In5)** in order to identify any patterns in responses. Patterns evident in the eight remit groups (Table 5.5) are provided at the bottom of each sub-section. Square brackets have been used to remove reference to specific sites or interests which would compromise the anonymity of the interviewee. For example, replacing a specific item with [interest]. {} brackets have been used where a word or phrase in the original transcript is unclear but the overall meaning can be unambiguously deduced from the intelligible text.

5.3.3 How is treeline scrub conceptualised by policy creators, implementers and influencers?

Two analyses of the interview text were carried out. They were both based on responses from the first part of the interview, before photographs of treeline scrub had been shown. The first (vision of the upland landscape) was based on the whole responses to the request for a description of their ideal hill landscape. The second (inclusion of treeline scrub in visions) analysed the same text for the following words: 'treeline', 'scrub', 'montane scrub' 'mosaic' 'willow' 'juniper'.

Visions of the upland landscape

Policy creators (C)

There was an interesting contrast in this group between those who provided a personal picture of how they would like to see this landscape and those who tended to respond by indicating the current key drivers of change. In some cases, both perspectives were given. Personal views tended to include reference to natural heritage features:

> "*I would like to see a productive landscape, I mean productive in the widest sense, not just economically productive. Productive in terms of biodiversity, productive in terms of what people want to look at*." and, perhaps a desire to see a change from over-managed vegetation, "*you will see vegetation that responds to the underlying ecology*" (**C1**).

> "*my own view is that there's still a tremendous opportunity to improve the uplands ecologically and aesthetically by increasing the area of native woodland and scrub and shrub ecotones in large areas...*" (**C5**)

Compared to one who avoided the question, or was reluctant to express personal as opposed to official views:

"*I [and the Government] will be better placed in the autumn to have a wider view across the piece. The biggest problem … is livestock reduction. The Government has a policy to try and keep populations in remote places*." (**C3**)

Policy implementers (I)

With two exceptions all the responses included reference to or implied a change in the balance from the current to a less uniform, more diverse landscape, for example:

"*we would like to see a much less intensified landscape, much more diversity, more mosaic between different habitats* " (**I7**)

In contrast, one respondent, echoing the policy-driven vision from some policy creators, was more functional and expressed their vision in terms of ambitions for the rural populace, as "*sustainable rural communities*" (**I2**) but acknowledged that there was not a precise definition for 'sustainable'.

Another ideal vision was "*that the hills are unrestricted by man made artefacts*." (**I3**). But they did acknowledge the human reliance on such artefacts (E.g. pylons).

Policy influencers (In)

There was a greater range of views expressed across this group, reflecting the range of interests of the organisations interviewed. At one level:

"*I suppose it would be very difficult to change the landscape of upland Scotland.*" (**In3**)

But in terms of land use activity: "*we would like to ensure that there is a balance.. in terms of what goes on there*." (**In3**).

Other responses tended to be more functional. One did not attempt to provide a vision but was essentially reactive to current land management trends:

"*We're interested in how [the upper forest edges] are being restructured, second rotations*" and "*There's scope for some expansion, scope for some restructuring and scope for some removal too. That's the extent of our vision*" (**In2**).

Another was very prescriptive and had previously developed a vision that had been presented to a different audience (unrelated to this interview):

"*a largely heather dominated landscape but not a blanket wall to wall heather*." and "*We accept there is a strong need for other elements, particularly a tall-shrub, willow essentially … component within the landscape*." (**In5**)

In4, also expressed a wish for greater diversity:

"*a matrix of habitat*" and "*we would expect [native woodland] to go up to a more natural treeline .. and it would finish where it would naturally finish*."

In1 was essentially policy-orientated:

"*pretty much a mosaic of different land uses*" but with the desire for "*softer boundaries in terms of how policy is shaped and implemented ..to better reflect the complementarity rather than reinforce the conflict of land use*."

This response was very land-use focussed and appeared to be looking for greater flexibility between land uses which would subsequently be reflected in the landscape, but perhaps with a more managed outcome than that desired by those seeking greater habitat diversity.

In summary policy creators, with one exception, primarily wished to see a more diverse or natural landscape. Policy implementers, with one exception, also wished to see a more diverse or natural landscape. Policy influencers were more difficult to categorise and their visions encompassed: recognising an obligation to more diversity; a real desire for more diversity, including more diverse land uses (rather than necessarily biodiversity); and suspicion of the motives of public bodies in developing diversity.

Inclusion of treeline scrub in visions

The use of the words: 'treeline(s)', 'mosaic', 'montane scrub', 'krummholz', 'willow' or 'scrub' before photographs of treeline scrub had been shown or discussed was taken as an indication of prior awareness of the habitat. Although only "treeline" is specific to treeline scrub, all the other words can be used to describe aspects or characteristics of treeline scrub and, prior to inclusion in the results, the context in which each was used was checked to verify its relevance.

Policy creators (C)

One interviewee made reference to scrub woodland suggesting awareness of a natural treeline scrub habitat:

"*a lot more scrub native woodland*" (**C1**).

Another referred to "*krummholz*" (**C4**) which is the German word for treeline woodland (See chapter 1, figure 1.1), suggesting an understanding of the nature of treeline scrub.

C5, specifically referred to the treeline ecotone "*we haven't given enough emphasis to that ecotone, that treeline edge, the outer edge of forests*" implying considerable knowledge and understanding of natural treelines, one element of treeline scrub.

Policy implementers (I)

As illustrated in the previous section, five of this group referred to treeline scrub directly or indirectly. For several the vision tended to stop at the treeline. In some cases the awareness of the treeline as a continuum was strengthened by qualifying text elsewhere in their vision answer.

"*we do need to see all the components from the river valley right up to the treeline*" (**I1**)

I7 showed an appreciation for the concept of natural transitions of habitats from the forest out to the treeline zone and beyond and referred to knowledge of Scandinavian landscapes:

> "*out to the treeline and montane areas*" from "*managed forest, natural bog … graded out to mosaics as you move up hill*"

Policy influencers (In)

Despite reference by **In1** to "*a mosaic of different land uses*" there was nothing in the subsequent interview, prior to showing photographs, to suggest awareness of treeline scrub.

In3 commented that "*You may get the odd tree but it's going to be scrub, juniper, birch possibly rowan, possibly the odd Scots pine*" which suggests a level of awareness of the current hill ground but not necessarily of treeline scrub as a vegetation type.

In5 recognised "*a strong need for other elements, particularly a tall-shrub, willow essentially*". Knowledge of the vegetation from time spent in Scandinavia was confirmed later in the interview and this suggested a relatively high level of awareness and knowledge.

The policy creators and influencer groups showed a wide range of awareness and knowledge of treeline scrub. In both groups there were individuals with very high awareness and knowledge and at least one at the opposite end of the spectrum. Policy implementers were generally more aware than either other group.

Range of visions and awareness of treeline scrub across land use sectors

Examining the responses from both these searches across the different remit groups revealed that all of those working in land use for conservation departments or organisations from both policy creator and implementer groups (but not influencers), professed a wish to see a more diverse upland landscape (table 5.7 allows cross-reference with quotes above).

Reference to a more diverse hill landscape was coupled with subsequent use of terms equated with treeline scrub ('treeline(s)', 'mosaic', 'montane scrub', 'krummholz', 'willow' or 'scrub') by all those involved in conservation/land use. It was not expressed by individuals from the agriculture/land use group, the conservation/biodiversity group or the conservation/forestry group. Another result apparent from these searches was that the more mechanistic or policy-driven approaches to a vision tended to come from those with very low or no prior awareness of treeline scrub (for example **C3, In2**).

5.3.4 How does treeline scrub feature in Scottish biodiversity and rural land use policy?

This question was primarily answered through the desk review of rural and land use policy currently applicable to Scotland. The purpose of including information on current policy in the interviews was to ascertain the level of understanding of how treeline scrub is considered (or not) in policy, current attitudes to it, and so the likelihood of implementation.

Two searches of response text were used to draw out an overall picture of treeline scrub and policy.

Policies relevant to different interviewees

The first looked at the policies each interviewee cited as pertinent to their role (Table 5.7). Policy creators and implementers work directly with policies from above, either interpreting European or UK level policy in a Scottish context, or developing implementation strategies for Scottish policy. Policy influencers tended to be reactive, aiming to influence draft policy or implementation strategies, either during consultations or pre-emptively to stimulate change.

Policy creators (C)

Primarily, this group are working with CAP and the EU Rural Development Regulation (RDR), and the Scottish interpretation of these, the Scottish Rural Development Programme (SRDP). The exceptions to this were **C2**, who primarily refers to the Convention on Biological Diversity (CBD) and **C5** who works with the Scottish Forestry Strategy and the Scottish Biodiversity Strategies.

Policy implementers (I)

The use of policy by this group was wide ranging. Some were involved in the direct interpretation of government policy into implementation strategies, for example the development of the Scottish Forestry Strategy (**I1**). Some in the interpretation of any or all rural policies or strategies within the particular legislative remit of their organisation (**I5**) and some whose remit was partly controlled directly by EU and/or national legislation (**I3** and **I7**).

Policy influencers (In)

Essentially this group of organisations tend to comment on or lobby for their interests within any rural policy. The nature of the organisation determined where their focus or priority lay. For example, for **In3** access legislation was a priority issue, but for **In4** the focus was forestry policy, either through the country Forestry Commissions or local authority indicative forestry strategies.

Interviewee attitude to treeline scrub

A second search analysed text coded to ‘policy’ or ‘projects’, and ‘attitudes’ and ‘treeline scrub’. A large number of responses was generated and these were analysed by functional group.

Policy creators (C)

The responses from this group ranged from engaged enthusiasm through passive interest to qualified acceptance. For example:

> "*I'm tempted to say this is all good. ...if it's not denying Scottish agriculture any profitable grazing land then I don't have any issue with that, that's absolutely fine*."

And: "*The scrub ...In terms of the land area my assumption is that there's scope for both [scrub and profitable grazing land] where it might be difficult is on the financial side, does one support this or prioritise something else. I can see that might be an issue*." (**C3**)

Passive interest was portrayed through a number of comments in appreciation of the habitat, but making the point that the only likely route for action would be through NGOs, and not mainstream funding packages:

> *"I don't see how anyone who is informed could possibly object*", "*The obvious [opportunity] is where the NGOs have land. ..where they resolve to do it*." (**C2**)

The enthusiasm was aspirational:

> "*We might call that treeline woodland, treeline scrub, montane scrub. That would be an exciting development. We do have some thoughts along these lines and we do have aspirations within* [interest] *where we own the hill tops*" (**C5**)

Policy implementers (I)

Interest in the habitat was generally tempered by identification of constraints through lack of awareness amongst potential scheme applicants, the incentive schemes themselves, or lack of integration between biodiversity interests and other land uses. For example:

> "*But how do we ensure that appropriate woodland beyond the current forest edge is always considered when we're creating new woodland*." (**I1**)

or

> "*actually getting measures into a scheme is one thing, finding the people to do these things is another*." (**I4**)

and

> "*This whole area of influencing SRDP is something that we're putting a lot of effort into and it's very frustrating*." And "*No we don't sit on the RPACs, .. They can call on us for advice but they rarely do*." (**I5**). (RPACs are Regional Priority Assessment Committees which determine funding applications to SRDP)

Policy influencers (In)

Many of the responses from this group reflected the underlying interests of their organisations. Where there was no coincidence between what treeline scrub is perceived to deliver and the objectives of an NGO, it was unlikely that any activity would follow. For example:

> "*No we wouldn't [actively seek expansion of treeline scrub] because we haven't identified it with [our interest]*" (**In2**)

For others, there might be a more difficult adjustment to make. For example this comment was in response to being shown the photos of treeline scrub;

> "*It comes back almost in a way to the introduction of an alien species. But they are all native and yes, you have to conserve them.*" and "*if you want to introduce them .. you need to say this is the objective for that piece of ground*." (**In3**)

Amongst policy creators there appeared to be a perception that agriculture takes priority over treeline scrub and this was coupled with the view that main stream funding may not be available. There was almost a perceptible sense of frustration among policy implementers at their inability to influence the outcomes of implementation programmes, particularly the current agri-environment measures of the SRDP. Policy influencers generally, with one exception, were relatively disinterested in this habitat, and in one case reluctant to recognise its legitimacy within the landscape.

Perception of biodiversity in policy

Although it was not a direct question, it is worth highlighting how those, whose primary remit was biodiversity, perceived the place of biodiversity in policy. This potentially has a direct bearing on treeline scrub as it would be considered part of biodiversity. The following comments were made by a policy creator and an implementer:

> "*In a sense we can only influence in a way. We try and influence across the broad span of people so we try and influence across forestry policy and agriculture, agri-environment scheme.*" (**C2**)
>
> "*The one place where it is policy, which is supported by legislation but it is so spectacularly vague, is the biodiversity duty*." …. *"and we have [the biodiversity] duty*[2] *but that is really about the only lever that we have to try to encourage folk to do things one way as opposed to another*." (**I4**)

5.3.5 Could restoration activity happen within the current policy implementation strategies?

The desk review of current rural policies identified some data to answer this question (Table 5.5). In order to assess interviewees' perception of the likelihood of positive management for treeline scrub arising out of the current incentives and grant systems, responses to

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[2] The biodiversity duty was enshrined the CBD in 1993, and included in the Nature Conservation (Scotland) Act 1994 see sect 5.1, page 229.

questions were analysed for mention of existing projects or explicit inclusion in current measures. The following summarises the responses across the functional groups

Policy creators (C)

There was a clear view that treeline scrub could be funded within the current SRDP framework and that a number of existing operations would be appropriate to it.

> "*there are current options for grazing, in order to manage grazing for environmental benefits*" and "*So the tool kit is there*" (**C1**)

> "*In terms of the legislative position it's probably OK*" (**C3**)

Others felt that there were serious issues with other policies:

> "*Resources are always difficult to come upon. Also it is difficult if you're spending money to overcome a problem that's created by policy..*" (**C2**)

> "*The whole issue of GAEC, this scrub thing … doesn't fit neatly within any definition or concept of agriculture*" (**C4**).

Since this comment was made, there have been changes in the eligibility criteria for single farm payment (SFP, Donnelley 2010) which will have implications for the interpretation of Good Agricultural and Environmental Condition criteria (GAEC).

At the same time, there was recognition of some major constraints in the system, particularly cultural attitudes to natural heritage in general and treeline scrub in particular:

> "*That presupposes that they want to look [for treeline scrub options] in the first place.*" (**C1**);

> "*People are generally hostile to change. You might get some people who become so familiar with the big broad hillside*" (**C2**)

And, a more fundamental economic point:

> "*The issue then is that ..above the plantation what is the commercial value of forestry versus what you may be able to generate through an agricultural enterprise, albeit a marginal agricultural enterprise. You are probably going to generate more in terms of cash income.*" (**C4**)

Policy implementation (I)

There was no real pattern in the responses to this topic except that most interviewees were familiar with the potential for or, in some cases, actual projects for treeline scrub.

There has been management on designated sites to ensure compliance with EU Habitats Directive regulations. **I6** reported:

> "*at* [interest] *we've just concluded an agreement with the landowner there. We now consider that the features [willow scrub] are in favourable condition.*"

In terms of agricultural incentive schemes, **I4** understood that scrub was in the current, and had been included in the previous, agri-environment programme.

Similarly, **I1** referred to the forestry strategy:

> "*I'm sure somewhere either in the strategy itself, which is strategic by nature, or in some of the biodiversity papers, treeline and montane scrub is specifically mentioned*."

Policy influencers (In)

Generally it was not within the remit of those interviewed in this group to be familiar with incentives and grants. Respondents from NGOs that actually owned land at higher altitudes identified these projects, but their knowledge of the management of sites was limited. In some cases other interviewees mentioned estates or sites where they knew of management or aspirations for treeline scrub, but no details were available. There did not appear to be a good understanding of the current funding mechanisms available.

Within policy creators there was a range of views. Some respondents clearly understood that there were provisions in the existing agri-environment programme, but were sceptical that there would ever be interest among applicants. Others felt that the differential between forestry and agricultural payments was too great a disincentive for applicants to take land out of agriculture. Generally policy implementers were also aware that measures for treeline scrub exist within the current agri-environment programme, and there was a feeling that the future of treeline scrub on designated sites should now be safeguarded. Policy influencers generally had a low level of knowledge of current funding mechanisms or projects.

5.3.6 What type of scheme is likely to deliver the broadest policy objectives?

This question essentially attempted to explore the options for integration between treeline scrub and other upland land interests. Perhaps due to the relatively low level of understanding of the place of treeline scrub in the hill landscape there was not sufficient detail in the interview texts to answer this question fully. The following gives a picture of the range of views expressed:

Policy creators (C)

Some interviewees considered that there was room in Scotland for an expansion of scrub without compromising other interests.

> **C1**: "*I think there is space. I don't think it's an either you do this or you do commercial forestry. Great Britain is too small to go down the single land use option.*"

And:

> **C3**: "*the natural treeline example, if that's delivering more carbon sequestration and it's not denying Scottish agriculture any profitable grazing land.*".

Policy implementers (I)

This group identified a number of situations or opportunities where expansion of treeline scrub might be complementary to the main objectives.

> **I1**: "*There's now an opportunity to use the shelter that's created [by non-native regeneration] to develop a much more appropriate range of species ultimately removing the ones that aren't*."

I3 identified that

> "*There's no doubt that if a wind farm company thought they could get good PR out of it they would be interested.*"

Conversely**, I7** felt the opportunity in the SRDP to deliver landscape-scale benefits was being missed because there was still so little integration between the delivery organisations.

> "*There needs to be more pro-activity by the people who manage the scheme to look at how to get .. joint applications from adjacent land owners or farmers which cover a much larger scale and at the same time address a lot of the issues that need to be addressed*."

Policy influencers (In)

Perhaps because there is a tendency for the organisations in this group to be focussed on a particular aspect of land management or use, there was less direct interest expressed in integration. The two land-owning NGOs interviewed both mentioned land ownership that extended above the treeline ecotone. One where it was known that plans for treeline scrub management existed, the other was unclear owing to their own lack of awareness of the habitats. **In5** felt there was scope to integrate areas of treeline scrub on sporting estates with careful planning. **In3** promoted the view that it was necessary to focus one land use on an area of ground. For example, *"agriculture is about food production*."

Both policy creators and policy implementers identified potential opportunities for treeline scrub through integration with other policy or land management objectives, such as carbon sequestration or sharing land with wind farms. The current agri-environment scheme was recognised as an opportunity, but there was a certain amount of frustration expressed by policy implementers that it has yet to deliver truly integrated projects on the ground. Policy influencers did not contribute much to this topic apart from one view that it would be better to manage areas of hill ground for one land use objective.

5.4 DISCUSSION

From the results it is clear that all treeline scrub habitats feature in policy. In particular, *Salix lanata* and *Juniperus communis* have attracted specific targeted management activity within the current biodiversity provisions in Scotland. However the existence of provisions does not guarantee management for the ecotone or, on its own, safeguard the future of treeline scrub.

Generally the concept of natural treelines as the natural upland boundary to forests was known amongst policy creators. The more complex concept of treeline scrub was less well known. In contrast - and with one exception - knowledge and understanding of the habitats was low. Despite this, there was near unanimous recognition that the upland landscape was generally too uniform and, with caveats regarding the sustainability of agriculture, that greater diversity would be desirable. Terms used to qualify diversity were [more] "*treeline woodland"*, "*scrub woodland*", "*krummholz*" and "*rich, biodiverse*". This desire for greater diversity was echoed amongst the policy implementers, where the overall knowledge of treeline scrub was generally much higher, with one exception. There was greater variation of awareness amongst the policy influencers although, even within this group, there was recognition that *"yes, you need to conserve them*."(**In3**). The conclusion is that there is a degree of knowledge amongst the three groups, but that the level of consciousness of treeline scrub is generally low - with a few exceptions. This result supports the first hypothesis that while provision has been made for treeline scrub in policy, it remains largely invisible in terms of implementation.

The level of knowledge and understanding of treeline scrub was low amongst those involved in agriculture. Amongst those involved in conservation there was a high degree of variation, from very limited appreciation to very knowledgeable. As a result, the second hypothesis of a division of knowledge across the sectors has not been clearly proven. There is potential sympathy for retention of these habitats and the idea of expansion, but there is a need for promotion of treeline scrub and its benefits, particularly amongst those conservation-orientated policy influencers where there are potential cross-interest benefits.

Current land use policy allows for management of treeline scrub through the competitive rural priority options of the SRDP. The level of awareness of this option amongst those interviewed was generally low. The tools and mechanisms are available within the current provisions yet, despite this, the expectation is that projects would be confined to NGOs and those estates which, for reasons of conservation designations or the owner's particular interest, have received advice from sources who would have the interest and management knowledge to search for options. Whether, or how, applicants to SRDP would be likely to know about the option, and whether they would have the awareness or interest to look was raised by a number of both policy creators and implementers.

Provision for all the habitats and species included in treeline scrub within the UK Biodiversity Action Plan (UK BAP) is variable, but the recent review and update has improved the situation (Maddock 2008). The action plan element of the strategy has yet to be finalised, so it is unclear whether any actions for treeline scrub vegetation will be included. Both *Salix lanata* and *Juniperus communis* do have specific actions through their respective Species Action Plans (UKBP 2010, Anon 2007) and action for both these species is ongoing.

These outcomes reflect in many ways the outcomes from the expert opinion survey carried out by Milne *et al.* (2007) on the effective delivery of biodiversity policy in the uplands. They identified a lack of coordination between policies and a serious lack of translation into action. The new agri-environment provisions were intended to make progress on these issues but, as was identified in this survey, those working in biodiversity still feel they are entirely dependent on their ability to influence, primarily, agriculture. More recently, Midgely and Price (2010) have further stressed the need for more coherent policy for upland areas, with the importance of biodiversity to their economic and social future being fully recognised and integral to any solutions.

The picture that emerges from this study is that, with the exceptions of *Salix lanata* and *Juniperus communis,* the care and safeguard of this rare marginal native vegetation is uncertain and primarily left to chance:

- chance that, among the range of options available and different access routes to them on the SRDP website, an applicant who happens upon option 39, for scrub and tall herb communities, also happens to know what it refers to, has suitable ground, and recognises that the option is relevant;
- chance that the assessment officer and RPAC responsible for determining the application also have sufficient knowledge and understanding of the habitat to deem it worthy alongside all the other competing projects.

This does not bode well for the future of treeline scrub species and habitats in the Scotland. To reduce the chance element of this process, a far greater promotional effort is required across the range of the SRDP delivery processes, and amongst members of the RPACs, application assessment officers and advisers to SRDP applicants. There is also an urgent need for further work to clarify and elucidate the role of treeline scrub in the upland landscape, particularly in relation to the cross-sectoral benefits and contributions to ecosystem services. In theory the SRDP was established as an integrated scheme. However in practice, this has been very difficult to achieve on the ground.

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APPENDIX 5.1 DOCUMENTS IN CLUDED IN THE DESK REVIEW OF CURRENT POLICY

Table A5.1. List of policy documents, extracted primarily from Milne *et al.* (2007) reviewed for this study, with url addresses used at the time (Autumn 2008) and more recent documents added.

Level	Policy or Implementation	Process & Document names and/or websites
Global	Policy**	Convention on Biological Diversity: CBD. 1993. Convention Text. Article 6. General Measures for Conservation and Sustainable Use. **http://www.biodiv.org/convention/articles.asp?lg=0&a=cbd-06** CBD. 2001-2005a. Sustaining Life on Earth. How the Convention on Biological Diversity promotes nature and human well being. **http://www.biodiv.org/doc/publications/guide.asp** The Convention on Biological Diversity CBD. 2001-2005b. Mountain Biodiversity. Introduction. **http://www.biodiv.org/programmes/areas/mountain/default.asp**
Global	Policy**	United Nations Framework Convention on Climate Change 1992. **http://unfccc.int/resource/docs/convkp/conveng.pdf**
Europe	Policy*	Bern Convention
EC	Policy*	EC Habitats Directive (92/43/EEC)
EU	Policy**	European Biodiversity Strategy European Union. 1998 Communication to the European Commission to the Council and to the Parliament on a European Biodiversity Strategy **http://ec.europa.eu/environment/nature/biodiversity/comm2006/index_en.htm**
EU	Policy/ Implementation*	Common Agricultural Policy EC Biodiversity Action Plan for Agriculture (2001)
EU	Policy	Water Framework Directive
UK	Policy/ Implementation**	UK Biodiversity Action Plan Joint Nature Conservation Committee. 2006. UK BAP Website. **http://www.ukbap.org.uk/**
Scotland	Implementation**	The Scottish Biodiversity Strategy Scottish Executive. 2004c. *Scotland's Biodiversity. It's In Your Hands. A strategy for the conservation and enhancement of biodiversity in Scotland*. Edinburgh. Scottish Biodiversity Forum. 2005. Scotland's Biodiversity. It's in Your Hands. Strategy Implementation Plans 2005-2008. Scottish Biodiversity Forum. 2006. The Scottish Biodiversity List. **http://www.biodiversityscotland.gov.uk/pageType2.php?id=35&type=2&navID=92**
Scotland	Implementation**	Scottish Executive. 2006a. Rural Development Programme for Scotland 2007-2013. The Strategic Plan. Edinburgh. Scottish Executive. 2006c: Agri-Environment Scheme. Accessed on the web at: **http://www.scotland.gov.uk/Topics/Agriculture/Environment/Agrienvironment**

		Scottish Executive. 2006b: Less Favoured Areas Support Scheme: LFASS 2006: EXPLANATORY NOTES. Accessed on the web at: **http://www.scotland.gov.uk/Publications/2005/12/15150019/00197#1**
Scotland	Implementation**	Sectoral Strategies: Scottish Executive. 2001. A forward Strategy for Scottish Agriculture. **http://www.scotland.gov.uk/library3/agri/fssa.pdf** Scottish Government. 2008. The Muirburn Code. **http://www.scotland.gov.uk/Publications/2008/04/08154231/0** Deer management is now within the remit of SNH (2010) Promoting the management of all wild deer in Scotland. Accessed on the web at: **http://www.snh.gov.uk/snh-for-you/deer-managers/** Forestry Commission Scotland. 2006. Scottish Forestry Strategy. Accessed on the web at: **http://www.forestry.gov.uk/sfs** Scottish Natural Heritage. 2006c. Sites of Special Scientific Interest. Accessed on the web at: **http://www.snh.org.uk/publications/on-line/designatedareas/sssi2/intro.asp** Scottish Natural Heritage. 2004. Scotland's National Nature Reserves. A policy statement. Accessed on the web at: **http://www.snh.org.uk/pdfs/polstat/nnrpolcy.pdf** Scottish Natural Heritage. 2005a. Scotland's Natural Nature Reserve. **http://www.nnrscotland.org.uk/default.asp**
Scotland	Implementation	Scottish Climate Change Bill Halcrow (2008) STRATEGIC ENVIRONMENTAL ASSESSMENT OF THE SCOTTISH CLIMATE CHANGE BILL CONSULTATION PROPOSALS SEA Statement, ISBN 978 07559 1921 5 (Web only)
Regional	Implementation**	Local Biodiversity Action Plans from: Argyll and Bute; Ayrshire, Cairngorms, Caithness, Clackmannanshire, Dumfries and Galloway, Inverclyde, Renfrewshire and East Renfrewshire, Inverness & Nairn, Lochaber, North East, Ross and Cromarty (East), Skye & Lochalsh, South Lanarkshire, Stirling, Sutherland, Tayside, Western Isles, Wester Ross All plans are available on: **http://www.biodiversityscotland.gov.uk/pageType1.php?id=9&type=1&navID=40**

APPENDIX 5.2 SRDP RURAL PRIORITIES OPTION 39: SCRUB AND TALL HERB

Downloaded directly on 8th September 2010 from:
http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/Options/Scrubandtallherbcommuniti

Scrub and Tall Herb Communities

Introduction

This Option aims to enhance and extend areas of native scrub vegetation and tall herb communities and secure the survival of associated flora and fauna.

What this will achieve

This will help to secure the survival of specific BAP species and protect soils and watercourses. BAP species that may benefit include Common Linnet, Pearl-Bordered Fritillary Butterfly, Chequered Skipper Butterfly, Juniper, and Woolly Willow.

What you can do

Requirements

The key focus for managing scrub and tall herb communities will be the grazing regime. This will normally involve light grazing in the summer, and none in the winter.

You must:

* manage the grazing of scrub and open habitat mosaic to maintain an appropriate balance between these components (overall within the mosaic, scrub cover will vary depending on the type of scrub you are managing - see appropriate technical guidance. The scrub should be in good condition and regeneration should be sufficient to maintain its current extent. This may involve the complete but temporary removal of grazing see appropriate technical guidance. The open habitats should be managed according to the appropriate technical guidance notes

* eradicate any rhododendron present on the site

* avoid poaching by managing stock carefully when ground conditions are wet

* retain all mature or over-mature standing trees and all standing and fallen deadwood , unless they are a genuine safety hazard and you have the Scottish Ministers' prior agreement. Tree surgery must be limited to that required for the safety of people and farm livestock

* in upland areas, where relevant to Capercaillie and Black Grouse, mark all new fences with bird strike markers

* do not apply fertilisers, slurry, farmyard manure or lime to areas of scrub habitat except with the prior written agreement of Scottish Ministers

* do not apply pesticides to the site

* no supplementary feeding is permitted on the site

* do not plough or cultivate the site unless this is required to establish trees and shrubs. Any reseeding, rolling or chain harrowing work should be clearly described in a management plan submitted with your application

* do not cut new drains or modify or improve existing drainage systems. You can maintain existing drains

And, where appropriate:

* cut areas of scrub to encourage regeneration from the stump (coppicing) and carry out thinning (the selective removal of individual stems or shrubs) to introduce structural diversity to the stand

* remove dense vegetation and scarify the ground in order to help create favourable conditions for natural regeneration of scrub species to occur

* mow or flail open areas each year. Do this in late summer or autumn to avoid destroying seeding herbs

* on sites where regeneration cannot occur naturally, layering may be used to regenerate stands and planting should be considered as a last resort

* bare earth is important for invertebrates and pioneer species in scrub stands. It can be created and maintained during scrub management by limited de-turfing and uprooting of established scrub

Who can apply:

All land managers are eligible to apply for this Option.

Eligibility criteria

The Option is targeted at areas with scrub of high environmental value as defined in the list of types below

Scrub includes all stages from scattered bushes to closed canopy vegetation dominated by locally native shrubs or tree saplings usually less than 5m tall occasionally with a few scattered trees. This includes carr, scrub in the uplands and lowlands (including wood edge habitats), montane scrub and coastal scrub.

Scrub can be of high conservation value for the following reasons:

* where the shrub species is of conservation importance in its own right, such as Juniper or Downy Willow

* where other species associated with the scrub have high conservation importance, such as lichen species associated with Coastal Hazel

* where the scrub occurs as a landscape element within an ecological unit, such as birch and willow at the edge of wet heaths and mires, at altitude where scrub occurs at the interface between woodland and montane heath, and on sheltered coasts where scrub and elfin woodland are part of the characteristic mosaic of habitats. A list of relevant scrub types with characteristic species is given below.

Table A5.2 Scottish Rural Development Programme Axis 1 Rural Option: Scrub and Tall Herbs. This table sets out the scrub habitats and their characteristic species that are included in the option.

Scrub Community	**Characteristic species**
Lowland wet scrub (or carr)	Grey Willow (*Salix cinerea*), Downy Birch (*Betula pubescens*), Alder (*Alnus glutinosa*), Hawthorn (*Crataegus monogyna*)
Lowland dry scrub on calcareous soils	Hazel (*Corylus avellana*) on limestone
Lowland dry scrub on neutral soils	Hawthorn
Lowland dry scrub on acidic soils	Gorse (*Ulex europaeus*)/Broom (*Scoparium*
Upland scrub - wet scrub forest zone	Willow (*Salix* sp), Bog Myrtle (*Myrica gale*)
Upland scrub - dry scrub forest zone including treeline	Scots Pine (*Pinus sylvestris*) and Willow
Upland juniper scrub	Juniper (*Juniperus communis*)
Upland dwarf birch scrub	Dwarf birch (*Betula nana*)
Upland dwarf willow scrub	Downy (*Salix lapponum*), Woolly (*S. lanata*), Mountain (*S. arbuscula*) and Whortle-leaved Willow (*S. myrsinites*)
Coastal shingle scrub	Blackthorn (*Pruinus spinosa*), Bramble (*Rubus fruticosa*), Elder (*Sambucus nigra*), Juniper
Coastal sea cliff scrub	Hazel, Blackthorn, Bramble
Coastal dune scrub	Creeping Willow (*Salix repens*), Alder, Grey Willow, Bog Myrtle

Land receiving payments for similar management under other agri-environment schemes is not eligible under this Option.

What costs could be supported

Any cost claimed must be fully justified. The following are examples of what may be claimed for:

* eradication of Rhododendron (by mechanical or chemical methods)
* fencing, gates and fence removal - as appropriate
* small-scale tree and shrub planting
* open range deer management to enhance the natural heritage.

When completing your Proposal, you can select the appropriate capital item(s) from the dropdown list of standard cost capital items for this Option.

In addition to the above capital items, financial support of up to 100% of eligible actual costs is available in respect of the following:

* Capital works required for Sites of Special Scientific Interest (SSSI) and Natura features
* Renewable energy powered pumps for water troughs

Please note that these capital items will not appear in the dropdown list of Standard Cost capital items for this Option and will need to be entered manually in the box for Actual Cost capital items. Only costs for the types of capital works listed above should be entered in the Actual Cost capital items box for this Option. Any other costs entered cannot be considered for funding.

To ensure value for money we require you to provide 2 competitive quotes for any capital items applied for which are based on actual cost. If, however, you are seeking grant support towards something so specialised it is only available through 1 source then we would accept 1 quote. Please see the guidance on quotes and estimates for more information.

Rate of support

This is a 5 year commitment. We will pay you £94 per hectare per year. We will pay at the end of each year.

Inspection/Verification

The inspector will check the requirements (as detailed above under "what you can do") of the Option are being met, by a visual assessment on the day of inspection.

Beneficiaries must comply with the requirements of cross compliance and the minimum requirements for fertiliser and plant protection products. You must also comply with the requirements to avoid damaging any features of historic or archaeological interest, and follow Scottish Ministers' guidance for the protection of such areas or features (detailed in links below)

The following is a brief overview of the inspection procedures, for a full explanation please see links below:

Inspectors will check:

* Works detailed in your management plan have been carried out.

* Rhododendron eradication is being carried out.

* No poaching has occurred on the site

* No standing trees or deadwood have been removed from the site without prior approval of Scottish Government.

* No supplementary feeding has taken place on the site.

* No ploughing or cultivation has taken place on the site unless for the establishment of trees and shrubs.

* Visual check to ensure no fertiliser/ FYM/Slurry/lime has been applied to the scrub without prior written permission from Scottish Ministers

* Pesticide records to ensure pesticides have not been applied to the site

* There are no modifications to drains or new drains created

* Black Grouse and Capercaillie areas bird strike markers have been used on new fences

* Claimed capital items have been completed to approved amounts and scheme standards.

List of links to relevant technical guidance

* Minimum requirements for Fertiliser and Plant Protection Products - detailed guidance

* Minimum requirements for protection of historic or archaeological features

* "On the spot" inspections - overview of the inspection procedure

* The appropriateness of any new deer fencing should be considered in the context of the Joint Agency Fencing Guidance

Chapter six: THE FUTURE OF TREELINE ECOTONE SCRUB IN SCOTLAND

As the impacts of climate change advance a number of ecologists have highlighted the increasing importance of marginal and ecotone habitats in the adaptation of vegetation to these changes (Hester and Brooker 2007, Crawford 2008). Ecotones are boundaries between major habitats which tend to fluctuate and have the capacity to facilitate the migration of slower moving species from the bounding habitats (Risser 1993). In the UK there is currently very little opportunity for this dynamic to function at the treeline ecotone because the forest-open ground transition habitats are scarce and in urgent need of management to ensure their future. Climate change will not act in isolation of other drivers of change in upland ecosystems and it is crucial to understand how combinations of current land management and current climate are driving the condition of the existing treeline ecotone scrub (treeline scrub) populations and their potential for self-perpetuation, in the context of future projections of climate and land management changes. Upland land use policy is also a major driver of change through its influence on land management, and it is critical to discussions about the future of treeline scrub to understand how such policy operates and is likely to change in future. The aim of this thesis was to develop a better understanding of these issues. In so doing it has characterised the treeline ecotone sites of existing populations of *Betula nana, Salix myrsinites* and *Juniperus communis* and has demonstrated how the interactions of herbivory and wind exposure, and differences in snow cover affect young plants of these species. In addition to the experimental and survey findings, this thesis has clarified how treeline scrub fits within current upland land use policy and the expectation of action for the future of these habitats.

The following research questions were raised:

1. a) Are there unique factors (firstly topography, altitude and aspect, secondly soil pH and chemistry, thirdly land cover) associated with the sites occupied by existing populations that suggest the current distribution of treeline scrub is at its maximum?

   b) Are land management factors, particularly herbivory, limiting treeline scrub growth and survival?

2. Do interactions between climate and land management, two major features of the Scottish upland landscape, affect the growth and development of young treeline scrub plants?

3. Is the future of treeline scrub likely to be ensured or not as a result of the current provisions in rural and land use policy and the strategies for delivery?

The following sections summarise the findings from the research described in the foregoing chapters outlining how each has addressed the questions above, how they complement each other and contribute to our understanding of the key issues. Finally the findings are brought together in a summary discussion to identify how this new understanding might guide the management of existing and future treeline scrub. Through the investigations undertaken further questions and research needs critical to the future of these populations in the UK have also been raised and these are summarised at the end of this chapter.

6.1 WHERE DOES TREELINE SCRUB CURRENTLY GROW IN SCOTLAND, AND WHAT MIGHT AFFECT ITS DISTRIBUTION?

The survey of existing treeline scrub sites (Chapter two) primarily contributed to both parts of research question 1, and contributed to answering 2. There was a wide range of variation found in the characteristics measured within the sites surveyed for each species (*Betula nana*, *Salix myrsinites* and *Juniperus communis*). Whether these same combinations of characteristics are more widespread was not tested, but the initial site selection process identified land-cover (Macaulay Land Use Research Institute 1993) and soil types (Macaulay Institute for Soil Research 1984) currently occupied by each population which are not uncommon in upland Scotland. Averis *et al.* (2004) identified more NVC types in which the three species occur in addition to the community they are primarily associated with (Table 1.1, page 16). All three species appear to be long-lived, although there is no specific data on the ages in the UK of *B. nana* and *S. myrsinites*. Circumstantial evidence suggests that the current populations have survived, quite possibly with the same individuals, for a very long time. All three species reproduce vegetatively through layering, and in the case of *B. nana* and *S. myrsinites* through suckers from both roots and horizontal stems.

Across all the sites surveyed a number of features were common. All sites, with the exception of one *B. nana* and one *J. communis* site, had patches of bare ground that might be suitable niches for the establishment of seedlings. At many sites at least some plants were flowering and most of the dioecious populations had both male and female plants present. It is not possible to draw conclusions about the seeding capacity of a plant population from the presence of flowers, or from a single visit, and this observation only demonstrates that the populations were sufficiently productive in 2008 to produce flowers. Male flowers appeared to be scarce at *B. nana* sites but they generally open early in the year before females (De Groot *et al.* 1997) and are likely to have dropped off the plants by the time of many visits.

Evidence of seedling recruitment into populations was absent from most sites and rare when it did occur. The evidence of a fluctuating but frequently high number of herbivores in the uplands over the twentieth, and now into the twenty-first centuries suggests that herbivores might be a controlling factor, as has been reported for other woodland habitats (e.g. Milne *et al.* 1998). The unpredictable nature of tree birch regeneration is well documented (Thompson 2004), and *B. nana* appears to be very similar (De Groot 1997). Successful establishment of willow and *Juniperus* spp. seedlings also seems unpredictable, particularly at higher altitudes, for a variety of reasons including the weather during pollination and seed dispersal, and the availability of establishment niches (Sullivan 1997, 2001, Brome 2003, Shaw 2006).

All three species have seen a retraction of their distributions in Scotland over the years between the last two plant atlas censuses (1986 – 1999, Preston *et al.* 2002). Further work is required to test why they have retracted, and to test for the availability of additional areas with similar characteristics to those surveyed, but which do not currently support treeline scrub populations. The following is a discussion of the key findings from the survey for each species, focussing on aspects which were particularly pertinent to each particular species.

6.1.1 *Betula nana*

Site and population characteristics

For *B. nana* the majority of sites surveyed, with one particular exception, were blanket mire with an intact moss layer. As found in this survey, Kallio and Mäkinen (1987) reported that, in Finland, *B. nana* rarely forms extensive stands on steeper slopes, but “steep” is not quantified. They describe it as occurring on a wide range of sites; exposed summits, heaths and peatlands, including areas where the ground cover includes pleurocarpous moss (*Hylocomium proliferum* and *Pleurozium* sp.) mats. There is a specific heath type named after the plant (skierrevađđas, where skierre refers to *B. nana*). Whittaker (1993) reports *B. nana* from older glacial foreground (between 200 and 300 years old) with fine damp soils. The Glen Muick site was topographically and edaphically different from the others surveyed, as demonstrated by its isolated position at the extreme left hand end of the Principal Component Analysis scores plot of the first two axes (Fig. 2.2). The key features relevant to this part of the axis are steepness of slope, an eastern location and high altitude (Fig. 2.1). The results of the field survey showed that the soil at Glen Muick had lower concentrations of carbon and nitrogen than all the other sites (Fig. 2.13), yet the pH was towards the middle of the range. Notably the site had the largest plants found in the survey (Fig. 2.10) which raises a fundamental question about the ‘ideal’ site type for this species. Rodwell (1991a) describes an anthropogenically-stimulated succession of *Calluna – Eriophorum* mire (which is the main community described as supporting *B. nana* in the UK) to *Eriophorum* mire, an impoverished version which lacks the moss ground cover and ericaceous associates (and presumably *B. nana*), following burning or drainage and/or heavy grazing. He also makes the point that it is a readily reversible change but does not consider the presence of *B. nana* in this comment.

The evidence from this survey suggests that the population at Glen Muick may exist on a site type which is towards one end of a range of tolerances for the species in the UK and the majority of other sites appeared to be at the opposite end. This indicates that site factors suitable for this species may be broader than generally perceived (De Groot *et al.* 1997) and more widespread across Scotland than the current distribution suggests.

Land management impacts

Across all the sites surveyed horizontal stems and suckering were common and so individual plants are actively expanding, or over the longer term 'moving around' the site. There is a possibility, given the prolific nature of the suckering, that small discrete populations may be derived from a single individual. The presence of some plants with relatively (for the sites studied) long leader lengths (up to 10cm, measured at the end of July) at Carn Dubh, the site with the smallest plants and the highest browsing pressure, suggests that these plants may have the capacity to grow year on year if grazing were reduced (Scott 2001). However, this may not always be the case (Crete and Doucet 1998) if summer foliage browsing occurs, and further work would be valuable in determining the potential for population recovery on the poorest sites.

The presence of a moss layer at many sites may be crucial to the long-term survival of *B. nana* where land management includes burning, draining and/or grazing and this warrants further study. The hypothesis proposed here is that the moss layer provides cover for horizontal stems protecting them from browsing, and where it retains sufficient moisture, from fire, and that these protected stems subsequently readily produce new shoots. There is no concrete evidence to support this view, although circumstantial evidence suggest that the loss of the populations at these two study sites over the last twenty years coincided with the loss of the moss layer, in one case following an intense burn, in the other both burning and drainage.

Recruitment potential

Seedling establishment is enhanced by the presence of mycorrhizal associates (Andy Taylor, *pers com*), and particularly in situations of low nutrient status (Harley and Harley 1987) and

B. nana is known to readily develop ectomycorrhizal associations (Kallio & Mäkinen 1978, Harley and Harley 1987). However, these organisms are strict aerobes (Andy Taylor, *pers com*) and are unlikely to be present in saturated peat soils. This suggests that the successful seedling-based expansion of the species may be more likely on sites without water–logged soils. *B. nana* seedlings are very small in their first year and very vulnerable to desiccation. At the majority of sites seeds are likely to fall on deep *Sphagnum* carpets and the seedlings roots would not penetrate through the upper levels of the *Sphagnum* layer in their first year. Rodwell (1991a) described *Calluna- Eriphorum* community as being the driest mire which frequently dries on the surface during the summer months. This suggests that it is very unlikely that many seedlings would survive into their first winter. The Glen Muick population was the only one at which seedlings were seen, although they were uncommon even here. Kallio and Mäkinen (1987) suggest that there may be different strains of the species and no work has been done on this in the UK.

6.1.2 *Salix myrsinites*

Site and population characteristics

The *Salix myrsinites* populations surveyed had low percentage cover across the sites. The wide range of pH, including many acidic sites, questions the categorisation of this plant as "distinctly basiphilous" (Christensen 2000) in the UK, and suggests that it is tolerant of a relatively wide range of soil base-status, as suggested by Mardon (1994). This is reflected in the variety of vegetation associations found across the sites.

Land management impacts

Like most *Salix* species (Bryant and Kuropat 1980, Stolter 2005) it is clear from the survey that *S. myrsinites* is able to tolerate browsing from the evidence of continuous browsing at most sites. Shaw (2006) demonstrated that simulated browsing had a negative effect on flower production of *S. arbuscula*, even at relatively moderate levels. Stolter (2005) demonstrated that the response to natural browsing by *S. phylicifolia* tended to be confined to the particular stem that had been browsed and subsequent flowers were concentrated on unaffected parts of the plant. From a UK perspective, an obvious question arising from this work is – 'how does the plant respond when every stem is subject to browsing?' Research to date on the dynamics of herbivory of sub-arctic or arctic willows has been in areas where willows are prolific and not at risk (Archer and Tieszen 1980, Bryant and Kuropat 1980, Danell *et al.* 1991, Jones *et al.* 1999, Mårell *et al.* 2006 to name a few). Literature examining the effects of continuous high levels of browsing on willows and the point at which the balance of impact may kill the plants is scarce (Maschinski 2001, Herder *et al.* 2008). It is also clear that different species of willows tend to have different responses to browsing, as Stolter (2005) reported for *S. phylicifolia* and *S. myrsinifolia* following a browsing-impact study of both species, and so one cannot assume that *S myrsinites* would respond in the same way as any other *Salix* species.

Inter-species competition

Most sites were in situations where the willow was taller than the surrounding vegetation. These sites tend to be on steep, unstable slopes, with limited browsing, and away from dense grass swards. At Inchnadamph a population exposed to browsing and one protected from sheep and red deer browsing were both surveyed. Overall the protected plants were taller than those outside the fence, but the surrounding vegetation generally exceeded the willows and leader lengths were similar between the two populations. Willows are known to be weak competitors (Grime 2001, Crawford 2008). However, there is little literature documenting the dynamics between alpine willow scrub and other open upland swards, particularly calcareous grasslands which are themselves uncommon in the UK and of conservation concern (JNCC 1999). From the results of this survey it is difficult to determine whether the current location of willow scrub is a response to competition from other vegetation, particularly grassland, or confinement to areas away from intensive herbivory, or both. There are many factors which control the potential for woody plants to invade grassland areas, including physical sites factors as demonstrated by Dullinger *et al.* (2003) who showed that the predicted invasion of subalpine grassland by *Pinus mugo* was more likely to be determined by local variations in topography and climate than just the warmer temperatures resulting from climate change. Understanding these relationships better would allow judgement to be made about the need for these plants to inhabit precipitous, eroding crags. Inchnadamph was described as an anomaly and as secondary scrub by Poore & McVean (1957). This site is at a low altitude and there are tree species present in the vicinity of the willow. However this has been the case now for well over fifty years and both trees and shrubs are still present suggesting that the scrub is not threatened by the presence of the trees in the medium term. This may be a very rare example of true UK treeline scrub. It was also the only site where the plant exists away from precipitous conditions, and yet has not succumbed to competition from surrounding vegetation despite being enclosed behind a large-mammal-proof fence for over fifty years. Despite this the plants at this site were relatively small and there has been no evidence of recruitment into the population since the fence was erected (Scott 1997). Only two plants were flowering during the site survey but no conclusions can be drawn from this.

Recruitment potential

The individual plants across most sites were predominantly widely spaced and frequently on steep crags where the distribution of plants was interrupted by rock out-crops or cliffs. *S. myrsinites* male and female flowers contain nectaries and are predominately insect-pollinated. In south west Norway Peeters and Totland (1999) found that a minimum of 2% of *S. myrsinites* flowers were wind pollinated. That individuals are widely spaced as well as being generally sited in exposed locations is likely to have a negative impact on the rate of pollination (Totland and Sottocornola 2001). Fifty metres is reported to be a reasonable distance for invertebrates to travel between different flowers to achieve effective pollination (Marriott 1997), presumably in a straight line. The insect pollinators of *S. arbuscula* were mostly small Diptera which were very dependent on weather conditions (Shaw 2006). As a result Shaw (2006) proposed that pollination levels were limiting seed production at the sites she studied. Other willow species at the same sites tended to be pollinated by species of bumblebees, which are larger, carry more pollen and are less sensitive to weather. Although pollination of *S. myrsinites* was not studied as part of this thesis, at sites where plants were sparsely distributed it would seem likely to be a limiting factor to current seed production.

Other factors arising from the survey

Relatively large populations of a gall (cf *Rhabdophaga rosaria*, unconfirmed identification) were found at two sites. Given the condition of most willow populations it would be valuable to learn more about the dynamics of this species as it has an impact that mimics heavy browsing by preventing all the new growth on inhabited shoots.

6.1.3 *Juniperus communis*

Site and population characteristics

Without exception all the *Juniperus communis* populations were composed of over-mature plants. Generally the populations were relatively densely spaced and occupied a wide range of sites. All sites surveyed faced between just west of south and north–west. Rodwell (1991b) suggested that *Juniperus communis* ssp *communis*-*Oxalis acetosella* woodland tends to favour a northern aspect. Sullivan (2003) surveyed 14 open growing *J. communis* populations above 350 m asl during the Scottish Natural Heritage juniper survey. Although 12 of these populations were in 1 km squares which predominantly faced between south-west through north to north-east, the aspect of the *J. communis* populations was not recorded. Collectively this information suggests that aspect may be important but this would need further research. In addition, all the sites surveyed for this thesis had relatively dry soils. This latter point agrees with the habitat description provided by Rodwell (1991b) for *Juniperus communis* ssp *communis*-*Oxalis acetosella* woodland (NVC W19). Although *J.*

communis ssp *nana* occurs in areas with considerably higher rainfall than NVC W19 (> 1600 mm yr^{-1} compared to 80 – 1200 mm yr^{-1}, Rodwell 1991a) the soils at the sites surveyed were very well drained.

Land management impacts

The age attained by juniper plants suggests that it can persist on areas which are subject to continuing grazing and browsing, unlike the other two species, by virtue of its low palatability (Miller *et al* 1982, Thomas *et al.* 2007). The literature suggests that *J. communis* is not tolerant of burning (reported by Thomas *et al.* 2007) and discussions with estate staff suggested their management supported this. At a number of *J. communis* populations the management aimed to prevent the spread of the tall-shrub onto areas which created conflict with other estate interests, and burning was used as the tool to achieve this.

Recruitment potential

At many of the sites the *J. communis* scrub was part of a larger area which was used for grazing by domestic stock and it was very unlikely that there would be regular successful recruitment into the neighbouring ground due to the grazing and the lack of niches within the grass sward. Young plants were rare and seedlings were seen at only two sites, both of which were in areas where the red deer population had been significantly reduced recently, so it is possible that herbivores are limiting seedling establishment of this species. It is not clear from this survey that browsing is necessarily the only factor limiting recruitment. At one site the sward appeared to be recovering from past management (there was evidence of past drainage), potentially involving grazing, and was so dense and unbroken that it was unlikely young juniper would be able to establish (Rodwell 1991b). In an earlier study one Scottish population of *J. communis* at 420 m asl was shown to have seed abortion rates of 50% in cones collected over a three year period (García *et al.*2000). However, this was from a small number of plants (6) and may not be representative. As with the other two species this requires further research.

6.1.4 Summary

This survey has shown that for *B. nana, S. myrsinites* and *J. communis* ssp. *communis* it is unlikely that geographical site factors are limiting their current distribution.

Essentially, all the populations of tall-shrubs at the sites surveyed were browsed to some extent and the level of intensity varied. *S. myrsinites* was largely confined to sites which are difficult to access and in most cases the base and larger part of each plant was not accessible to most browsers, and so the impact of ongoing levels of browsing is minimised. *J. communis* is of low palatability to large mammals (Thomas *et al.* 2007) and populations may have survived the recent high levels of herbivory due to the longevity and physical size of individuals at most sites.

Burning is a feature of the wider landscape in which both *B. nana* and *J. communis* (both subspecies) exist. Although very few of the populations appear to have been actively burned in the recent past, there was evidence of old burning at many *B. nana* sites and it was a current management on the areas uphill from a number of *J. communis* ssp *communis* populations. There was no evidence of burning being used as a vegetation management tool at any *S. myrsinites* population site.

6.2 TREELINE SCRUB: HERBIVORY AND EXPOSURE

The data from the experiment which investigated interactive effects of exposure and intensity of herbivory on young plants (Chapter three) contributed primarily to answering research question 2 and to a lesser extent question 1. The response of young cutting-origin plants of *Betula nana*, *Salix myrsinites* and *Juniperus communis* to the combined treatments of exposure and browsing was mixed and varied across the species.

6.2.1 *Betula nana*

Overall, *B. nana* grew better at low exposure, than at high exposure. The negative effect of high exposure appeared to mask the effect of clipping, particularly in year two, indicating that clipping to simulate browsing had little or no additional detrimental effect on plants whose growth was already limited by high exposure. However although growth was reduced the plants showed no exposure-related increased mortality. At low exposures there was a negative correlation between dimensional growth and clipping, indicating the detrimental effects of clipping on these plants. Kallio & Mäkinen (1978) reported *B. nana* was present on exposed mountain tops in Fennoscandia as low growing, prostrate plants. On the basis of physiological differences they also suggested there may be different genotypes or strains in Fennoscandia related to different growth forms in different habitats. The genetic variation across *B. nana* in the UK has not been examined.

6.2.2 *Salix myrsinites*

Some exposure increased the growth of the young *Salix myrsinites* plants. The effect may have been indirect because of apparent competition (for nutrients or light) with other vegetation at the low exposure site (the surrounding sward was denser and taller than at the higher exposures and from previous literature competition is expected to be a limiting factor) and the greater growth at mid-exposure was probably the result of less competition. This is supported by greater *Salix* shoot growth at the mid-exposed site compared with the high exposure site. The swards at both these exposure levels were similar in height and density, and shorter and less dense than at the low exposure site. The apparent response of this species to competition is potentially a very important factor in its distribution and requires further controlled experimental research.

Generally the effect of clipping was masked by the negative effect of shelter (competition).

6.2.3 ***Juniperus communis***

Juniperus communis was less affected by exposure than either *B. nana* or *S. myrsinites*. *J. communis* had reduced growth at the low exposure site, compared with other exposure levels. In contrast it showed a clear response to clipping of less new growth with increased clipping, and this was particularly apparent in the sheltered cages. However, canopy area measures were larger in 100% clipped plants than in 50% clipped so herbivory impacts were not clear cut in this species.

6.2.4 Summary

Shelter increased growth on young plants of *B. nana*, but reduced growth on young plants of *S. myrsinites* and, to a smaller extent, *J. communis*. Generally, the response of *B. nana* and *S. myrsinites* to clipping was masked by exposure effects, whereas *J. communis* showed a clear reduction in growth with increased clipping. Overall there was a large between-year difference in the response of *S. myrsinites* and *J. communis* to the treatments suggesting that perhaps the plants were still under-going changes associated with establishment. The results suggest that there would be benefit in maintaining the experiment for a longer period to allow the treatment effects to become clearer.

6.3 TREELINE SCRUB AND SNOW

The experiment investigated the effect of snow on the growth of young plants (Chapter four) and contributed to answering research question 2. Snow was found to be non-essential to the survival of young cutting-origin plants of *Betula nana, Salix myrsinites* or *Juniperus communis* as evidenced by over 60% of individuals of all species remaining alive in control cages and 76% in snow cages at the end of the experiment. The growth response of young plants to winter snow cover and altitude was mixed and varied between species.

6.3.1 ***Betula nana***

B. nana showed a small response to snow cover, and also showed reduced growth with increased altitude (as with exposure in the previous experiment) and there was some suggestion in the second year that snow might be more important at higher altitude (significantly greater growth in snow cages at the second highest altitude classes, Fig. 4.3).

Given that in the UK *B. nana* is very uncommon above 600 m asl it might have been expected to respond more negatively to altitude, and /or positively to snow cover at higher altitudes. Although more *B. nana* fatalities were in the higher, rather than lower, two altitude classes (6 compared to 2), and in the control, rather than snow, cages (5 compared to 3), the differences were not significant in analysis.

6.3.2 *Salix myrsinites*

The strongest effect of snow on young *S. myrsinites* was to mask the differences in growth due to altitude that was recorded in control cages. Although no clear trend was identified there was generally more growth at lower altitude in control cages. There was a positive, but small, effect of snow with consistently larger growth in snow cages compared to controls. There was no clear effect of altitude or snow on fatalities in *S. myrsinites*.

6.3.3 *Juniperus communis*

J. communis exhibited the smallest growth response to snow or altitude. This may be because the results were compounded by high mortality rates (32%), and high between-year growth differences. However there were consistently more deaths in the control cages (65%) across the altitude classes than in snow cages and a suggestion of increased mortality with higher altitude (altitude class 1:3, 2:6, 3:10, and 4:7). This suggests that snow may protect or facilitate *J. communis* establishment and growth at higher altitudes, but requires more research. Thomas *et al.* (2007) reported that snow causes breakages of mature *J. communis* and may be the reason that higher altitude plants are more prostrate. However there is little literature on the response of young plants to snow cover.

6.3.4 Summary

While there was some evidence of a positive effect of snow on the growth of young *Betula nana, Salix myrsinites* or *Juniperus communis* it was not critical to their survival and the projected loss of snow in Scotland is unlikely to adversely affect the establishment of young plants. However other climatic changes such as increased temperature, particularly if it is accompanied by growing competition from other plants migrating up hill, were not studied and may have a different effect on the fate of treeline scrub.

6.4 UPLAND LAND USE POLICY AND TREELINE SCRUB

The upland policy review and qualitative survey of people involved in policy in Scotland primarily provided the material to answer research question 3.

6.4.1 Policy review

The land use policy review identified that there is nothing in Global, European or UK policy which specifically excludes treeline scrub. Neither is it specifically included as a coherent vegetation type. At a European and UK level a number of different plant communities which include treeline tall-shrub species are identified as of conservation interest, and two species have attracted specific conservation action (Table 5.7). At a Scottish level the different elements of treeline scrub all feature in policy, and are included in the current Scottish Rural Development Programme (SRDP), which is the primary strategic implementation plan providing incentives to all land managers and so is a key driver of land management in the uplands (Appendix 5.2 Table A5.2).

6.4.2 Policy interviews

Across those interviewed who are involved in writing and delivering policy there was no collective consciousness of this group of habitats, compared, for example, to the profile of Capercaillie, or Caledonian Pine Forest. There was a wide span of knowledge and understanding (from very limited to very knowledgeable) both across different land use sectors, but also within each land use sector and particularly within conservation. This range of knowledge and appreciation was even broader across the representatives of non-governmental organisations interviewed as policy influencers. The conclusion from this is that there is a general a lack of ambassadorial effort from those in a position to influence land managers and therefore significant action to raise awareness of these habitats and promote the uptake of the incentives for their management seems unlikely to happen. These results suggest that there may not be any need to press for changes in policy, but there may be a need to change implementation processes. The future of these habitats will be partly dependent on those involved in upland land use policy, and on the wider public developing a greater understanding of the role of diversity in the uplands and the broader benefits this would provide to society as a whole, but particularly to those who use the landscape.

6.5 TREELINE SCRUB IN UPLAND SCOTLAND

6.5.1 Current and future scrub distribution

The survey of existing sites (Chapter two) indicated that the current distributions of the three species surveyed were probably more restricted than their potential range. The survey attempted to capture the full range of different site types currently occupied by each species. Without additional survey it is not possible to determine how successful it was in achieving that aim. Nonetheless the results suggest that even the sites which were surveyed span a wider range of characteristics than those previously reported for UK populations of *B. nana*

(De Groot *et al.* 1997) or *S. myrsinites* (Meikle 1984), but not for *J. communis* (Thomas *et al.* 2007). A key site selection factor was that each population comprised at least 10 plants. This was necessary in order to gather sufficient useful data, but it restricted the choice of populations and it is possible that the full range of site types is wider. With the recent history of high herbivore numbers there was a strong possibility that some populations may be relatively small only because of browsing pressure, rather than necessarily any topographical or edaphic site characteristics. Nonetheless the range of characteristics found at both *B. nana* and *J. communis* sites suggest that these species could be more widespread than they currently are.

Critical to the future of all populations of treeline scrub will be their ability to perpetuate themselves in the future. Vegetative spread is prevalent and documented to be important to high latitude and altitude species (Bliss 1971, Crawford 2008) with seed production at least an occasional feature of willows and birch in these areas (Belisle and Maillette 1988, De Groot *et al.* 1997). Many of the populations of all the species surveyed were flowering. However there was only very limited evidence that this investment was producing recruitment into the populations and this may be a critical phase which is limiting in the UK.

The exposure/clipping experiment at the Ben Lawers NNR showed that young plants of the three species responded differently to the combined impact of browsing and exposure. Perhaps the most interesting outcome was the contrasting responses of *B. nana* and *S. myrsinites,* with the former responding positively to shelter and the latter negatively. This response by *S. myrsinites* was particularly significant as there were high levels of mortality at the low exposure site (73 % in the sheltered cage, and 60% in the open) which suggests that shelter, or competition from other species, such as grasses, may be a more important negative effect than browsing or high exposure. Shaw (2006) suggested this may also be the case for *S. arbuscula,* a species present in the grazed grassland at Ben Lawers. These outcomes indicate that where expansion or re-creation of treeline scrub habitats was proposed care would be required in the choice and management of site for either species.

The response of *S. myrsinites* to simulated browsing was less clear than for the other two species, and this species appeared to increase shoot extension following intensive clipping. This indicates compounding of the normally negative effects of tissue removal by browsing with some other positive (compensatory?) effect associated with browsing. Further research to identify the strategic response of this willow to browsing would be very useful in relation to future management. For example to determine whether individual browsed shoots respond separately from the whole plant, as recorded in *S. phylicifolia* by Stolter *et al.*

(2005), and if so, how the whole plant responds if all shoots are browsed, would potentially improve the quality of management advice. The rocky and precipitous nature of the sites surveyed suggests that exclusion of herbivores would be very difficult. On more stable sites an exclosure would have the potential to promote increased sward growth in direct competition with willow plant development. Better understanding of the sward-willow-herbivore dynamics should increase the precision of management recommendations and so would improve the potential for positive management.

Snow cover over winter had a positive effect on the young plants of all three species to different degrees. However it was apparently not critical to their survival, as evidenced by the low levels of mortality, particularly in *B. nana* and *S. myrsinites*. There were higher levels of mortality in *J. communis* but these were still less than 50%. This appeared to be largely due to poorer initial root growth of the cuttings compared to both *B. nana* and *S. myrsinites*. It would be useful to undertake further research with well rooted cuttings or established plants of this species to remove this source of variation.

The outcomes of the survey suggest that both grazing by large herbivores and burning has had a direct negative impact on the distribution of both *B. nana* and *J. communis*, and continues to do so. It is also clear that current *S. myrsinites* populations are in locations which are largerly inaccessible to large-herbivore browsing. This suggests the long-term future of these species may be dependent on the management of large herbivores, and particularly in the case of *J. communis*, changes in practices related to sporting and agricultural land management, such as reduced burning.

In summary, land management appears to have had a large influence on the distribution of *B. nana*, *J. communis* and *S. myrsinites* and it seems likely that the populations of these plants could be more widely spread than they currently are. However, the successful increase in plant size, seed production and recruitment that would facilitate their spread will require species specific management solutions for the dynamics between herbivory and competition. In addition, consideration of other potential impacts of climate change on their growth and survival will be required.

6.5.2 The influence of land use policy

There is evidence from the reference to treeline scrub habitats in Forestry Commission strategy documents (FCS 2009), a range of local biodiversity action plans (Table A5.1), and the measures in the current agri-environment programme (Scottish Government 2010) that the general level of awareness of treeline scrub in the Scotland, UK is higher in 2010 than it was in 1996. However, the likelihood that an applicant to the incentive scheme would find and independently choose to take up this option is probably low. The evidence from the survey of attitudes to this vegetation (Chapter five) suggested that the level of understanding of these habitats and the issues relating to their management was almost entirely confined to interested individuals. In particular, there remained a low level of awareness within agriculture and in some elements of the hunting sectors. These two sectors control most of the land on which treeline scrub populations exist and their involvement will be important to their future. Those who were known to have utilised this option specifically for treeline scrub were land-owning environmental charities whose understanding of the habitat was high.

6.6 CONCLUSIONS

A number of conclusions can be drawn from the outcomes of this research, and these in turn raise a number of issues for the future.

6.6.1 Existing populations

The existing populations of *B. nana, S. myrsinites* and *J. communis* currently appear to occupy a subset of their potential biophysical distribution. Large plant size across the three species was generally coincident with evidence of low browsing impacts.

The condition of many populations suggests that they have a restricted age range and are composed mainly of old plants, and that the rate of new plant recruitment is very low or non-existent. In many cases the lack of recruitment probably relates both to limitations due to herbivory and to the physical nature of the site. This suggests that it will be necessary to intervene in order to alleviate the issues, but further direct research would be required to verify this.

In the case of *B. nana* there is a need to address the issue of whether existing populations are growing on their optimum substrate or not. There may be an argument for an experimental investigation of the development of populations on different heath and mire substrates. A similar investigation of site characteristics for *S. myrsinites* combined with manipulative experiments may shed some light on the relationship between competition, exposure and herbivory. Better understanding of these two aspects would improve management guidance for these species.

Reduction in browsing pressure and cessation of burning close to their boundaries may be all that is required to facilitate recruitment of young plants into some *J. communis* populations. However to achieve this the perceived conflict between *J. communis* and open moorland management would need to be addressed. Three of the studied populations exist on land which is currently under management to improve the condition of the semi-natural vegetation cover. It is too early to tell whether reduced herbivore numbers will be sufficient to allow *J. communis* recruitment on these sites. One of the highest numbers of young juniper seen during the survey was on one of these sites.

6.6.2 Expansion of the current population base

From the experimental data collected the projected reduction in winter snow cover in the UK is unlikely to limit the distribution of suitable sites for establishment of young *Betula nana, Salix myrsinites* or *Juniperus communis* within their current altitudinal range. However loss of snow cover may adversely affect the suitability of the highest altitude sites that could be occupied.

The apparent currently restricted distributions and the absence of existing natural recruitment into populations suggests there is an argument for propagating species and establishing new populations by planting. There are already several projects initiated with this aim, including one for the rare *S. lanata*. In the case of *B. nana* this may require collecting seed and / or cuttings. There are accessible populations with enough apparently fertile individuals to produce seed in quantity. However caution must be expressed over collecting seed from only one or a small number of locations. De Groot *et al.* (1997) reported that *B. nana* was not completely self-sterile but were unclear about the circumstances which cause self-incompatibility to break down. All the evidence quoted was from more northern populations and so may not relate to UK populations. There is a possibility that small groups of individuals in the UK may be clonal and so would not make good sources of seed. *B. nana* readily hybridizes with *B. pubescens* (Kallio and Makinen 1978). As interest in *B. nana* has grown in the UK so has the number of records of hybrids and there is no guarantee that seed collected from relatively isolated populations will not contain some hybrid material. Seed collected close to existing woodland which contains *B. pubescens* will almost certainly contain hybrids.

Production of propagation material from *S. myrsinites* poses different issues. All the populations are relatively small and relatively inaccessible, with widely spaced individuals. Despite this most populations surveyed had both sexes present and were flowering. Shaw (2006) showed that flower production was related to herbivory and that viable seed production was related to the type of pollinators and the weather. There has been no study of the numbers of seed produced or their viability for *S. myrsinites*. If other species of *Salix* are present there is a possibility of hybrid material being present, although Meikle (1984) does not report any for *S. myrsinites* in the UK, Christensen *et al.* (2000) report hybrids from

Norway with *S. herbaceae, S. myrsinifolia* and *S. phylicifolia* all of which occur in the UK. The taking of cuttings is a safer method of producing young plants that are true to the parent and their collection is less dependent on the correct timing. However, the growth rates in many populations surveyed were poor and it is more labour intensive per plant than seed collection. It is unlikely therefore that the existing populations would make appropriate sources for such material. It was not possible to collect the target size (10 cm minimum) and number (200) of cuttings for this research at the three *S. myrsinites* populations visited within the constraints of the protocol agreed with SNH (Appendix 3.1). Other methods of propagation are available (for example tissue culture) and their appropriate application to this purpose would require investigation.

6.7 THE FUTURE OF TREELINE SCRUB: RESEARCH REQUIREMENTS

During the course of this research the following additional knowledge gaps were identified which would require further research in order to provide for the sustainable future of treeline scrub in the UK.

- There is a need to clarify the range of substrates that *B. nana* can utilise, and determine which are best suited for the self-perpetuation of the plant.
- Impact of climate change on flower production and pollination, particularly in *B. nana,* requires further investigation. Male and female flowers of different species respond to different stimuli De Groot *et al.* (1997). They reported that male flowers of *B. nana* release pollen at snowmelt and that late flowering does not produce viable pollen. Some *B. nana* populations in the UK do produce viable seed and so the significance of this in the UK where most populations will not be covered in snow over winter is unknown. They also quote from earlier work that “male flowering was strongly controlled by genetics while weather had a greater control on female flowering”, with no further explanation of the apparent inconsistencies. This suggests that there is a lack of clarity about the details of pollination in *B. nana,* particularly in the UK. In addition, during the survey the male flowers that were found tended to be close to the ground and well below the height of the surrounding vegetation. The potential for effective pollination of neighbouring plants from this position appeared compromised. Both these points suggest that further research is required to clarify whether pollination is a limiting factor now or likely to become so if the gap in timing between male and female flower opening is lengthened by a warmer spring.

- The competitive relationships between *S. myrsinites* and the surrounding vegetation types on more stable ground require clarification. How invasible is the grassland for *S. myrsinites*? If it can, in theory, invade the vegetation surrounding existing populations what is the current limitation (see below)?
- The reproductive capacity of existing *S. myrsinites* populations requires better understanding. Are the individuals close enough to each other to allow effective pollination? What size of population, and what proportion of male to female plants generally produces enough viable seed to facilitate a minimum level of recruitment to sustain the population? How do the dynamics of seed production relate to different levels of natural herbivory?
- What wider benefits arise from having a larger component of treeline scrub in the upland landscape? If considered beneficial, how can this be effectively communicated to land managers and the wider population? How would such a habitat contribute to the broader delivery of sustainability aims for better water quality and hydrological processes, increased carbon sequestration, increased nutrient cycling and improvement of upland soils for example?

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ABBREVIATIONS AND CONVENTIONS

The following are the abbreviations and conventions used in this thesis

ANOVA	Analysis of Variance
BAP	Biodiversity action plan
BFT	Borders Forest Trust
CBD	Convention on Biological Diversity
CCS	Crofters Commission Scotland
CNPA	Cairngorms National Park Authority
DAMS	Detailed Aspect Method Scoring
EC	European Commission
EC	European Community
EU	European Union
FCS	Forestry Commission (Scotland)
HAP	Habitat action plan
HLF	Heritage Lottery Fund
IUCN	International Union for the Conservation of Nature
JNCC	Joint Nature Conservation Committee
L.S.D.	Least Significant Difference
LFAS	Less Favoured Area Status
LTNPA	Loch Lommond and Trossachs National Park Authority
m asl	Metres Above Sea Level
MISR	Macaulay Institute of Soil Research
MLURI	Macaulay Land Research Institute
NGO	Non-Governmental Organisation
NTS	National Trust for Scotland
NVC	National Vegetation Classification
PCA	Principal Component Analysis
RCM	Regional Climate Model
REML	Residual Maximum Likelihood
RPAC	Regional Proposal Assessment Committee
S.E.D.	Standard Errors Difference
SAP	Species action plan
SEPA	Scottish Environmental Protection Agency
SG	Scottish Government
SNH	Scottish Natural Heritage
SRDP	Scottish Rural Development Plan / or Programme
TfL	Trees for Life
UK	Britain, the British Isles and Northern Island
UK BAP	British biodiversity action plan

UK plant names follow the conventions of Stace C.A (2001). *New Flora of the British Isles* 2nd Edition, Cambridge University Press

Modern animal names follow the convention of Harris S., and Yalden, D., 2008. *Mammals of the British Isles: Handbook* (4th Ed) The Mammal Society, London, UK