School of Agriculture and Environmental Science

MSc Project:

Comparison Of Dead Wood Composition and Forest Regeneration in Broadleaf and Coniferous Stands - 'Wild' Ennerdale, Cumbria, UK

Are there implications to management strategy?

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Abstract

There is a shortage of studies in Britain focused on Coarse Woody Debris (CWD) composition and interactions with woodland regeneration. CWD can facilitate seedling establishment by providing protection from ungulate grazing and optimal substrate for seed germination. This study explores the relationship between CWD and woodland regeneration in various stand types across Ennerdale valley located in the North West of England.

Comparisons of CWD were made between ancient, native, even-aged conifer plantation and thinned conifer plantation under continuous cover forestry (CCF). Woodland regeneration was assessed by estimating tree species seedling and sapling cover and comparisons between woodland types and environmental parameters made using multivariate techniques.

CWD volume was found to be 50.90m^3ha^{-1}, across the whole valley The even-aged conifer stand had the lowest amount (17.96 m^3ha^{-1}) and the ancient woodland stand exhibited a significantly higher CWD volume (70.06m^3ha^{-1}; $p=0.024$) than both the even-aged and native woodland types. There were low numbers of standing dead trees and large diameter logs throughout the whole valley limiting the diversity of habitat type for biodiversity and reducing the longevity of CWD composition in the valley.

There were indications that log volume; by providing protection from sheep grazing in the ancient woodland and providing more optimal substrate for seed germination in the conifer stands had influenced specific species; holly in the conifer woodlands and birch and rowan saplings in the native woodland, although not found to be a significant relationship. Further investigations into the implications of CWD on specific species would be beneficial to aid decisions relating to the intensities of grazing and the establishment of native woodland species into conifer stands converted to CCF.

Table of Contents

ABSTRACT I

LIST OF ABBREVIATIONS V

1. INTRODUCTION 6

1.1 Study Area 6

1.2 Landform, Geology and Climate 7

1.3 Management 8

1.4 Woodlands 9

1.4.1 Native Woodland 10

1.4.2 Conifer Plantations 11

1.5 Corse Woody Debris as a Biodiversity Indicator 11

1.6 The Influence of CWD on Forest Development 14

1.7 Management of CWD for improved forest ecosystems 16

2. AIMS AND OBJECTIVES 18

2.1 Aim 18

2.2 Objectives 18

3. MATERIALS AND METHODS 19

3.1 Study Area and Sites 19

3.2 CWD Classification and Measurements 21

3.3 Fallen CWD Sampling Protocol 23

3.4 Calculation of deadwood volume 24

3.5 Environmental Parameter Measurements 24

3.6 Stand Composition and Development 25

3.7 Data Analysis 25

3.7.1 CWD Composition 25
3.7.2 Forest Development 26

4. RESULTS 27

4.1 Composition of CWD 27
4.1.1 CWD Volume and Type 27
4.1.2 Diameter Class 30
4.1.3 Decay Class 31

4.2 Woodland Regeneration 34
4.2.1 Whole Valley 35
4.2.2 Native Woodland 37
4.2.3 Conifer Woodland 39

5. DISCUSSION 41

5.1 CWD Composition in Ennerdale 41
5.1.1 Estimated Volumes 41
5.1.2 CWD Types, Diameter and Decay Class 43

5.2 Factors Influencing Woodland Regeneration 46
5.2.1 Overall Woodland Regeneration 46
5.2.2 Native Woodland Regeneration 48
5.2.3 Coniferous Woodland Regeneration 49

5.3 Limitations 50

5.4 Management Implications 51

5.5 Future Research Possibilities 52

6. CONCLUSION 53

ACKNOWLEDGEMENTS 54

REFERENCES 55

APPENDIX 1. - *MAPS* 60

APPENDIX 2.- *DATA ANALYSIS* 65

APPENDIX 3.- *RAW DATA* 79

List of Tables

Table 1: Coarse Woody Debris Decomposition Classification……………………….22

Table 2: Mean volume of Coarse Woody Debris by stand type. 27

Table 3: Median snag number and wood volume by stand type............................. 28

Table 4: The CWD Type and volume allocated to decay class by stand type 33

Table 5: CCA results for the whole valley, native woodland and conifer woodland . 39

Table 6: Studies quantifying dead wood levels around the world 42

List of Figures

Figure 1: Ennerdale Valley Location.. 6

Figure 2: The mean volume of logs and stumps by stand type. 28

Figure 3: GIS Map showing the distribution of CWD Type and Volume 29

Figure 4: The total volume of logs allocated to diameter class by stand type.......... 30

Figure 5: The number of snags found in each diameter class by stand type........... 31

Figure 6: The total volume of CWD types allocated to decay class 32

Figure 7: Percentage occurrence of trees by successional stage. 35

Figure 8: Canonical axes 1 and 2 obtained from CCA - Whole valley..................... 36

Figure 9: Canonical axes 1 and 2 obtained from CCA - Native woodland 38

Figure 10: Canonical axes 1 and 2 obtained from CCA - Conifer woodland 40

List of Abbreviations

ASH	Ash
ASPN	Northerly Slope Aspect
ASPS	Southerly Slope Aspect
AW	Ancient Woodland
BCH	Beech
BIR	Birch
CCA	Constrained Correspondence Analysis
CCF	Continual Cover Forestry
COWN	No Cow Grazing
COWY	Cow Grazing
CPY	Percentage Canopy Cover
CWD	Coarse Woody Debris
DDW	Downed Dead Wood
EC	Even-aged Conifer
EEA	European Environment Agency
ELV	Elevation
GIS	Geographical Information System
HAZ	Hazel
HOL	Holly
LAR	Larch
LGN	Log Number
LGV	Log Volume
MT	Mature Tree
MT1	PC1 axis of the Mature Tree Data
MT2	PC2 axis of the Mature Tree Data
NW	Native Woodland
OAK	Oak
ROW	Rowan
RSPB	Royal Society for the Protection of Birds
Sd	Seedling
SHPN	No Sheep Grazing
SHPY	Sheep Grazing
SLP	Angle of Slope
SNN	Snag Number
SNV	Snag Volume
Sp	Sapling
SPR	Spruce
SSSI	Site of Special Scientific Interest
STN	Stump Number
STV	Stump Volume
SYC	Sycamore
TC	Thinned Conifer
WESP	Wild Ennerdale Stewardship Plan
WV	Whole Valley

1. Introduction

1.1 Study Area

Ennerdale valley is situated in the north west of England, 10 km due east of the town of Whitehaven and within the Lake District National Park, Grid Reference NY 110148 (Figure 1). The valley is approximately 14 km long and 5 km at its widest, it covers an area of around 4711 hectares with an altitudinal range of 100 m on the valley floor to nearly 900 m AOD on the mountain summits. Ennerdale Water which is fed by the river Liza lies at the bottom of the steep sided valley and is designated a SSSI for its high biological value characteristic of an oligotrophic lake (Natural England, 2013a).

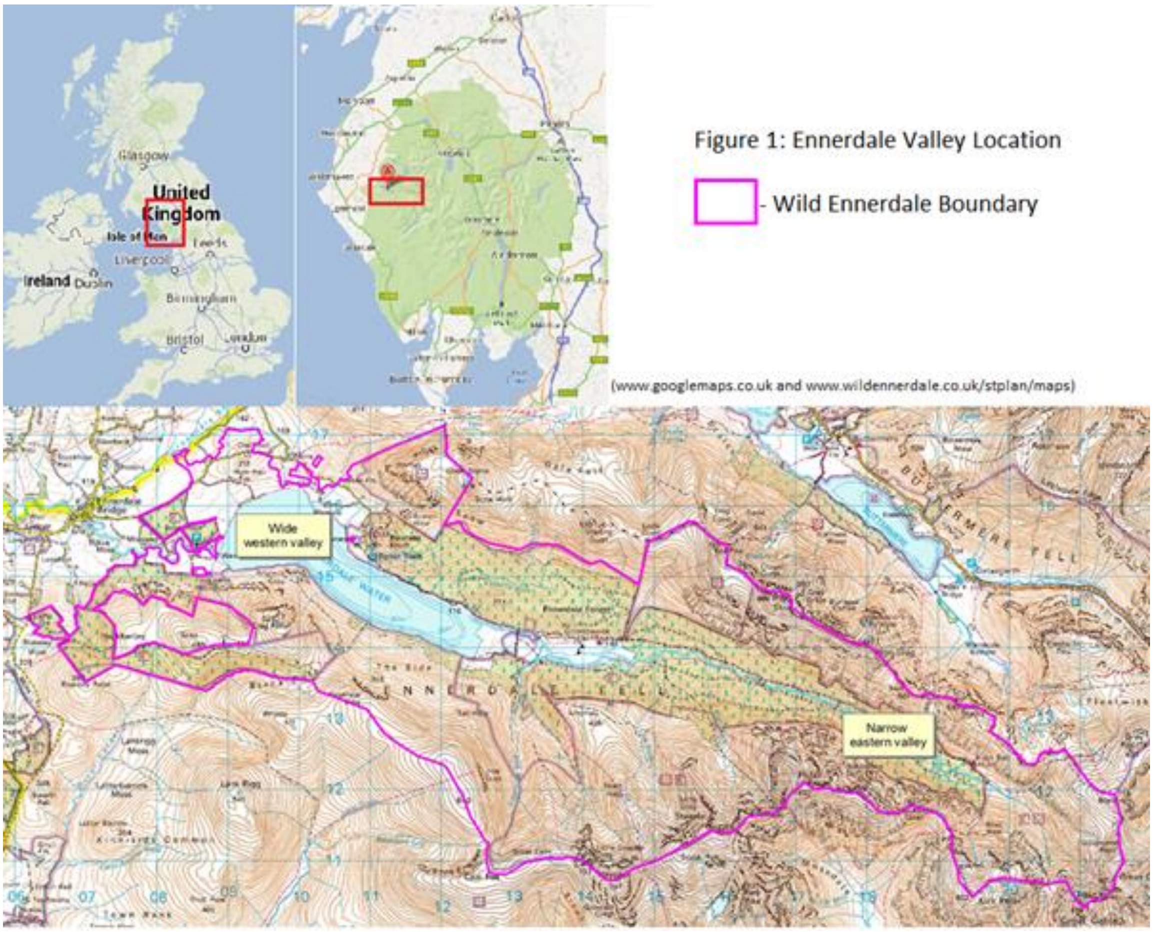

Figure 1: Ennerdale Valley Location

(www.googlemaps.co.uk and www.wildennerdale.co.uk/stplan/maps)

Within Ennerdale there is a diverse set of land uses; including farming, forestry and recreation. Around 40% of the area is designated as a Site of Special Scientific Interest' and 'Special Area of Conservation' (Browning and Gorst, 2011). Conservation interests are focussed particularly on areas of native oak woodland, which exhibit one of the best known examples of altitudinal succession in England as well as supporting rare lichen and bryophyte communities (Natural England, 2013a).

Flora and fauna species of interest include lesser (*Utriculana minor*) and intermediate (*Utriculana intermedia*) bladderworts, the nationally rare char (*Salvelinus alpinus*), the endangered red squirrel (*Sciurus vulgaris*), the re-introduced Marsh fritilary (*Euphydryas aurinia*), the amber listed; green woodpecker (*Picus viridis*), wood warbler (*Phylloscopus trochilus*) and red listed song thrush (*Turdus philomelos*) (RSPB, 2013) as well as breeding species of birds including; buzzard (*Buteo buteo)*, peregrine (*Falco peregrinus*), merlin (*Falco columbarius*), wheatear (*Oenanthe oenanthe*), whinchat (*Saxicola rubetra*) and ring-ouzel (*Turdus torquatus*) (Natural England, 2013a).

1.2 Landform, Geology and Climate

The majority of the eastern side of the valley is underlain by Borrowdale Volcanics of the Ordovician era (443 to 495 million years ago), and specifically Ennerdale Granophyre estimated to be around 1100m thick (re-named Lake District Ordovician Felsic Plutonic Suite) which is an igneous bedrock formed with intrusions of silica-rich magma (British Geological Survey, 2013). In the Devonian era (417-354 million years ago) the area experienced increased earth movements and compression of the crust which caused up lifting and buckling of earlier deposits of the metamorphic Skiddaw Slate series (Natural England, 2013b). To the south west of Ennerdale Water is the

Buttermere Formation made up of mudstone and sandstone deposited under marine conditions throughout the Ordovician and the Silurian age (443-417 million years ago). Along with weathering of these rocks the steep valley sides and shallow valley floor of Ennerdale was largely created as a result of past ice ages, with indications that the most recent glacial period shaped the eastern side of the valley with a glacier 1.28km^2 by 0.049km^3 formed on the crags of Great Gable to the south east of the valley (Sisson, 1980).

Ennerdale has an oceanic wet climate with The Met Office Climate data for the period 1981-2010 (taken from the nearest weather station 15km away in Keswick) giving the average annuals for; rainfall as 1521 mm, with 176 rainfall days (1mm or more of rain). In July maximum temperature averages about 19^0C and in January averages about 1^0C (Meteorological Office, 2013) making the winters relatively cold.

1.3 Management

In 1872 Ennerdale Fell (3090 hectares) was enclosed and now owned by the Forestry Commission, surrounding the valley Kinniside Common (2100 hectares) and Stockdale Moor (1010 hectares), has remained as unenclosed common land (C.C.H.T, 2013). The other major owners of land in Ennerdale are The National Trust and United Utilities (Appendix 1- maps) which covers 90% or 4300ha of the whole of Ennerdale valley (Wild Ennerdale, 2006).

Historical records indicate that Ennerdale was completely forested, predominantly by oak, alder and birch before human influence took over around 3500 years ago. Since then there has been fluctuations between intensities of pastoral farming beginning in the Bronze age, iron ore extraction, water abstraction, deer farming, forestry (Wild Ennerdale, 2006) and in 1829 and 1847 a lead mine and smelter were in operation (C.C.H.T, 2013). Along with much of Britain, the post 1920's saw unprecedented clear felling and increase in forestry plantations, in a bid to reduce reliance on Europe for timber production. However, since the Rio de Janeiro Summit in 1992 (Humphrey and Bailey, 2012) these priorities have changed, influencing bodies such as The Forestry Commission to move towards a more sensitive management approach, where natural processes are given a greater hand in determining how the valley will evolve in the future.

The Wild Ennerdale Stewardship Plan (WESP) was finalised in 2006 by The National Trust, United Utilities and The Forestry Commission with the support of Natural England, their aim is to "sustainably manage the North West England Forest District estate, to maximise public benefit and achieve a balance between social, environmental, and economic prospects" (Wild Ennerdale, 2006). It is hoped that this will enable a robust series of ecosystems to develop which will be more adaptable in the face of external pressures such as climate change. One of the uncertainties is the prediction of how the current woodlands are going to succeed under minimal management interference, therefore monitoring and surveying play a large part in understanding this as well as helping to measure sustainability.

1.4 Woodlands

The majority of the valley consists of larch and spruce plantations (around 800ha) with smaller pockets of broadleaf woodlands (see Appendix 1 - maps) including "Latterbarrow Wood" (8.24ha) and "Side Wood" covering (33.93ha). Cattle and sheep grazing occur at various intensities throughout the woodlands, with two herds of Galloway cattle introduced through the WESP covering 300ha mainly to the far east of the valley and in the middle of the valley to the south of the lake, it is hoped that the selective way cattle graze and break-up dense ground litter will be of benefit to seedling regeneration (Wild Ennerdale, 2006). Sheep however significantly out number cattle largely due to the common land that surrounds the woodlands see (Appendix 1 – maps) this is especially apparent in side wood which is located on common ground where high intensities of sheep grazing occur and have dominated for over 600 years.

1.4.1 Native Woodland

Side Wood occurs on the north facing slopes directly above the lake and represents one of the best examples of upland *Betula pubescens* (Downey Birch) – *Quercus petraea* (Sessile Oak) woodlands in West Cumbria and has been in existence since at least AD 1600. This site is designated as a SSSI as it contains a rich and diverse bryophyte flora with a number of uncommon species, such as *Polytrichum strictum* mixed with *Sphagnum palustre* or *Sphagnum capillifolium* on wetter soils, and development of *Sphagnum quinquefarium* hummocks with *Mylia taylorii*. It is also of regional importance for its lichen communities with the most notable species being the rare *Ochrolechia inversa* (Natural England, 2013a).

There is a small unit of oak woodland adjacent to side wood at a higher elevation and under lower impact from sheep grazing that is combined with dry heath and wet heath in a SSSI occupying 27.85ha. Latterbarrow wood is a long-established secondary woodland, also characterised by Downey birch and Sessile oak, occurring on the steep south facing slope just above the lake. This site is also a SSSI which is classed as “recovering towards a favourable condition” by Natural England due to the invasion of non-native Sitka spruce (*Picea sitchensis*), European beech (*Fagus sylvatica*) and European larch (*Larix decidua*) species (Natural England, 2013a).

1.4.2 Conifer Plantations

The conifer plantations date from 1925 (C.C.H.T, 2013) and cover around 600 hectares of land which is owned and managed by the Forestry Commission. The stands mostly consist of either Sitka spruce or European larch under either an 'even-aged' monoculture management or thinned for 'Continuous Cover Forestry' (CCF). The even-aged conifer stands are tightly packed trees with a uniform age exhibiting a species poor understory limited by the lack of light and a thick carpet of pine needles. The thinned coniferous stands are as a result of a change in harvesting technique away from clear felling where instead only selected trees are chosen in an effort to maintain a "continuous canopy" (Farmer and Nisbet, 2004) and protect soil and water processes. This shift to CCF is linked to the sustainability requirements set out by the Rio/Helsinki process and certification (Pommerening and Murphy, 2004) as the thinning of mature trees opens up the canopy allowing light penetration to the ground floor and creating space for a more species rich understory to naturally develop.

1.5 Corse Woody Debris as a Biodiversity Indicator

Dead wood, also named coarse woody debris (CWD) is comprised of standing dead trees (snags) and downed dead wood (logs). CWD affects soil processes, soil fertility, hydrology, and wildlife microhabitats thereby influences biological diversity within stands (Guby and Dobbertin, 1996). International initiatives such as the Convention on Biological Diversity, Forest Europe and the European Environment Agency 'Biodiversity Baseline' project include deadwood as a key indicator for sustainable forest development (Humphrey and Bailey, 2012). This is due to the services it provides in the form of water storage, influencing soil chemistry and providing habitat for animals, insects, lichen, mosses, bryophytes and fungi; these attributes aid in fixing nutrients essential for successful seed germination and seedling survival (Sweeney et al., 2010), for instance in the ancient woodland stand in Ennerdale the uncommon liverworts *Tritomaria exsecta* and *Tritomaria. Exsectiformis* were found consistently on rotting logs (Averis, 2001).

European forests have been intensively managed over long periods of time resulting in a simplification of forest structure, and the loss of late development phases characterised by a high amount and diversity of dead wood. Lonsdale, Pautasso and Holdenrieder (2008) report that a 90% reduction in dead wood substrate could be followed by the extinction of 50% of wood-inhabiting species. In Scandinavia alone there are thought to be around 5000 species or 20-25% of all forest species that spend some or all of their life cycle associated with dead wood (Stockland and Kaurserud, 2004). This shortage of dead wood in intensively managed forests compared to natural forests has led to a severe loss of saproxylic species (Vanha-Majamaa *et al*., 2007), considered to be one of the key factors leading to the decrease of biodiversity in European forests (Schuck,*et al*., 2004).

Saproxylic beetles are often used as indicator species to the quality of the ecosystem, in Scandinavia there are reported to be 1257 species of which several hundred are red-listed (Franc *et al*., 2007). In the boreal forests of Fennoscandia red-listed beetles were found to occur 6-7.5 times more likely in key sites where there was a high variety of dead wood type with volume not being a significant factor (Djupstrom, Weslien and Schroeder, 2008). Investigations into preferences for dead wood type (snag or log) by Gibb et al (2006) found that snags held the highest diversity of beetle species including the most red listed, whereas Hjältén *et al* (2007) found out of 16 red-listed beetles 11 species preferred logs as opposed to snags. This highlights the importance of having a range of dead wood types to obtain optimal diversity by catering for all species requirements.

The presence of dead trees in varying states of decay, ranging from intact, through lost bark and degraded heartwood and sapwood, to complete loss of structure and incorporation into the soil, indicates the level of continuity within the woodland (Humphrey and Bailey, 2012). When this continuity is lost the diversity of species such as fungi (Ódor *et al.,* 2006), bryophyte's (Madžule, Brūmelis and Tjarve, 2012) and polypore's (Junninen and Komonen, 2011) has been seen to drop due to the low variation in suitable dead wood substrate. The amount of dead wood was found by Blaser *et al*., (2013) to be the main driver for fungal community diversity with Ylisirniö *et al*., (2012) suggesting a dead wood volume threshold level of 18 m^3 ha^{-1} for occurrence of certain red-listed polypore species. However Abrego and Salcedo (2013) found the variety of woody debris explained much more variability in fungal communities than woody debris volume and fungal richness and diversity was found by Kebli *et al* (2012) to be up to 10% higher on highly decayed logs compared to logs at the medium decay stage.

Whether the quantity or the quality of dead wood is more beneficial will depend largely on the specific species or the type of management the woodland has been subjected to, but there is a consensus in all investigations that the presence of dead wood in a variety of conditions is a positive factor for fungal diversity (Jonsell, Weslien and Ehnström, 1998). Having a high diversity of fungal communities has a positive effect on biodiversity as they are essential for breaking down and opening up the dead wood for other saproxylic species (Odor *et al*., 2006). Therefore to increase and sustainably manage dead wood is widely accepted as a key measure to enhance biodiversity in forests (Bolton and D'Amato, 2011) which in turn can be used as an indicator of the biodiversity with in the forest stand.

1.6 The Influence of CWD on Forest Development

One of the hopes of the Wild Ennerdale plan is to encourage regeneration of the forest after being under intensive forestry for many years and encourage natural ecosystems to re-establish. CWD is known to be of importance at different stages of forest regeneration due to its ability to enhance moisture retention, increase nutrient recycling, provision of mycorrhizal fungi, biological control of soil-borne pathogens and protection against browsing (Lonsdale Pautasso and Holdenrieder, 2008). For instance when considering the effect of moisture loss from canopy gaps a 30% higher survival rate of Lenga Beech (*Nothofagus pumilio*) seedlings was found by Heinemann and Kitzberger (2006) to occur on CWD compared to the forest floor. Similar findings have been found for other tree species; red spruce *(Picea rubens)*, hemlock (*Tsuga Canadensis*) and balsam fir (*Abies balsamea*) found to occur in significantly higher densities on CWD than on the forest floor (Weaver *et al*., 2009) and up to 75-80% of Norway spruce (*Picea-Abies*) seedlings and saplings were found growing on dead wood which only covered 9% of the sampled area (Svoboda *et al.,* 2010).

Saplings are the next development stage after seedlings and are characterised by the British Forestry Commission as being over 1.3m in height and ≤7cm diameter at breast height (dbh) saplings are an important measure of forest development as they have been found to have a 90% (Forestry Commission, 2005) higher survival rate than seedlings and so are a good indicator for predicting the composition of the future forest (Kerr & Mackintosh, 2012). For saplings a major benefit of having a high amount of CWD is that is provides protection and subsequently experience lower herbivore damage (Van-Ginkela *et al*., 2013). An investigation into Sessile oak (*Quercus petraea*) by Smit *et al* (2012) found that the height of Sessile oak saplings increased and sapling browsing decreased with higher levels of CWD, therefore benefitting the regeneration of oaks in old-growth forests. This poses an important consideration to UK land managers aiming for more natural forest regeneration, who have to make decisions regarding the current explosion of the deer population and the types and intensities of ungulate grazing.

It is not only the amount of dead wood that's important but the stage of decay. Bolton and D'Amato (2011) found that the establishment of the historically important species Yellow Birch (*Betula alleghaniensis*) to forests in Minnesota, USA was strongly related to highly decayed, large coniferous pieces of downed logs with little recruitment occurring directly on the forest floor, in Japan the shrub species *Clethera barbinervis* was found to be associated with a particular stage of decay exhibiting an ideal pH as a result of wood rotting fungi (Fukasawa, 2012) and also in Japan a significantly positive relationship between CWD volume and seedling establishment of Norway spruce (*Picea-Abies*), Glehn's spruce (*Picea glehnii*) and Jezo spruce (*Picea jezoensis)* was found, but also a significant difference in the association of each species to varying stages of decay (Takahashi *et al.,* 2000). These studies support the theory that it is essential to have heterogeneity within the CWD composition to accommodate for all species requirements and to achieve optimal biodiversity targets.

Studies of Northern America and Northern Europe have estimated downed logs with decay class of greater than 3 to occupy approximately 1-2% of the forest floor (Weaver *et al.,* 2009) this is a relatively small area, and therefore possibly limiting forest regeneration. Compared to downed logs in the early stages of decay there is a reduction in time for the final stages of decay to become incorporated into the soil for this reason it is important to have large logs, which will remain intact for longer and provide a greater benefit to seedling establishment, nutrient cycling and water storage. As downed logs are an immobile object compared to that of a leaf the longevity within the area it falls provides a lasting legacy and increases the success of the seedlings into saplings and ultimately veteran trees.

1.7 Management of CWD for improved forest ecosystems

CWD volumes vary depending on stand age and type, management, and environmental factors including; fires, storms, insect outbreaks, pathogens (Sweeney, 2004; Bobiec, 2002). Due to anthropogenic activities, only small areas of Europe have remaining temperate forest communities that possess a natural stand structure and a natural distribution of CWD. Mature managed stands have been found to have a tenfold lower amount of CWD compared to natural old-growth forests (Bobiec, 2002), which may reduce the quality of this ecosystem.

Planting trees and vegetation is a good first step in restoration work but the delay in development of all components required for a healthy ‘natural’ ecosystem may be too long for some specialist or rare species. Therefore management initiatives that help to reduce this lag time could be of benefit, such as facilitating decay in standing trees by inoculating them with fungi (Lonsdale and Pautasso, 2008) or the artificial emplacement of CWD. Manning, Cunningham and Lindenmayer (2013) for example, demonstrated that adding CWD significantly increased reptile abundance within just 4 years, as opposed to an estimated 100-200 year barrier with no intervention.

There is no specified target volume set out by the European Environment Agency (EEA, 2011) due to a large variation in forests across Europe, however the Forestry Commission has set out guidelines to aim for dead wood volume at 40-100m^3ha^{-1} within ancient semi-natural woodlands and 20-40m^3ha^{-1} within managed plantations and secondary woodlands, and average more than 3 snags per hectare (Forestry Commission, 2002). The difficulty then comes in getting an adequate estimate of the volumes and structure to ensure management choices are made with relevant information. The spatial distribution of dead wood cause's issues for monitoring levels cost effectively and under time constraints therefore it is essential to follow standardised methods to enable comparisons to be made.

Harmon and Sexton 1996 set out guidelines for CWD Inventory to try and address the problems of accuracy of estimates and to strengthen the opportunities for CWD comparisons on a global scale. The main methods proposed are; fixed area plot sampling, variable radius plot sampling and the line intercept method. The chosen method largely depends upon the practical implications.

In the UK, pockets of protected ancient woodlands exist but are highly fragmented and historically have been subject to varying degrees of wood harvesting for firewood, charcoal, coppicing, disease prevention or aesthetic reasons. Because most forests in the UK have been under management involving CWD removal, UK studies of its importance in forest development are rare. Most of the literature emanates from the relatively undisturbed forests of USA, Canada and Scandinavia, therefore baseline quantification of CWD is an important first requirement in developing a UK knowledge base.

2. Aims and Objectives

2.1 Aim

Currently little is known about the amount of dead wood, its spatial distribution and connectivity within the various stands in Ennerdale; therefore this project aims to fill the gap in the dead wood data between all woodland stand types and ascertain to what extent the CWD influences forest regeneration with consideration of other key environmental parameters. With this information areas of concern can be identified that may benefit from management initiatives with the aim of achieving high standards of sustainable forest development.

2.2 Objectives

- Carry out an inventory of CWD to ascertain the distribution of dead wood volume, number, size and state of decay within different stand types and for the whole valley.

- Collect environmental parameter and forest regeneration data alongside the CWD inventory.

- Investigate any relationships found between the environmental parameters, CWD and forest regeneration data.

- Identify any possible factors that would enhance the valley's biodiversity, sustainability and forest regeneration plans.

3. Materials and Methods

3.1 Study Area and Sites

In order to accurately quantify dead wood distribution within the valley, broad woodland types were categorised according to main species and management. This allowed a reduction in variability in mean dead wood volume and a more accurate evaluation of the effects of environmental and management factors.

The four main woodland types were:

1. ***Ancient woodland***: characterised by the dominance of mature oak trees greater than 35cm diameter at breast height (d.b.h) and largely located to the south east of the lake.
2. ***Native woodland***: characterised by a dominant presence of broadleaf; Sessile oak (*Quercus petraea)*, Downy birch (*Betula pubescens*) mixed with sycamore (*Acer pseudoplatanus*), beech (*Fagus sylvatica*), ash (*Fraxinus excelsior*) , rowan (*Sorbus aucuparia*), hazel (*Corylus avellana*) or holly (*Ilex aquifolium*) in the canopy.
3. ***Even-aged coniferous plantation***: characterised by a single aged spruce or larch composition with a species poor field layer consisting of a thick carpet of needles.
4. ***Thinned conifer stands***: characterised by an open mature larch or spruce canopy with a more grassy field layer than the even-aged conifer stand with species such as creeping soft-grass (*Holcus mollis*), common bent (*Agrostis capillaris*), heather (*Calluna vulgaris*), bracken (*Pteridium aquilinum*) and occasional brambles (*Rubus fruticosus*), present (Jerram, 2004) .

Baseline survey work on forest development had previously been set up by the Forestry Commission in 2006 in conjunction with the Wild Ennerdale Stewardship Plan. They used circular plots of 8m radius (0.02hectares) to determine the composition of the woodland stands over the whole valley by counting the number and species of tree, seedling and sapling with the hope of repeating this in the future to determine how the woodlands are developing. It was agreed with the Forestry Commission to use these survey sites when quantifying dead wood to maximise potential comparison opportunities that come out of this and other monitoring work. The plots had been selected randomly by using a 300m grid in ArcView 3.2 to generate the 104 sample points which fell in both woodland and open fell areas (Browning, 2006).

For this survey only the plots with tree coverage were sampled which left 46 fixed area plots. This left a sample set that was weighted towards conifer plantations, so to increase accuracy of estimates a further 20 plots were randomly located in the ancient and native woodlands by walking 50 paces from each Forestry Commission plot within these woodland types in either a north, south, east, or west orientation which was pre-determined before entering the site. This approach ensured that the extra samples remained within the same woodland type and at sufficient distances to maximise sample independence while reducing bias. In total 64 sample plots were used: 13 in ancient woodland, 15 in native woodland, 16 in even-aged conifer stands and 20 in thinned conifer stands (see Appendix 1-maps).

3.2 CWD Classification and Measurements

Coarse Woody Debris (CWD) can be classified into the following categories according to Humphrey and Bailey (2012):

1. Snags (standing dead trees ≥45^0)
2. Wind-thrown trees (<45^0)
3. Fallen deadwood
4. Stumps

For the purposes of this study wind-thrown trees and fallen dead wood were grouped as ‘logs’ and counted if diameter ≥10 cm and length ≥1 m, with measurements of length, diameter at both ends and the diameter at the midpoint recorded, Snags with height ≥2m, diameter ≥10cm and pith falling within the plot area were counted and height and diameter at breast height (D.B.H, 1.3m) recorded, Stumps with height ≤2m and pith within the plot area are counted and height and mid-point diameter measured (Harmon and Sexton 1996). Dead wood <10cm in diameter are not considered due to time constraints. This approach is justified, since CWD provides a significant greater range of micro-habitats and supports much greater species diversity than fine woody debris (Humphrey and Bailey, 2012).

All CWD was allocated to decomposition (Table 1) and diameter class; calculated as the mean measurement (from the top, middle and base of a log) and allocated to: 5-9cm, 10-14cm, 15-19cm, 20-24cm, 25-29cm, 30-34cm and 35cm+, according to the system taken from Sain, Schilling and Aust, (2012).

Table 1

Coarse Woody Debris Decomposition Classification - *taken from Sain, Schilling and Aust, 2012*.

Decay Class	Structural Integrity	Texture	Colour	Invading Roots	Branches and Twigs
1	Sound freshly fallen/intact logs	Intact, no rot, decay absent	Original colour	Absent	If branches present twigs are still attached with bark
2	Sound	Mostly intact; sapwood partly soft can be pulled apart by hand	Original colour	Absent	If branches present most twigs gone, remaining have peeling bark
3	Heartwood sound; piece supports own weight	Hard large pieces; sapwood can be pulled apart by hand or absent but metal pin cannot be pushed through hard wood	Reddish brown or original colour	Sap-wood only	Branch stubs will not pull out
4	Heartwood rotten; piece does not support own weight, but maintains its shape	Soft small blocky pieces; a metal pin can be pushed into heartwood	Reddish or light brown	Through out	Branch stubs pull out
5	None; piece no longer maintains its shape, spreads out on ground	Soft, powdery when dry	Red-brown to dark brown	Through out	Branch stubs and pockets rotted down

3.3 Fallen CWD Sampling Protocol

Many CWD inventories and studies cite the guidelines given by Harmon and Sexton (1996) for measuring woody detritus in forest ecosystems. However, it is often unclear as to the inclusion zone given to logs (fallen deadwood and wind-thrown trees) when using circular fixed area plots. The protocols that appear to be the most widely used are:

1. ***'the stand-up method'***: selects every log whose base has fallen within the plot and calculates the volume for the entire length of the log regardless of what proportion falls within the plot area.
2. ***'the chainsaw method'***: uses the edge of the plot as the cut-off point and therefore volume calculations are only taken of the section of the log that falls within the plot.
3. ***'the sausage method'***: most recently proposed by Gove and Deusen (2011) where the entire log is selected if the plot perimeter intersects any part of the log.

Protocol 1 risks underestimating volume as logs may fall across the sample point but not be measured because their base is not within the plot, while Protocol 2, although a more accurate measure of volume, is prone to errors introduced when trying to calculate the volumes for slivers created by the cut-off zone. Errors are reduced with increasing plot size; however where large trees contribute to the dead wood volume the cut-off method is likely to result in underestimates as large sections of logs always go un-sampled. Protocol 3 biases by overestimating the volume by plot area but presents the lowest variance of all the protocols (Gove and Deusen 2011).

Due to the relatively small size of the Forestry Commission's existing fixed area plots, (0.02 ha) it was decided that Protocol 3 would be the best way to represent the distribution of CWD in this study; if a larger sample plot had of been used Protocol 1 would have been chosen due to the increased probability that the butt of a log would fall within the plot.

3.4 Calculation of deadwood volume

Newton's formula was used to calculate the volume of each log and snag:

$$V = (L\ (A_b + 4A_m + A_t))/6$$

Where V is the volume (m^3), L the length, and A_b, A_m and A_t the areas for the base, middle and top respectively (Yan *et al*., 2007)

Stump volume was calculated according to Huber's formula:

$$V = A_m L$$

Where V is the volume (m^3), A_m is the area at the mid-point, and L is the length (Harmon and Sexton, 1996)

3.5 Environmental Parameter Measurements

Coordinates and elevation were obtained for the centre of each plot using a Garmin etrex GPS handset. Slope angle was measured using a sighting clinometer and slope aspect (degrees) using a sighting compass. Tree canopy cover and rock outcrops were estimated as a percentage cover of the whole plot. Grazing regime was also noted for each plot as a "yes" or "no" to the presence of sheep and cows. Although deer damage is known to effect tree establishment, for this investigation deer impact was considered to be equal among all plots due to their ability to roam relatively un-restricted throughout the valley and therefore were not measured.

3.6 Stand Composition and Development

Within the sample plots the coverage of mature trees, saplings and seedlings of all species present were estimated according to the DOMIN scale:

1. <4%, few individuals
2. <4% several individuals
3. <4%, many individuals
4. 4-10% cover
5. 11-25% cover
6. 26-33% cover
7. 34-50% cover
8. 51-75% cover
9. 76-90% cover
10. 91-100% cover

Trees (mature) were classified as having a diameter at breast height (d.b.h., 1.3m) >7cm; saplings were classified as being taller than 1.3m and having d.b.h ≤7cm; seedlings were classed as having a height <1.3m.

3.7 Data Analysis

3.7.1 CWD Composition

Differences in volume of logs, stumps, snags and total CWD between stand types, were tested using a one way Analysis of Variance (ANOVA) and differences between individual stand types using Tukey's test. Data normality was evaluated using the Anderson-Darling test. None of the volume data was found to be normally distributed; therefore transformations were made; using a cube root function for log volume, the square root function for stump volume and the $\log_{10}$ function for total volume. Data for snag volume could not be satisfactorily transformed and was therefore analysed by non-parametric methods; Kruskal Wallace to find any significant difference between the four stands and the Mann-Whitney U test to find which stands were significant.

Analysis of Variance and non-parametric testing was conducted using Minitab 16 software.

The CWD composition for each plot was mapped using ArcMap 10.1, with pie charts used to visualise the distribution of log, stump and snag volume across the valley. Relative and total volumes of each piece of CWD found were calculated and allocated to diameter and decay class, bar charts were created using Microsoft Excel to visualise the data.

3.7.2 Forest Development

Multivariate techniques were used (through “R” software and the “vegan” package), to explore relationships between the CWD, environmental parameter and forest development data (R Core Team (2013).

As the species composition of mature trees within each stand type strongly influenced the species of seedlings and saplings found in the sample plot, the stand was characterised by carrying out a Principal Component Analysis on the mature tree data. PC1 (MT1) and PC2 (MT2), which explained the greatest amount of variance in the mature tree data, were then included as an additional environmental variable in the correspondence analysis (described below).

Constrained Correspondence Analysis (CCA) was then used to analyse the relationship between environmental variables and all tree seedling and sapling species (that had >5% occurrence over all sample plots). Separate analyses were conducted for a) broadleaf woodlands (ancient woodland and native woodland) b) coniferous woodlands (thinned and even aged plantations) and for all woodland types. Monte Carlo permutations (n=9999) were performed to test whether any of the environmental variables and species distributions were significant ($p<0.05$) (Oksanen, 2013).

4. Results

4.1 Composition of CWD

4.1.1 CWD Volume and Type

The mean CWD volume for the whole valley was 50.90 m^3 ha^{-1} with the ancient woodland stand having a significantly higher volume per unit area than the native woodland and even-aged conifer stands (ANOVA, F= 3.36, p=0.024; Table 2). This is attributable dominantly to a significantly greater log volume (ANOVA, F=4.27, p=0.008; Figure 2). However, stump volume was significantly *lower* in the ancient woodland than both the thinned and even-aged conifer stands. Thinned conifer stands contained significantly higher stump volumes than all other stand types (ANOVA, F=13.00, p<0.001; Figure 2). (See Appendix 2 for supporting statistical analysis).

Table 2
Mean volume, (±SE) of Coarse Woody Debris (m^3 ha^{-1}) by stand type.

Stand Type	Mean Coarse Woody Debris Volume (m^3 ha^{-1})			
	Log	Stump	Snag	Total
Ancient Woodland	66.60±24.40	0.24±0.21	3.22±2.20	70.06±24.30 ***a***
Native Woodland	10.70±2.62	2.55±0.88	9.89±3.04	23.14±5.01 ***b***
Thinned Conifer	34.80±13.10	11.70±2.15	13.01±7.47	59.51±16.10 ***ab***
Even-aged Conifer	9.80±3.31	5.56±1.52	2.60±2.17	17.96±5.00 ***b***
Whole Valley	**37.37**	**4.83**	**8.71**	**50.90**

Treatments with same letter are not significantly different (Tukey's test p≤0.05).

On average there was 1 snag found per hectare across the whole valley with the highest contribution to snag volume found in a very localised distribution (Figure 3), in the native woodland, which contained both a significantly higher volume (Kruskal-Wallis; $H=17.97$, $p=0.003$, $DF = 3$) and number (Kruskal-Wallis; $H=23.42$, $p<0.001$, $DF=3$,) than all other stand types (Table 3).

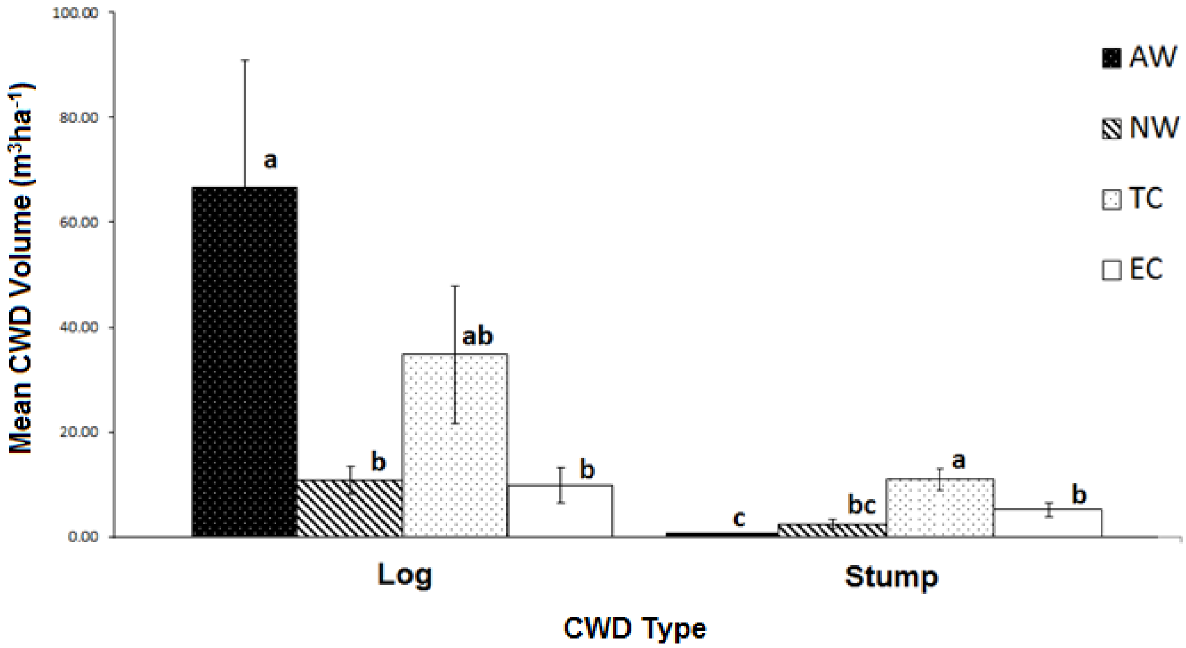

Figure 2: The mean volume of logs and stumps by stand type. Error bars = **±1 SE**. Debris type stand means with the same letter are not significantly different (Tukey's test $p>0.05$).

Table 3:
Median snag number and wood volume by stand type.

Stand Type	Median Volume $m^3 ha^{-1}$	Median Number ha^{-1}
Ancient Woodland	0.0 ***b***	0 ***b***
Native Woodland	4.7 ***a***	2 ***a***
Thinned Conifer	0.0 ***b***	0 ***b***
Even-aged Conifer	0.0 ***b***	0 ***b***

Treatments with same letter are not significantly different (Mann-Whitney test $p\leq0.05$).

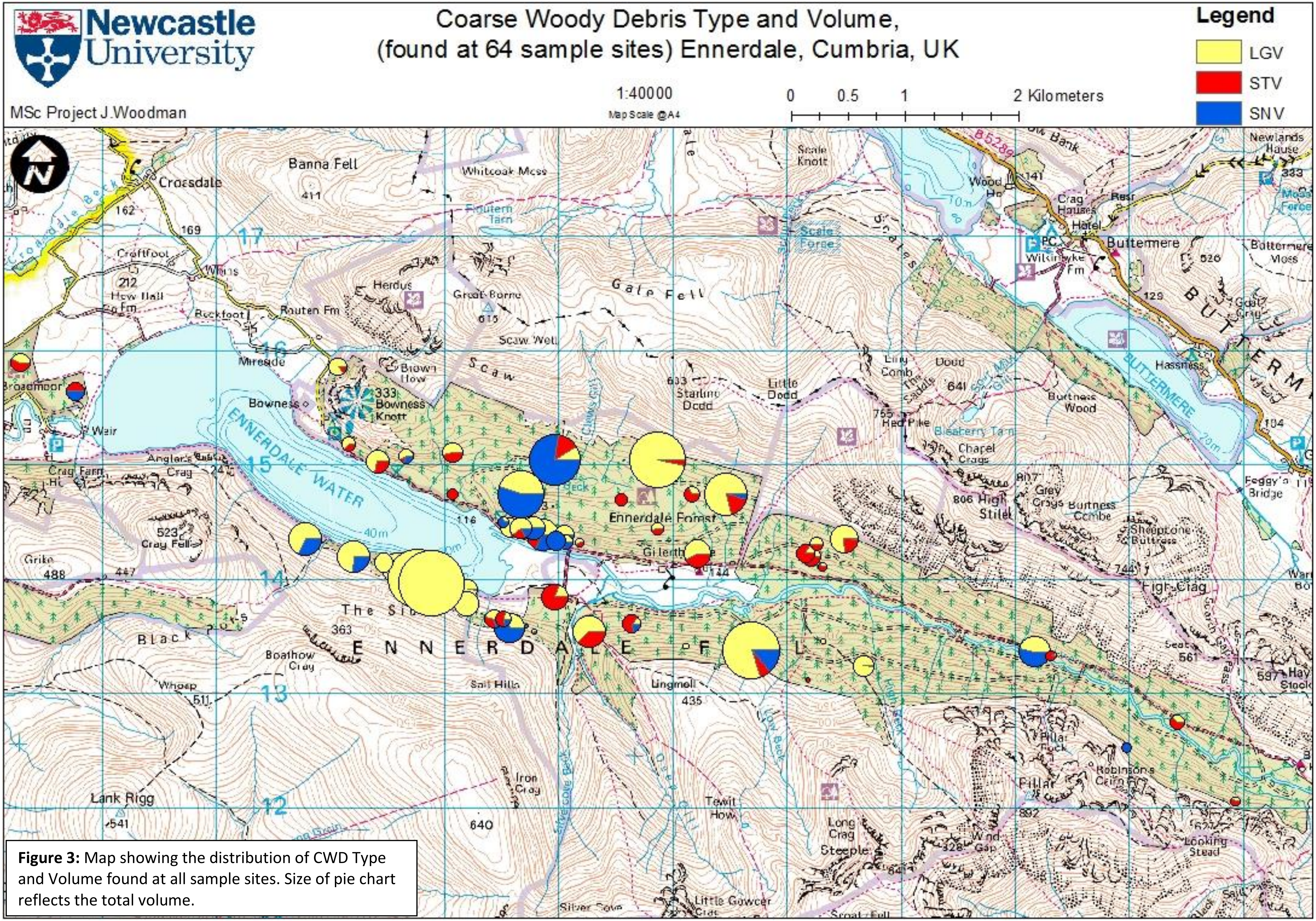

Figure 3: Map showing the distribution of CWD Type and Volume found at all sample sites. Size of pie chart reflects the total volume.

4.1.2 Diameter Class

There was a significant difference in the distribution of logs in both diameter class and decay class for each stand type (Chi-Sq = 57.964, DF = 12, P-Value ≤0.001) and (Chi-Sq = 101.148, DF = 12, P-Value ≤ 0.001). For downed logs the ancient woodland stand had the highest volume (388.71 m^3 ha^{-1}) in the diameter class 35cm+ (Figure 4). A high proportion of the total log volume in the thinned conifer stand was made up of logs from the smallest diameter class (413.64 m^3 ha^{-1}). The ancient woodland and the even-aged conifer stand had logs more evenly distributed throughout the diameter classes than the thinned and native woodlands.

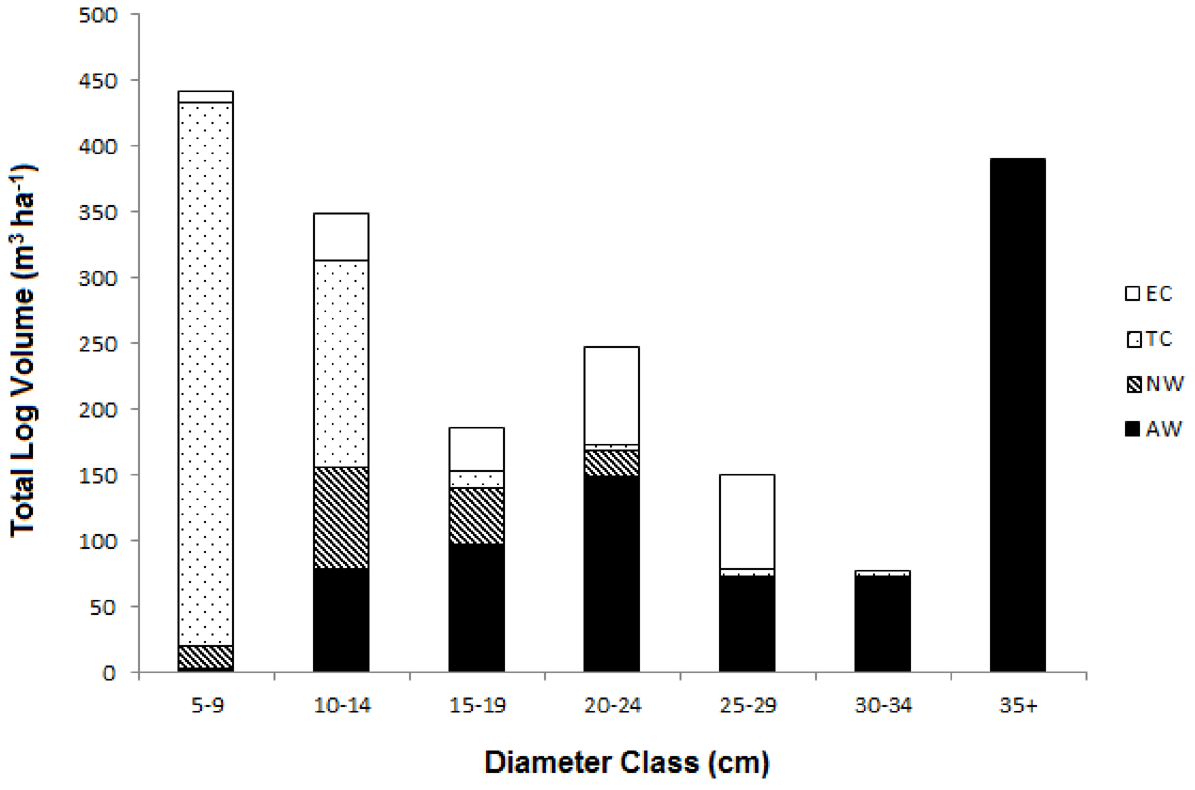

Figure 4: The total volume of logs allocated to diameter class by stand type.

Most of the snags found were in relatively small diameter classes (<25cm), with only two snags allocated to 35cm+, one from the even-aged conifer stand and the other from the thinned conifer stand (Figure 5).

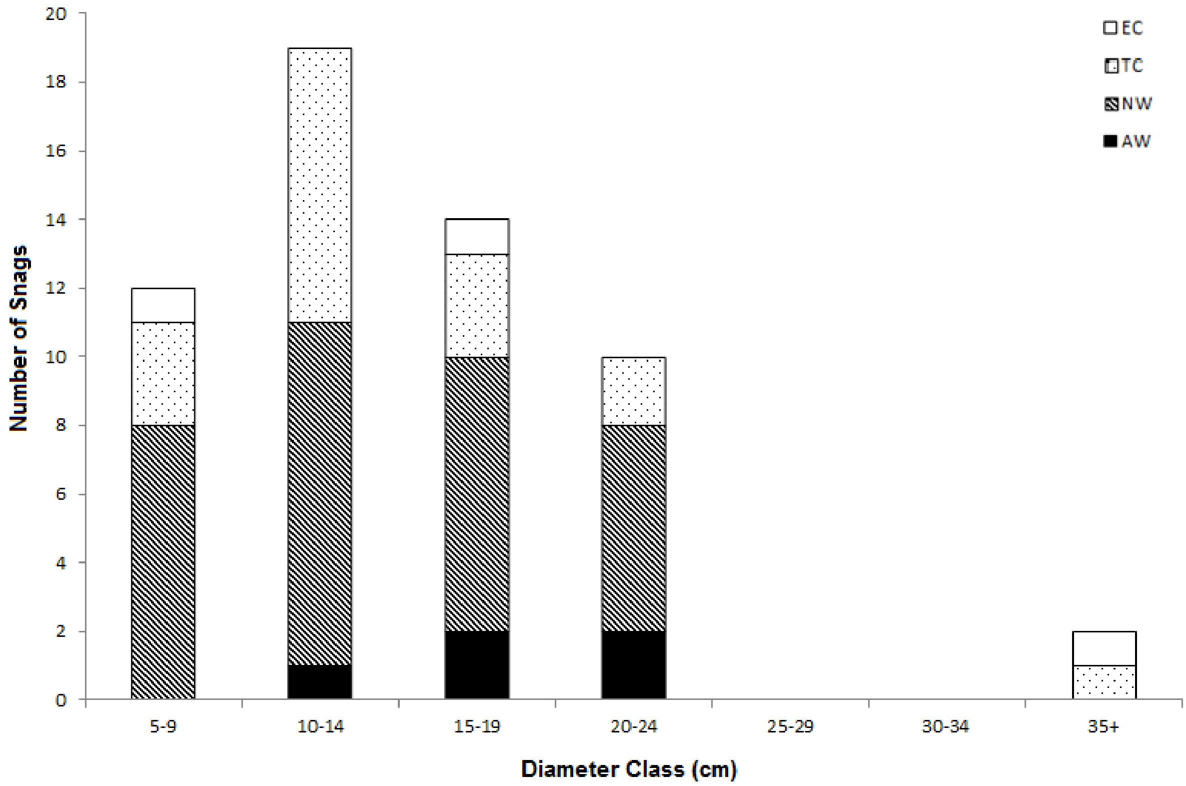

Figure 5: The number of snags found in each diameter class by stand type.

4.1.3 Decay Class

The majority of the total volume of dead wood was found in the early stages of decay in class 1 and 2 (69%) with decay class 2 accounting for the biggest volume of CWD found (1035.37 $m^3 ha^{-1}$) across all stands, this was largely due to the high log volume from the ancient woodland stand allocated to decay class 2 (Figure 6). Decay class 5 had the lowest volume of CWD (112.61 $m^3 ha^{-1}$) with decay class 4 and 5 accounting for just 12% of the total CWD volume.

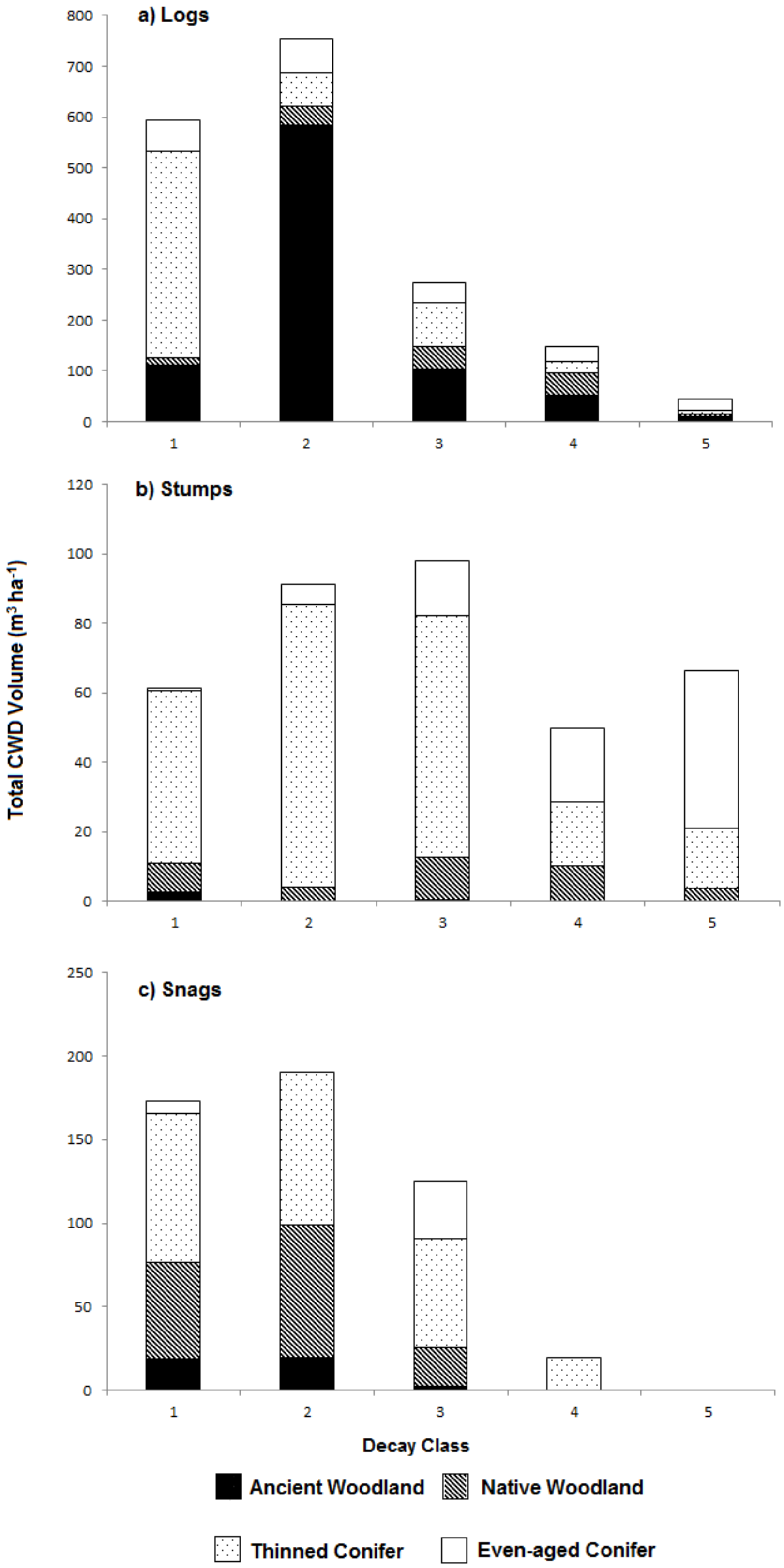

Figure 6: The total volume of CWD types allocated to decay class 1-5 for each stand type.

For the ancient woodland and thinned conifer stands decay class 1 and 2 accounted for a high amount of the log volume (81% and 80%) respectively (Table 4), with the native woodland having the highest relative log volume in decay class 4 and 5 (35%). The native woodland had the most even distribution of log and stump volume between all decay classes. Stumps from the even-aged conifer stand were the biggest contributor to dead wood volume in decay class 5 (45.38 m^3 ha^{-1}) across all CWD types. The only snags found with a decay class greater than 4 were in the thinned conifer stand with no snags found in the highly decayed class 5.

Table 4:
The proportion of CWD Type Volume (%) allocated to decay class by stand type.

CWD Type	Stand Type	No. pieces	Decay Class				
			1	2	3	4	5
Logs	AW	63	13	68	12	6	1
	NW	46	10	25	32	30	5
	TC	95	69	11	15	4	1
	EC	50	28	29	18	14	11
Stumps	AW	2	88	0	12	0	0
	NW	13	21	10	32	27	9
	TC	107	21	34	29	8	7
	EC	67	1	6	18	24	51
Snags	AW	5	46	48	7	0	0
	NW	32	36	50	14	0	0
	TC	17	34	34	24	7	0
	EC	3	17	0	83	0	0

4.2 Woodland Regeneration

Mature birch trees were the most common with a 50% occurrence in the sample plots, for seedlings rowan had the highest sampling percentage (59%) and for the saplings spruce and rowan were the most common (both, 45%). In the conifer stands (sample plots, N=36) spruce was the most common (mature trees = 92%, Seedlings = 67%, Saplings = 81%), in the native woodlands (sample plots, N=28) birch and oak were the most common mature trees (both, 86%), while rowan was the most common seedling and sapling (86% and 57% respectively).

The ancient woodland compared to all stands had lower species diversity, while the native woodland has the highest (Figure 7). In the ancient woodland both oak and ash had a relatively high level of seedlings but no saplings were found and despite a 30% occurrence of mature hazel no saplings or seedlings were found. The thinned conifer stand was more species rich in seedlings and saplings compared to both the even-aged conifer stand and the ancient woodland. There was over 10% occurrence of seedlings and saplings of larch and beech in the native woodland and over 10% occurrence of spruce seedlings, however no spruce saplings were found. The native woodland also had the highest presence of broadleaf saplings compared to all other stands.

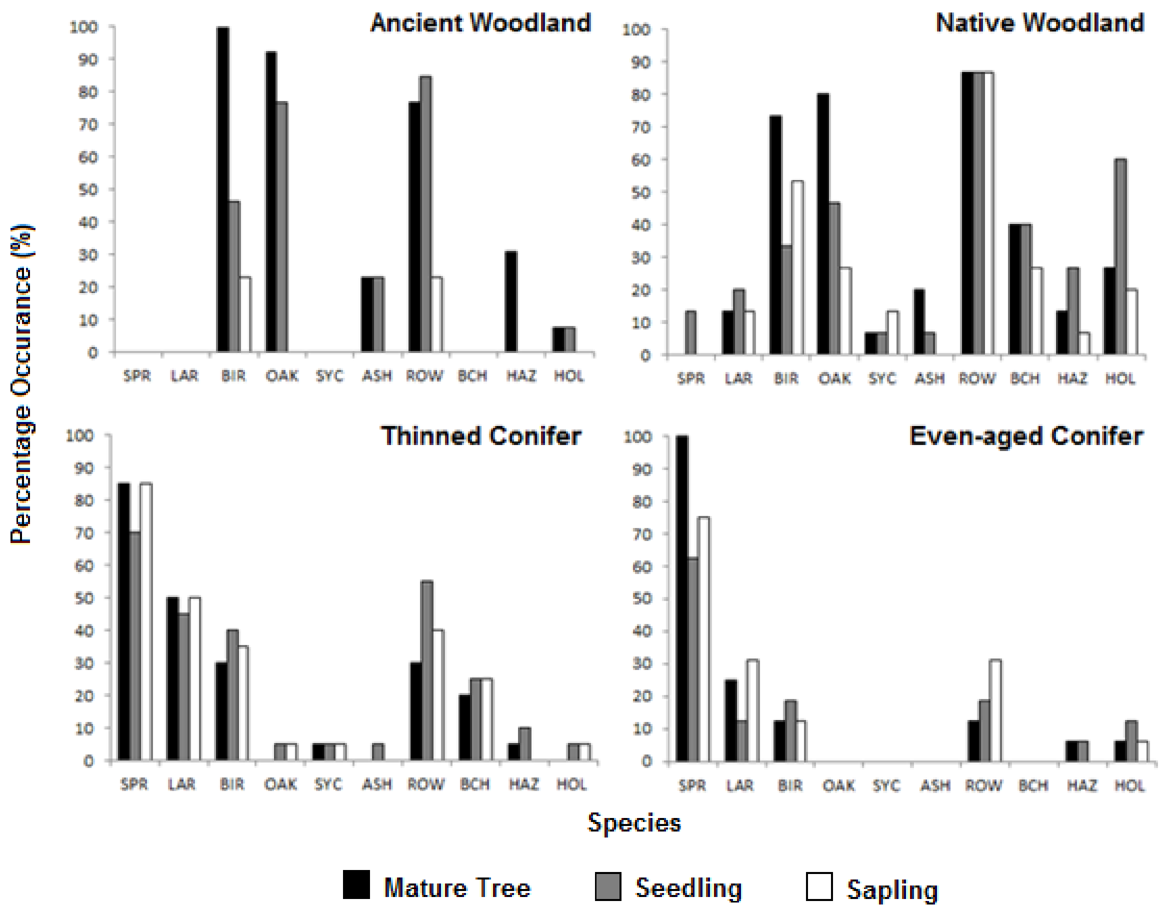

Figure 7: Percentage occurrence of trees by successional stage; seedling, sapling, mature tree, for all recorded species within stand type.

4.2.1 Forest Regeneration and Environmental Parameters - Whole Valley

There was a significant relationship between the measured environmental variables and species distribution across the whole valley (Figure 8) on the first five canonical axis; (F=16.7935; P≤0.001), (F=8.747; P≤0.001), (F=6.2665; P≤0.001), (F=3.4158; P≤0.001), (F=2.1239; P=0.025) respectively. The measured variables explained 29% of the variation in species distribution on the first two axes (Table 5). Seedlings and saplings of spruce and larch are found on the right hand side of the plot explained by the PCA analysis of mature trees (MT1) and having a positive relationship to elevation and canopy cover. Seedlings and saplings of beech had the least similarities to other species and are most related to a southerly aspect. Seedlings and saplings of broadleaf type are predominantly on the left side of the plot associated with the PCA analysis of mature trees (MT2), stand type, sheep grazing and rock cover.

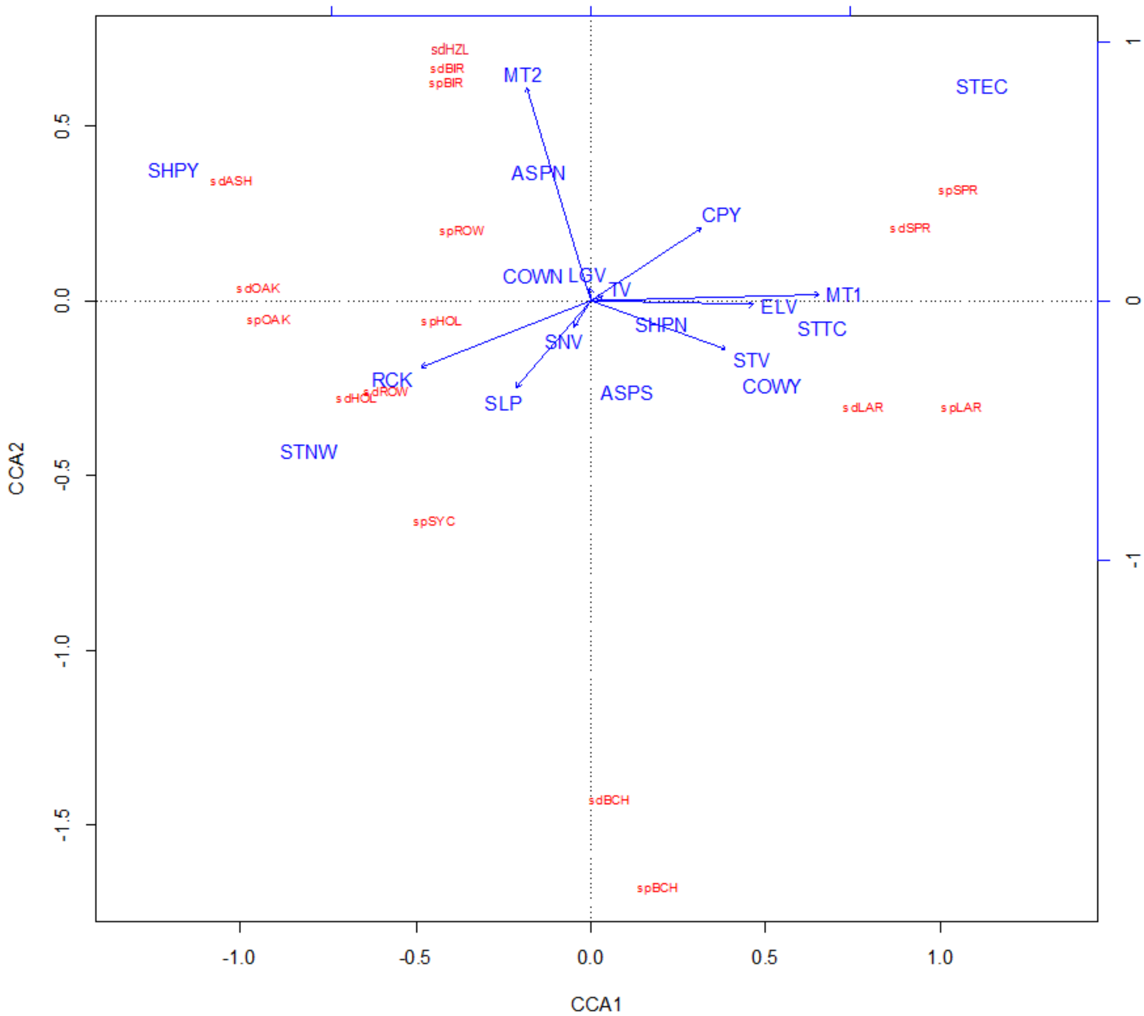

Figure 8: Canonical axes 1 and 2 obtained from Constrained Correspondence Analysis (CCA) for the whole valley, of seedling (sd) and sapling (sp) species; SPR=spruce, LAR=larch, BCH=beech, HZL=Hazel, BIR=birch, ROW=rowan, ASH=ash, HOL=holly, OAK=oak, SYC=sycamore, with both factor constraint environmental parameters; SHP=sheep grazing and COW=cow grazing (Y=yes, N=no), ASP=aspect (S=south, N=north), STEC=even-aged conifer, STNW=native woodland, STTC=thinned conifer, and constrained variables; RCK=rock cover, SLP=slope angle, ELV=elevation, CPY=canopy cover, LGV=log volume, TV=total volume, STV=stump volume, SNV=snag volume, MT1 and MT2 axis 1 and 2 from Prinicipal Componant Analysis (PCA) of mature trees. The longer the arrow the more important the parameters in explaining the variation in species distributions. Although species are represented as points, they should be interpreted as vectors extending from the origin and terminating at the species label (Rubino and McCarthy, 2003).

4.2.2 Forest Regeneration and Environmental Parameters - Native Woodland

There was a significant relationship between the measured environmental variables and species distribution in the native woodland (Figure 9) on the first (F=7.1517; P=0.001), second (F=6.2065; P=0.02) and the third (F=5.2689; P=0.001) canonical axes. The measured variables explained 32% of the variation in species distribution on the first two axes (Table 5). Axis 1 is strongly related to slope aspect and the presence of sheep grazing. Most saplings occur on the right hand side of the graph and are strongly associated with a southerly aspect and no sheep grazing. Axis 2 is strongly related to mature tree composition and the presence of cow grazing. Log volume has a positive relationship with both seedlings and saplings of birch and birch saplings are strongly associated with cow grazing. Saplings of oak, larch and holly, and seedlings of hazel, holly and spruce are all associated with presence of rocky outcrop and the absence of sheep grazing.

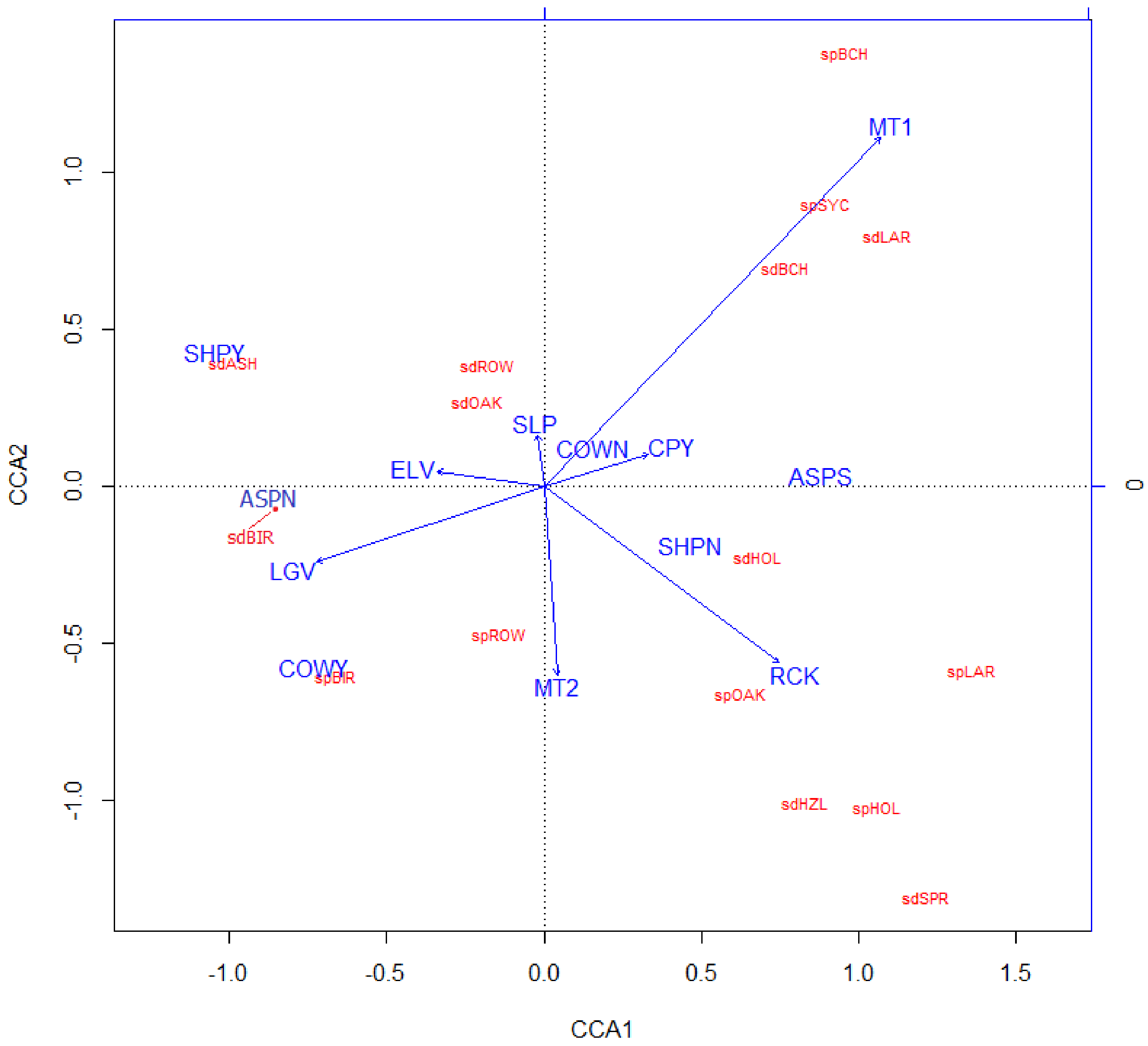

Figure 9: Canonical axes 1 and 2 obtained from Constrained Correspondence Analysis (CCA) of seedling (sd) and sapling (sp) species; SPR=spruce, LAR=larch, BCH=beech, HZL=Hazel, BIR=birch, ROW=rowan, ASH=ash, HOL=holly, OAK=oak, SYC=sycamore, with both factor constraint environmental parameters; SHP=sheep grazing and COW=cow grazing (Y=yes, N=no), ASP=aspect (S=south, N=north), STEC=even-aged conifer, STNW=native woodland, STTC=thinned conifer, and constrained variables; RCK=rock cover, SLP=slope angle, ELV=elevation, CPY=canopy cover, LGV=log volume, TV=total volume, STV=stump volume, SNV=snag volume, MT1 and MT2 axis 1 and 2 from Principal Componant Analysis (PCA) of mature trees, for the native woodland stand.

4.2.3 Forest Regeneration and Environmental Parameters – Conifer Woodland

There was a significant relationship between the measured environmental variables and species distribution in the conifer woodland (Figure 10) on the first four canonical axis (F=7.4833; P=0.001), (F=5.0518; P=0.001), (F=3.2245; P=0.004), (F=2.1545; P=0.023) respectively. The measured variables explained 30% of the variation in species distribution on the first two axes (Table 5). Axis one is related to the composition of mature trees (MT2) and the presence of cow grazing and axes two is related to the stand type; either even-aged or thinned conifer. There is a positive relationship with log volume and log number to holly seedlings and saplings respectively with holly saplings clustered with both seedlings and saplings of spruce and larch. Seedlings and saplings of birch and rowan are found clustered in the top right of the plot associated to the thinned conifer stand and to a lesser extent no cow grazing. Seedlings and saplings of beech showed the least similarities to other species and were positively related to rock cover.

Table 5:
CCA results for the whole valley, native woodland and conifer woodland

		Canonical Axis				
		1	2	3	4	5
Whole Valley	Eigenvalue	0.5269	0.2744	0.19662	0.10717	0.06664
	Proportion Explained	0.1936	0.1008	0.07223	0.03937	0.02448
	Cumulative Proportion	0.1936	0.2944	0.36661	0.40598	0.43046
Native Woodland	Eigenvalue	0.3382	0.2935	0.2492	0.08558	0.06759
	Proportion Explained	0.1696	0.1472	0.125	0.04292	0.0339
	Cumulative Proportion	0.1696	0.3169	0.4419	0.48479	0.51869
Conifer Woodland	Eigenvalue	0.3437	0.232	0.1481	0.09895	0.07357
	Proportion Explained	0.1785	0.1205	0.07692	0.0514	0.03821
	Cumulative Proportion	0.1785	0.299	0.37596	0.42736	0.46557

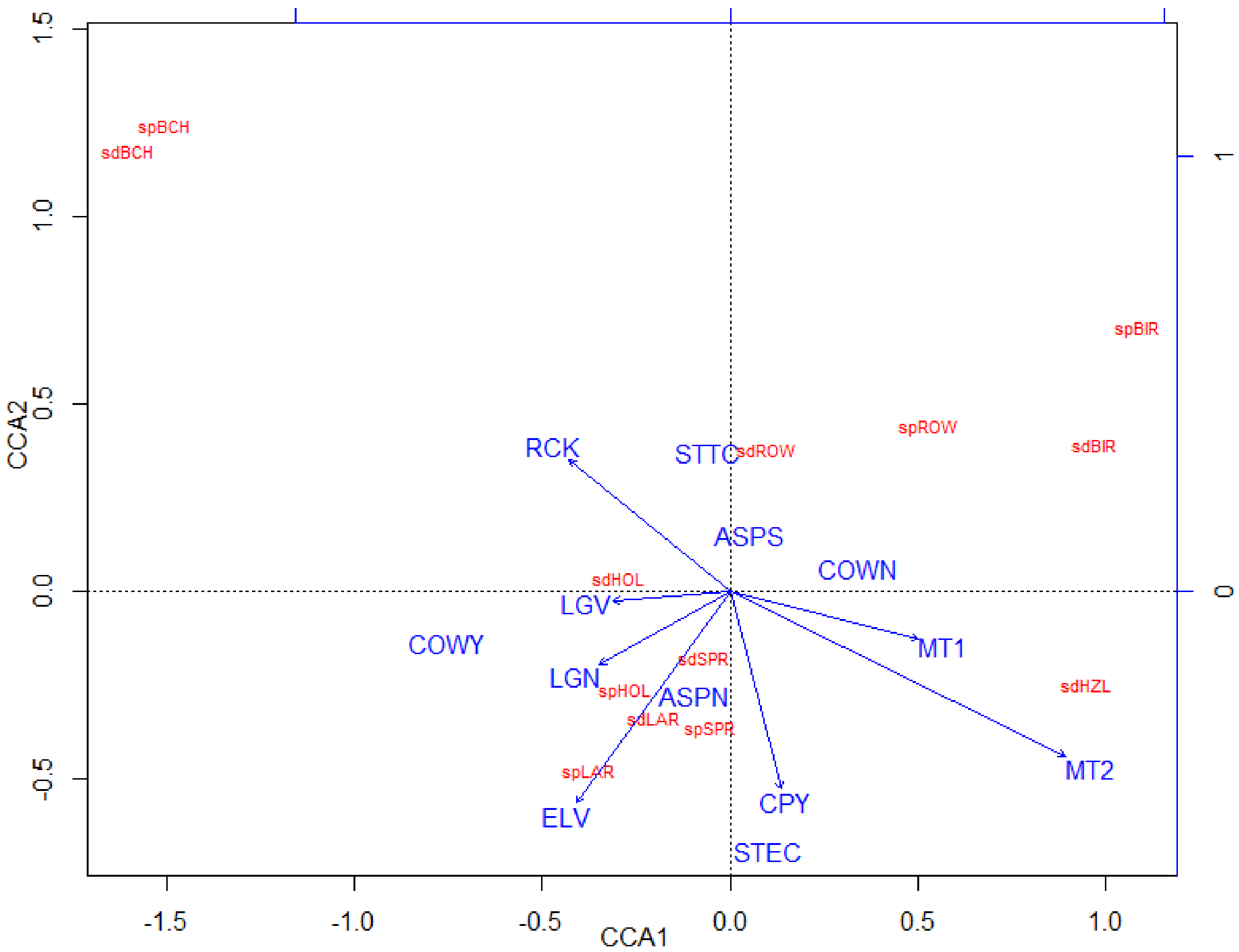

Figure 10: Canonical axes 1 and 2 obtained from Constrained Correspondence Analysis (CCA) seedling (sd) and sapling (sp) species; SPR=spruce, LAR=larch, BCH=beech, HZL=Hazel, BIR=birch, ROW=rowan, HOL=holly, OAK=oak, with both factor constraint environmental parameters; COW=cow grazing (Y=yes, N=no), ASP=aspect (S=south, N=north), STEC=even-aged conifer, STTC=thinned conifer, and constrained variables; RCK=rock cover, ELV=elevation, CPY=canopy cover, LGV=log volume, LGN=log number, MT1 and MT2 axis 1 and 2 from Princicipal Componant Analysis (PCA) of mature trees, for the conifer woodland stand.

(See Appendix 3 for table of raw data)

5. Discussion

5.1 CWD Composition in Ennerdale

5.1.1 Estimated Volumes

The average volume of CWD found per unit area for Ennerdale was above the targeted amount of 20m^3ha^{-1}. However when broken down into specific woodlands the even aged conifer stand had a lower amount (17.96 m^3ha^{-1}) than the target level and although the native woodland was slightly above the target levels (23.14 m^3ha^{-1}) it was still significantly lower than the ancient woodland stand (70.06 m^3ha^{-1}).

Comparisons with other studies (Table 6) show similar trends in British woodlands; Green and Peterken (1997) found old-growth native woodlands to contain between 15-113 m^3ha^{-1} and Kirby *et al*., (1998) estimated a volume of 60-140 m^3ha^{-1} in native woodlands that had been undisturbed for at least 80 years; similar to the ancient woodland stand in the current study. Values of 11-26 m^3ha^{-1} for young-growth stands (Green and Peterken, 1997) and 5-59 m^3ha^{-1} for native oak woodlands that had been under various management regimes in Ireland (Sweeney *et al*., 2010) are comparable to the native woodland stand in Ennerdale.

It was expected that the even-aged conifer stand would exhibit a lower amount of CWD with a reduced input rate as a result of a uniform age. However, the estimate mean volume is at the upper end of the range found in other studies for similar plantation stands, with estimated values ranging from 3-23 m^3ha^{-1} (Table 6). Most of the contributing dead wood in the even aged conifer stands existed as remnants from previous clear felling activities.

Table 6:
Studies quantifying dead wood levels in various forest types around the world.
(* U= Unmanaged, M=Managed)

Location	Forest Type	Management Method *	Estimated CWD Volume (m^3ha^{-1})	Reference
Britain	Old-Growth	U	15-113	Green and Peterken (1997)
	Young-growth	U	11-26	
	Managed	M	4-12	
	Plantation	M	3-20	
	Deciduous	M	12-23	Kirby, Webster & Antckzak (1991)
	Plantation	M	4-20	Hodge and Peterken (1998)
	Plantation	M	23	Humphrey *et al.*, (2003)
	Various	U	60-140	Kirby *et al.* (1998)
	Various	M	0.3-20	
Ireland	Native	M	5-59	Sweeney *et al*. (2010)
	Plantation	M	11.2	Forest Services (2007)
France	Near natural	U	160	Mountford (2002)
Germany	various	U	50-200	Albrecht (1991)
Bavaria	Deciduous	U	9-108	Detsch, Kolbel & Schulz (1994)
	Coniferous	Unknown	8	Burschel (1992)
Switzerland	Various	M	10	Leibundgut (1993)
	Various	U	22.5	
Finland	Old Spruce	M	8	Siitonen (2000)
	Old Spruce	U	32	
	Natural	U	60-90	
Sweden	Coniferous	U	7	Albrecht (1991)
Slovenia	Old growth	U	248-626	Debeljak (2006)
	Managed	M	41-67	
Poland	Deciduous	M	10	Kirby *et al*.,(1991)
	Deciduous	U	94	
	Various	M	1-5	Albrecht (1991)
Russia	Boreal	M	4-9	Ylisirniö *et al*. (2012)
USA	Deciduous	M	40	McCarthy & Bailey (1994)
	Mixed Oak	U	46	Macmillan (1981)
	Mixed Oak	U	94	Harmon *et al*. (1986)
	Mixed Oak	U	54	Muller & Liu (1991)

Adapted from: Guby and Dobbertin, 1996, Kirby *et al*., 1998 and Sweeney *et al*., 2010

It is difficult to compare the thinned conifer stand to other studies due to being under Continuous Cover Forestry (CCF), which reflects specific management priorities existing at the time of the survey. For Ennerdale the aim is to encourage a more natural regeneration of these stands and therefore it would be desirable to achieve deadwood volumes similar to that of an unmanaged coniferous forest. Some of the best examples of these are found in Scandanavia; for example in Finland Siitonen *et al*., 2000 estimated that the natural old growth forests characterised by Norway spruce (*Picea abies*) or Scots pine (*Pinus sylvestris*) intermixed with Downey birch (*Betula pubescens*), European birch (*Betula pendula*) and European aspen (*Populus tremula*) contained a CWD volume of 60-90 m^3ha^{-1}. This amount compares well to the volume of CWD found in the thinned conifer stand (59.51 m^3ha^{-1}) and suggests that the current concentration of CWD input is a good approximation of that in natural coniferous woodland. However, consideration should be given to the fact that this volume is made principally of remnant stumps and manually stacked piles of logs which while providing some beneficial habitat does not reflect natural CWD composition. It may therefore be desirable to add more logs as well as distribute logs in a more spatially random way.

5.1.2 CWD Types, Diameter and Decay Class

Lack of continuity in the ancient woodland likely reflects past harvesting regimes as well as the fact that hard wood takes longer to decay than the soft wood of coniferous plantations, if no more harvesting takes place then the continuity of decay stages will develop over time and positively impact bryophyte communities (Averis, 2001).

A major difference between the native and ancient woodland types was found to be the size of mature trees; in the native woodland oak trees are either younger or have been suppressed by competition due to having a much denser stand than the more open ancient woodland. This may help explain the significantly higher snag volume in the native woodland than all other stands; the snags were found to be in relatively small diameter classes (<25cm), which is consistent with an investigation into dead wood patterns in Irish forests by Sweeney *et al*., (2010) who found a high density of snags in younger growth forests of which less than 1% were >40cm. This is likely as a result of self-thinning due to competition in immature woodland (Siitonen *et al*., 2000). Conifer stands were the only woodlands that were found to contain the larger snags. In the case of the even-aged conifer stand this was likely due to difficulty in access for harvesting, therefore the tree was abandoned, and in the thinned conifer stand large snags have been left as a conscious decision to increase the continuity of dead wood composition.

In general snag numbers were noticeably low with an average of 1 per ha, short of the recommended target of 3 per ha (Forestry Commission, 2002). The lack of snags was especially evident in the ancient woodland where they are expected to occur as oak trees tend to die standing (Peterken, 1996). One possible explanation is that the ancient woodland is very open largely due to grazing pressures on the field layer, meaning competition for resources is low and the likelihood of tree mortality reduced. Another possibility is that there was a high volume of dead wood found in fallen trees of >35cm in an early stage of decay, which could be as a result of dead trees only recently falling. It is also worth considering that fresh sprouts can often occur out of a dead tree (Larsen and Johnson, 1998); this was noted as a concern by Odor *et al.* (2006) who suggested that the number of living trees with dead parts may have contributed to the under-representation of snags in Irish forests.

The relatively high log volume allocated to the smaller diameter classes in the thinned conifer stand could have implications for the continuity of the dead wood substrate as to sustain this volume requires the input to equal the rate of decay. The existence of the majority of the dead wood volume in small logs means that the rate of decay will be much faster than would otherwise be the case. This is especially important in areas with a wet climate such as Ennerdale with relatively high rates of decay (Sweeney *et al*., 2010). As thinning has only recently occurred in Ennerdale a lot of the logs (70%) are in an early stage of decay, therefore if there is a continued maintenance of the CCF technique as well as input of much larger diameter classes the CWD composition would be expected to even out and sustainability achieved.

The native woodland was found to have CWD most evenly distributed throughout the decay classes, while the ancient woodland was found to have a high proportion of its log volume in an early stage of decay. Compared to softwood species such as spruce and larch, oak takes a lot longer to decompose (Petritan, 2012). The lack of older decayed pieces of oak may therefore reflect historic harvesting (e.g. for charcoal and fire wood) which would have removed any logs that in the present day would have been in a higher stage of decay. The contribution of log volume in the higher diameter classes was much more pronounced in the ancient woodland increasing decomposition time and in turn the provision of beneficial properties particularly important for the bryophyte communities present.

In general the higher decay stages were under-represented with mainly stumps left from previous clear-felling in the even-aged conifer stands contributing to the dead wood volume. However, an aspect to consider when speculating on this is that the criteria set out in the classification for the highly decayed stages is that the piece "no longer maintains its shape" and "spreads out on the ground" with these properties it is much harder to accurately measure the volume of dead wood and it would be expected that a much smaller volume would be recorded.

5.2 Factors Influencing Woodland Regeneration

5.2.1 Overall Woodland Regeneration

The high occurrence of rowan seedlings and saplings in all stand types indicates their ability to survive under a range of conditions. The low occurrence of immature ash and sycamore was primarily as a result of relatively few sample plots containing their mature tree counterparts; similarly beech and hazel regeneration was largely influenced by the presence or absence of parent trees in the sample plot, which were not as wide-spread as other species such as oak, rowan, spruce and larch. The regeneration of spruce was lower in both the native woodland types compared to the conifer stands. This is particularly promising for the encouragement of more shade intolerant native broadleaf species which tend to have a low survival rate in spruce dominated canopies (Eerikäinena, Miina and Valkonen, 2007). However, spruce regeneration remains high in the coniferous woodlands, which is more of a concern in the thinned conifer stand as development into mixed woodland could be hindered.

The native woodland exhibits the highest tree species richness followed closely by the thinned conifer stand while the even-aged and ancient woodland were similar. Although there was a high amount of spruce and larch regeneration, the thinned conifer stand also showed encouraging signs of native woodland succession with all broadleaf species surveyed represented; of these rowan and beech were doing particularly well which could be as a result of their tolerance to shade. The even-aged conifer stands dominated by spruce had a high germination of spruce seedlings and saplings relative to all other species, although birch, rowan, hazel and holly were present in some locations. The lack of saplings in the ancient woodland is the most striking aspect to come out of the species composition data and highlights a limitation to the ancient woodland stand in terms of sustainable forest development.

CCA analysis of the seedling and sapling occurrence across the whole valley indicates that the species distribution is influenced more strongly by environmental factors such as elevation, mature stand composition, grazing and aspect than CWD type, number or volume. This is similar to multivariate results from Rubino and McCarthy, 2003 who also found no significant relationship between sapling number and CWD when considering other environmental data. However the shift in management towards conservation of dead wood is relatively new, and this may change over time as the composition and continuity of dead wood matures.

When analysing the multivariate data, potential interactions between environmental variables need to be addressed; for instance the significant positive relationship between sheep grazing and broadleaf seedlings and saplings is misleading due to the fact that sheep grazing was predominantly in the ancient woodland where broadleaf seedlings and saplings would naturally be expected to be present at greater concentrations than in the conifer woodlands. By separating the data into native woodland and conifer woodlands the confounding interactions were reduced.

5.2.2 Native Woodland Regeneration

In the native woodland there was a clear north-south divide between the species data with more saplings occurring on slopes with a southern aspect with the exception of birch and rowan. The presence of sheep grazing was one of the most important factors in explaining the distribution of species, displaying a negative relationship with oak, holly and larch saplings, although there was no effect on birch saplings, which were found to be strongly related to cattle grazing and log volume.

The aspect variable is confounded by the grazing regime; most of the sheep grazing occurred on the northern aspect slopes so the significant effect of aspect is likely due to be misleading. For this reason it is interesting that log volume shows a positive correlation to birch and rowan saplings which were the only saplings to show no effect from the presence of sheep grazing. This suggests that the logs could be protecting the saplings from the sheep, which is consistent with aforementioned findings by Van-Ginkela *et al*., (2013), which demonstrated dead wood provided protection from ungulate grazing; therefore log volume appears to be a significant positive factor to be promoted for the survival of birch and rowan saplings in regenerating stands. The lack of oak saplings in the ancient woodland even with a high log volume suggests that birch and rowan have a competitive advantage over oak, which is perhaps related to their ability to establish on earlier decay stages of dead wood.

The strong association of birch saplings to cattle grazing for the native woodland sites could indicate that the conservation initiative of introducing cattle to the valley is having a positive influence on birch regeneration; certainly it suggests that there is no detrimental effect to birch. As birch is an early pioneer species, this may indicate a wider positive effect of cattle grazing on woodland regeneration. However, further study would be required to determine the significance of this interaction. Seedlings of ash were strongly associated and birch moderately associated with sheep grazing, which may suggest the presence of sheep helps to encourage germination of seeds or at least not prevent seedling regeneration. However, the sheep grazing appears to prevent the maturation of the seedlings into saplings, which is consistent with other studies that found having either too high *or* too low a grazing intensity can be detrimental to species diversity (Coote, 2012). The multivariate analysis technique did not include grazing intensity as an environmental parameter. However the severe lack of oak saplings, strongly suggests sheep grazing intensities are too high, and therefore without intervention there will be a declining tendency of oak in the stand in the future.

5.2.3 Coniferous Woodland Regeneration

The thinned conifer stand is associated with birch, rowan and beech, while the even-aged stand (as well as the obvious larch/spruce) is associated with holly, which in turn shows a positive relationship with log number and volume for seedlings and saplings respectively. The reason for this is un-clear; holly requires moderate sun light, shelter from high winds to prevent drying out of leaves and a high organic soil content (K.E.W., 2013). The higher number of logs could provide wind protection. Another possibility is that as aforementioned decomposing fungi can create microhabitats that alter the substrate pH levels; in a coniferous plantation the soil is expected to be highly acidic and low in available nutrients, and the dead wood may provide more optimal conditions for seedling establishment.

5.3 Limitations

In general the choice of the sample plot worked well in this study, if a transect method was used limitations would have been found regarding the very dense even-aged spruce plantations making transects almost physically impossible, however in other stands such as the ancient woodland which was much more open a line intersect method would perhaps have reduced the error from the very random distribution of fallen dead wood.

The coeffient of variance is found to drop considerably with increasing plot size (Harmon and Sexton, 1996), and suggest plots greater than 0.06ha should be used. For this study we used plots of 0.02ha; however it was decided that the comparison opportunity with other woodland development data outweighed the increase in error from plot sampling size. The variation in estimates is also affected by the protocol used to select fallen dead wood, by measuring all logs that fell in the plot an over-estimation of CWD may have been made however as this would have been balanced due to using smaller plot sizes.

A proportionately higher number of sample points were taken in the native woodland types compared to the conifer stands, which covered a considerably larger area than the native woodland. This could mean that the accuracy of the CWD volume estimate is higher for native woodlands, however due to the uniform structure of coniferous plantations there is likely to be less variation in the distribution of dead wood and therefore the plots sampled still reflected the conifer stands well.

The DOMIN values used for woodland regeneration gives an approximation of the percentage cover however count data and measurements would be much more accurate in reflecting seedling and sapling presence. Also the number of zero values was high, which is not ideal for multivariate analysis, although still acceptable when investigating relationships accounting for the variability in the data set, having more plots to reduce this error would by advisable.

5.4 Management Implications

The main priority of land managers such as the Forestry Commission should be to increase the number of large diameter logs and snags throughout the valley by protecting selected mature trees from any future harvesting. It may also be of benefit to select some large pieces of dead wood from the ancient woodland or bring some in to the valley and distribute throughout the conifer stands this would help increase the longevity by balancing out the faster rate of decay that occurs to soft wood species such as spruce and provide more optimal habitat for the succession of a more native woodland within the CCF.

A decision needs to be made on whether the management is to support the regeneration of oak within this remnant ancient woodland and reduce grazing intensities, or continue to prevent the regeneration of oak and the success of other saplings with the aim of conserving more specialist bryophyte communities. When deciding on the best management to promote ‘naturalness’ in the woodlands, consideration must be given to the fact that sheep have been a feature of this landscape for over 600 years influencing the development of the protected lichen and bryophyte layer by preventing shrub to dominate the understory (Averis, 2001).

Grazing is an integral component of many ecosystems across the UK and therefore a part of our natural environment. One of the hopes of the Wild Ennerdale Partnership is to encourage a "robust series of ecosystems to develop which will be more adaptable in the face of external pressures such as climate change" (W.E.S.P, 2006). Focusing on conserving one component of the ecosystem such as bryophytes is likely to prevent the succession and development of a "robust" ecosystem and therefore place it at a much greater risk of collapse under environmental change. A more balanced management approach that encourages the highest amount of diversity throughout all levels of the ecosystem is most likely to achieve sustainable targets.

5.5 Future Research Possibilities

There is a limited amount of studies relating British woodland development to coarse woody debris composition. Further research into the interactions between regeneration of key woodland tree species, understory development and dead wood composition would be beneficial to silviculture management especially if focused on the physiological properties of regeneration.

The Bryophyte and lichen layer in the ancient woodland is highly important as it is one of the main reason for being classed as a SSSI therefore an investigation into the contribution of dead wood in providing optimal conditions for further development of this layer would be interesting.

Comparison of methods such as the line intersect method, and protocols to estimate CWD volume could be made to assess the variance and accuracy of estimates and provide further assurances to the CWD composition.

6. Conclusion

This study set out to estimate the CWD composition across the four main woodland types in Ennerdale valley and to explore relationships of this with woodland regeneration. With deeper understanding land managers such as The Forestry Commission can make more informed choices regarding promotion of a more 'robust' and sustainable ecosystem.

The volume of CWD was found to be achieving European targets in all woodland stands with the exception of the even-aged stand, which is slightly lower than recommended this however is likely to change as the stands mature and are converted to CCF. There was a lack of large diameter logs and snags throughout the valley as well as a high proportion of dead wood volume in the very early stages of decay. Ideally there would be a much more even spread of CWD type throughout the classes to be of more benefit to biodiversity.

There were indications that log volume; by providing protection from sheep grazing in the ancient woodland and providing more optimal substrate for seed germination in the conifer stands had influenced specific species; holly in the conifer woodlands and birch and rowan saplings in the native woodland. Further investigations into the significance of this would be beneficial to aid decisions relating to the intensities of grazing and the establishment of native woodland species into conifer stands converted to CCF.

The seedling establishment in the ancient woodland is being significantly limited by sustained grazing which is reducing the growth of understory wood therefore additions from this source into the future will be minimal, the input from large ancient oaks will continue for some time to come however there is likely to be a gap in the continuity of dead wood if oaks continue to be limited by sheep grazing. Without intervention there will be a declining tendency of oak in the stand in the future.

Management priorities should be to increase the size of dead wood and allow for over maturity of selected trees throughout all stands. In relation to woodland development consideration of grazing intensities are required as currently this is preventing the regeneration of seedlings and consequently limiting the development of a more robust ecosystem in the ancient woodland stand.

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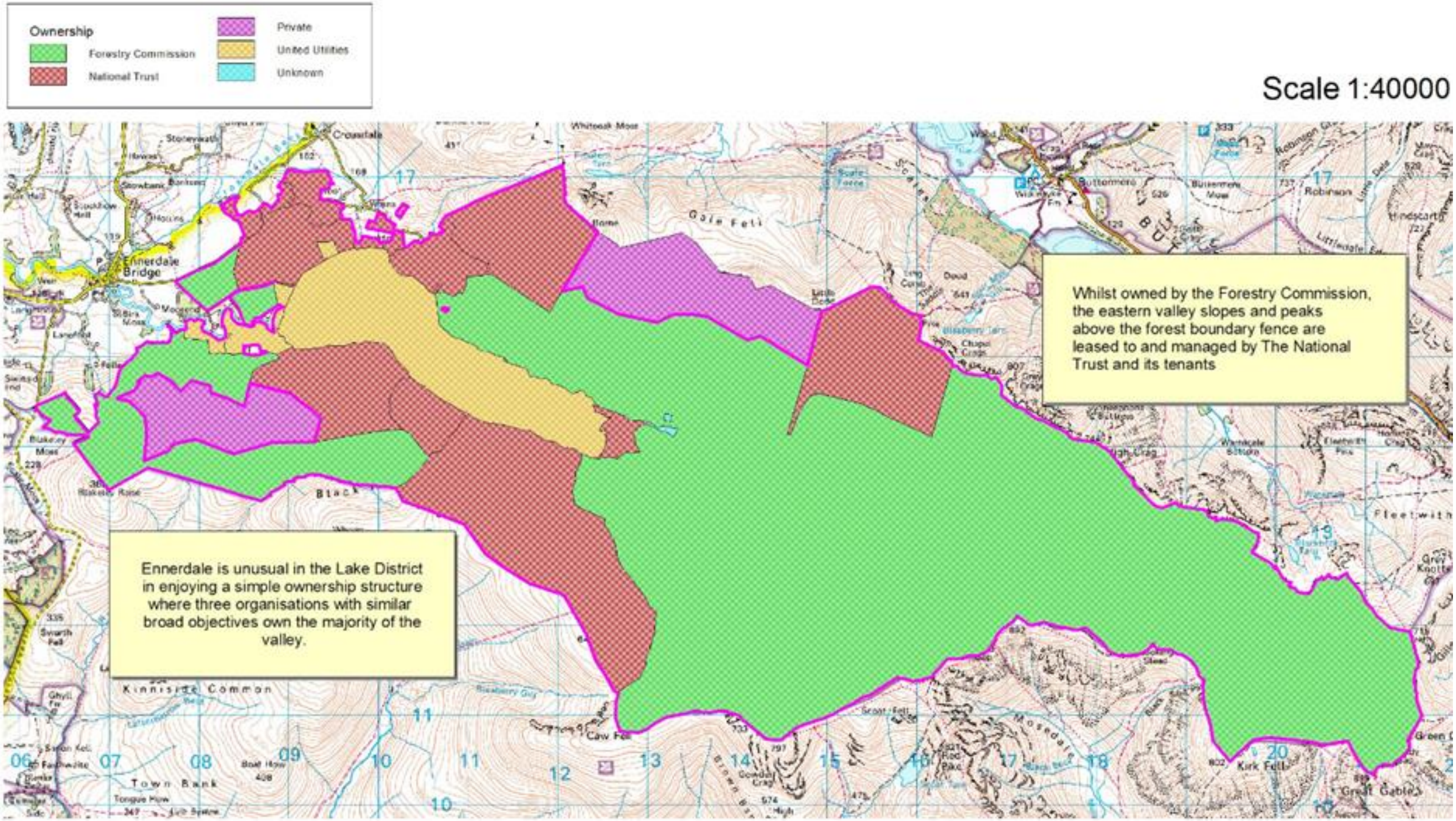
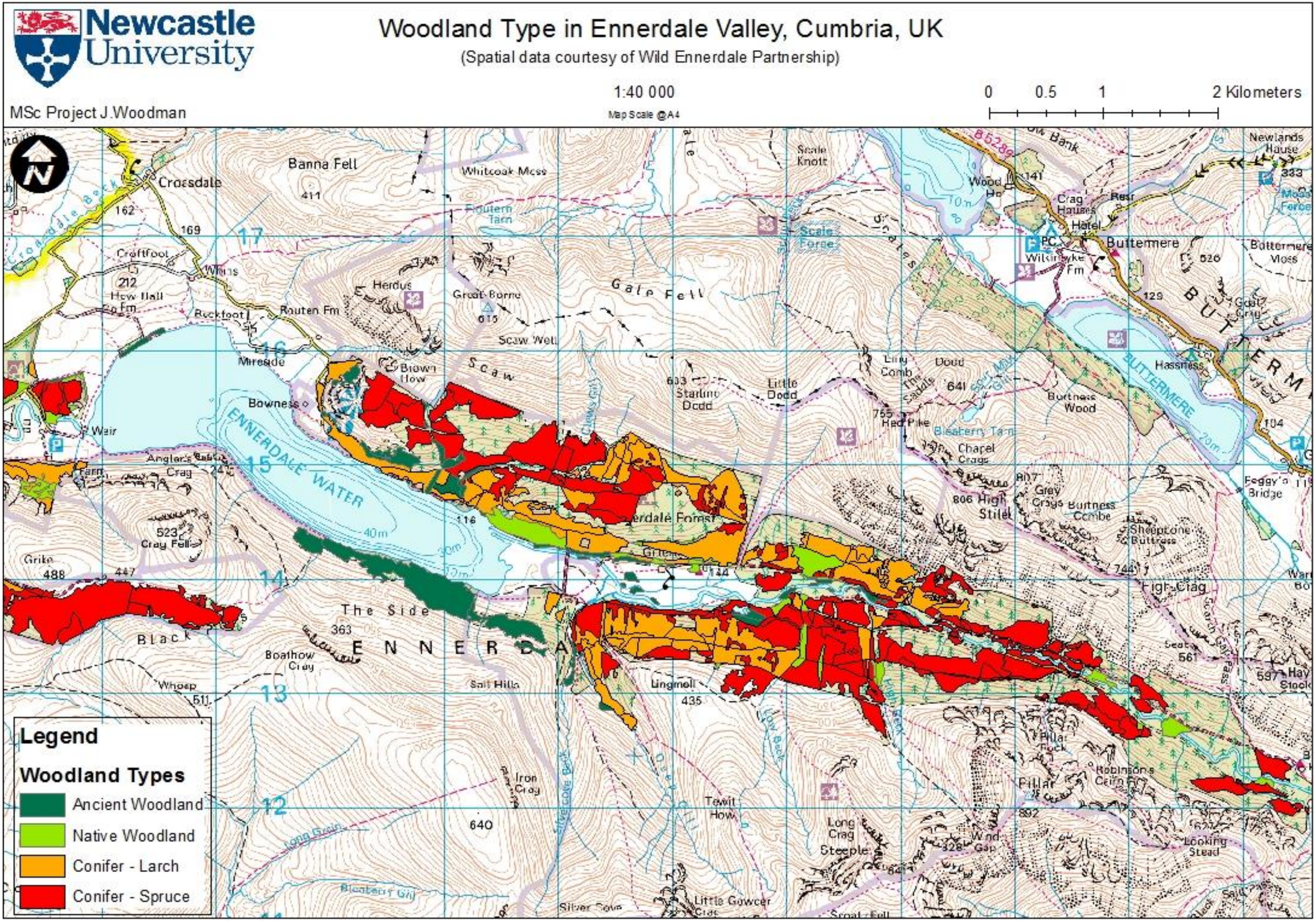
APPENDIX 1.

- Maps

Land Ownership in Ennerdale Valley, (map taken from the Wild Ennerdale Partnership)




Newcastle University
Woodland Type in Ennerdale Valley, Cumbria, UK
(Spatial data courtesy of Wild Ennerdale Partnership)
MSc Project J.Woodman
1:40 000
Map Scale @A4
0 0.5 1 2 Kilometers
Banna Fell
Crossdale
Whitcoak Moss
Gale Fell
Buttermere
ENNERDALE WATER
Bowness
The Side
ENNERDA
Ennerdale Forest
High Stile
High Crag
Pillar
Red Pike
Starling Dodd
Little Dodd
Scaw
Herdus
Great Borne
Lingmell
Boathow Crag
Crag Fell
Grike
Iron Crag
Steeple
Haystacks
Looking Stead
Legend
Woodland Types
Ancient Woodland
Native Woodland
Conifer - Larch
Conifer - Spruce

Newcastle University

Location of all Sample Plots, Ennerdale Valley, Cumbria, UK

Legend

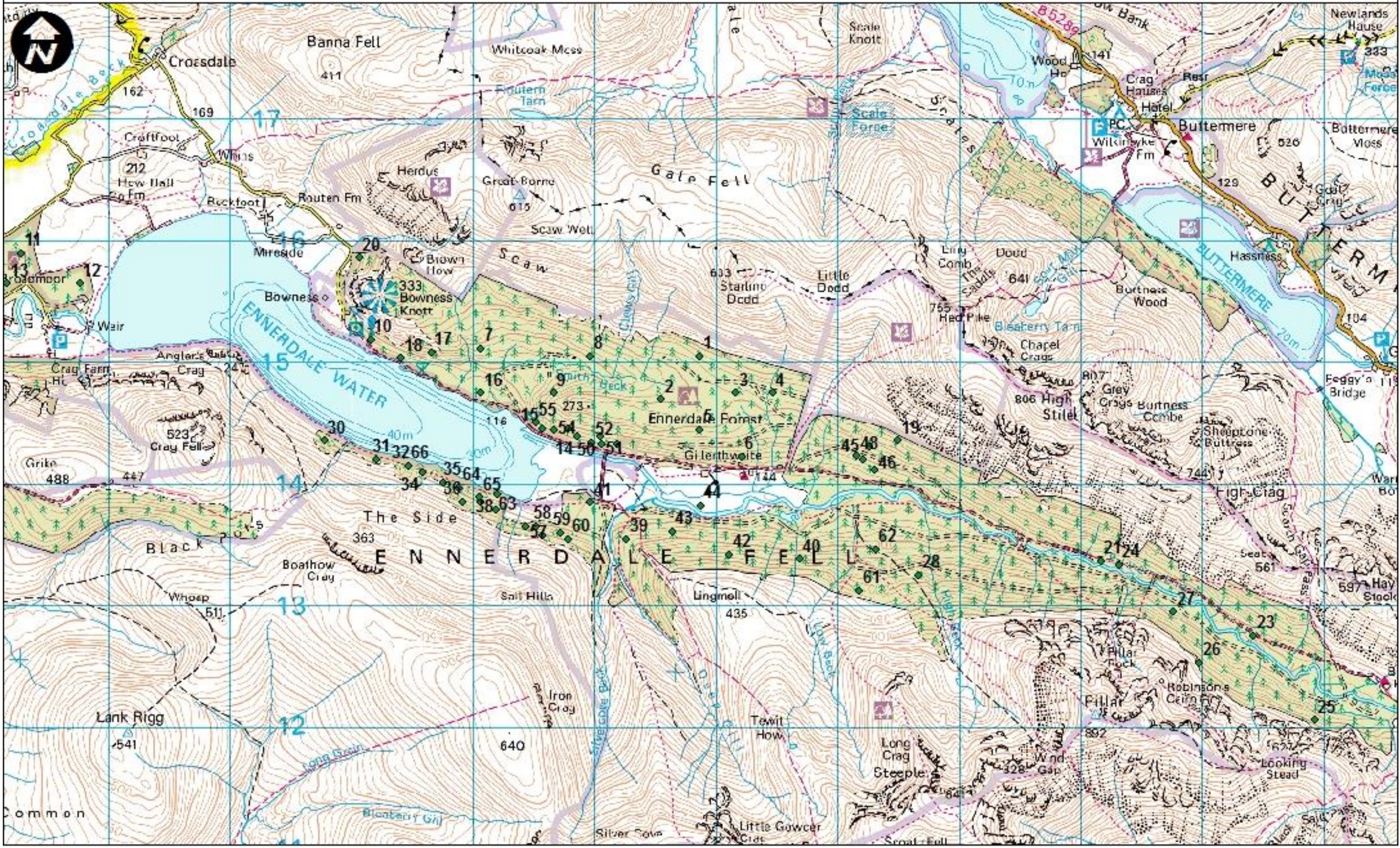
◆ Sample plots

MSc Project J.Woodman

1:40 000

Map Scale @A4

0 0.5 1 2 Kilometers



Newcastle University

Extent of sheep grazing and the sample plots effected, Ennerdale Valley, Cumbria, UK

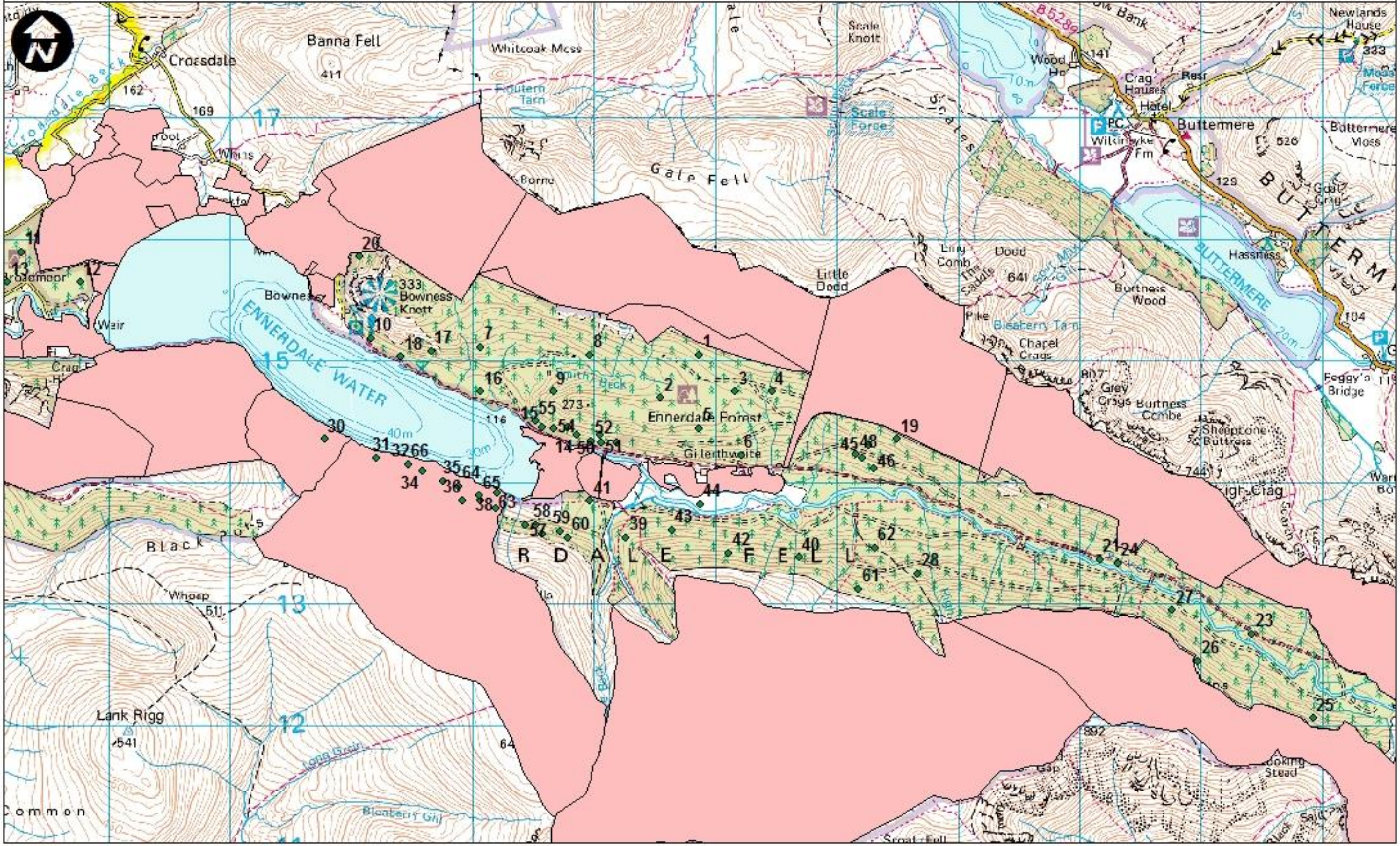
MSc Project J.Woodman

1:40 000
Map Scale @A4

0 0.5 1 2 Kilometers

Legend

- Sample plots
- Sheep grazing

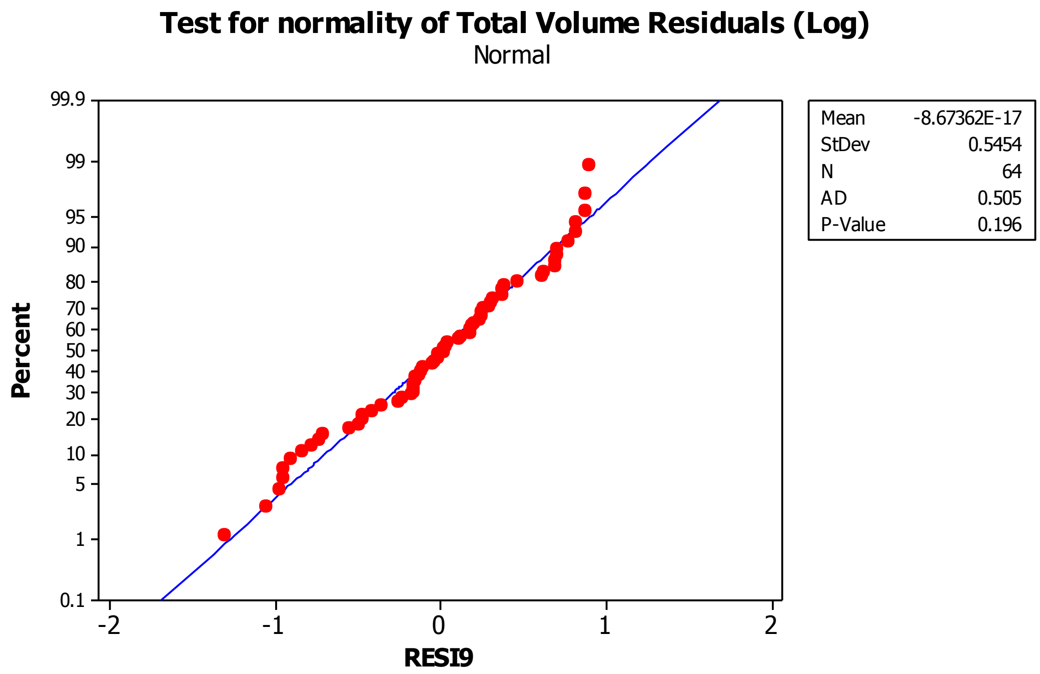


APPENDIX 2.

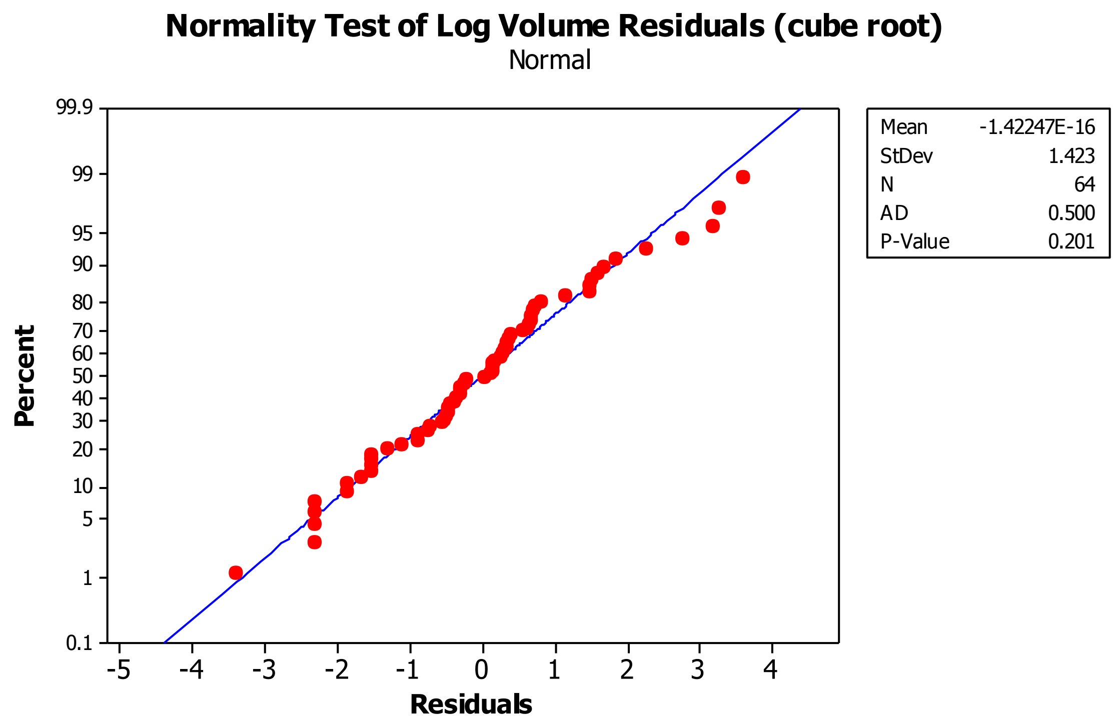
- Data Analysis

Transformations

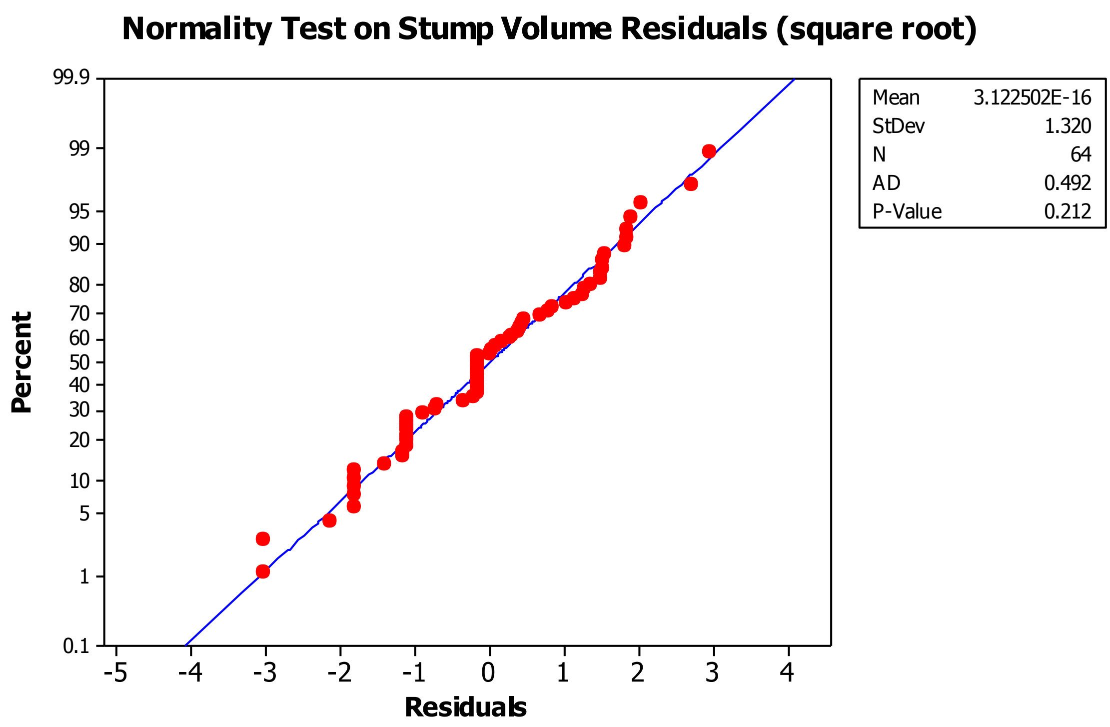
Total volume:



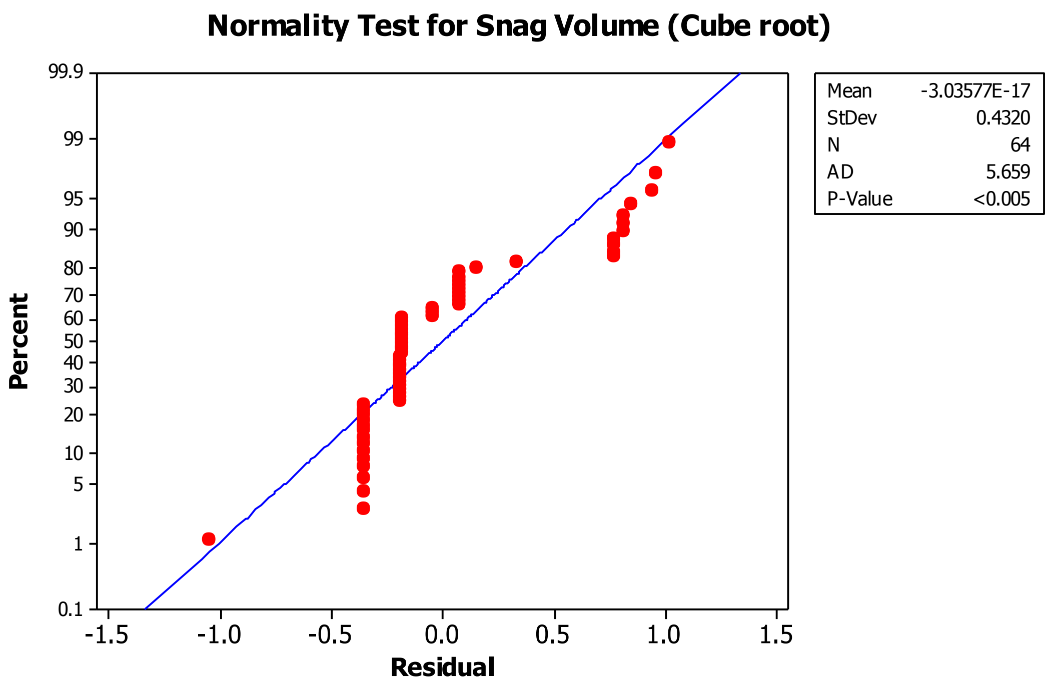
Log volume:

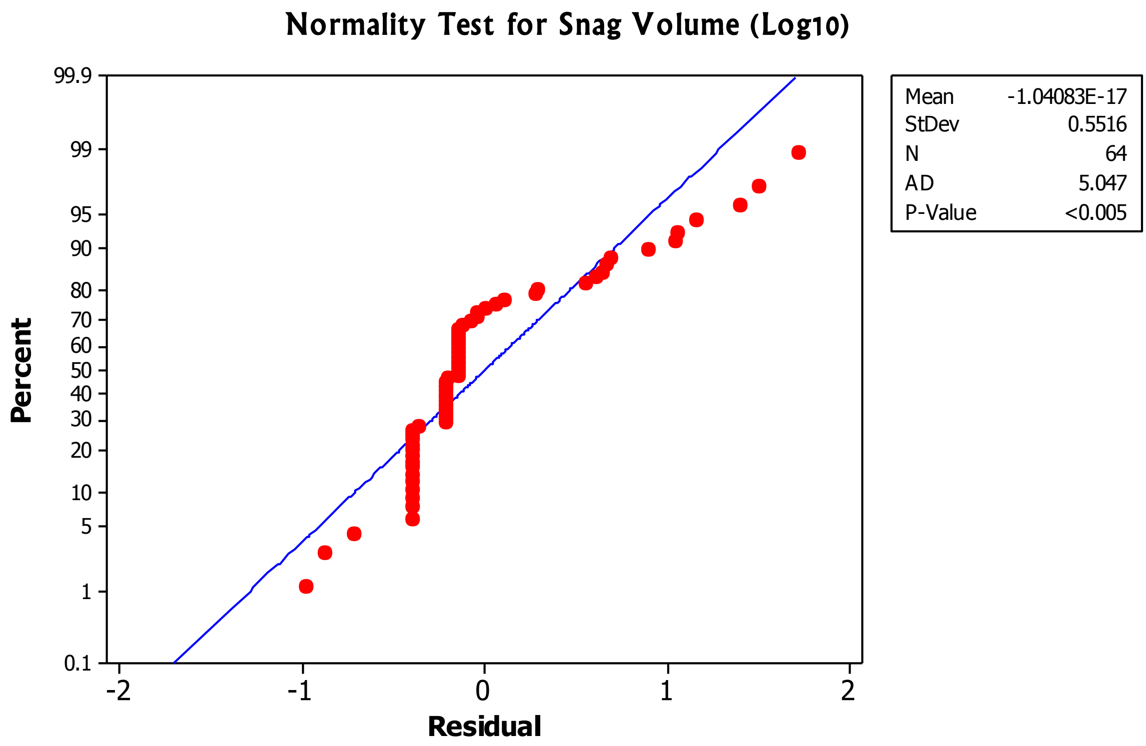


Stump volume:



Snag Volume: (Could not be transformed)




Normality Test for Snag Volume (Log10)
Percent
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
-2
-1
0
1
2
Residual
Mean -1.04083E-17
StDev 0.5516
N 64
AD 5.047
P-Value <0.005

Analysis of Variance and Tukey's Method

Log volume and stand type:

GLM

Analysis of Variance for lg_cube, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
ST	3	27.249	27.249	9.083	4.27	0.008
Error	60	127.633	127.633	2.127		
Total	63	154.882				

S = 1.45850   R-Sq = 17.59%   R-Sq(adj) = 13.47%

Tukey's

ST	N	Mean	Grouping
AW	13	3.4	A
TC	20	2.3	A B
NW	15	1.9	B
EC	16	1.5	B

Means that do not share a letter are significantly different.

Stump Volume and stand type:

GLM

Analysis of Variance for st_sq, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
ST	3	71.332	71.332	23.777	13.00	0.000
Error	60	109.769	109.769	1.829		
Total	63	181.100				

S = 1.35258   R-Sq = 39.39%   R-Sq(adj) = 36.36%

Tukey's

ST	N	Mean	Grouping
TC	20	3.0	A
EC	16	1.8	B
NW	15	1.1	B C
AW	13	0.2	C

***Total Volume*:**

GLM

Analysis of Variance for log, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
ST	3	3.1513	3.1513	1.0504	3.36	0.024
Error	60	18.7430	18.7430	0.3124		
Total	63	21.8943				

S = 0.558912   R-Sq = 14.39%   R-Sq(adj) = 10.11%

Kruskal-Wallis and Mann-Whitney Test

Snag volume data analysed using non-parametric tests:

Kruskal-Wallis Test: SNV versus ST

Kruskal-Wallis Test on SNV

ST	N	Median	Ave Rank	Z
AW	13	0.000000000	25.6	-1.49
EC	16	0.000000000	25.9	-1.64
NW	15	4.718279467	47.7	3.61
TC	20	0.000000000	30.9	-0.46
Overall	64		32.5	

H = 13.90 DF = 3 P = 0.003
H = 17.97 DF = 3 P = 0.000 (adjusted for ties)

Results for: Worksheet 3

Mann-Whitney Test and CI: SNV_AW, SNV_EC

	N	Median
SNV_AW	13	0.00
SNV_EC	16	0.00

Point estimate for ETA1-ETA2 is 0.00
95.4 Percent CI for ETA1-ETA2 is (0.00,0.00)
W = 192.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.9301
The test is significant at 0.8940 (adjusted for ties)

Mann-Whitney Test and CI: SNV_AW, SNV_NW

	N	Median
SNV_AW	13	0.00
SNV_NW	15	4.72

Point estimate for ETA1-ETA2 is -4.69
95.2 Percent CI for ETA1-ETA2 is (-6.63,-0.70)
W = 120.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0019
The test is significant at 0.0012 (adjusted for ties)

Mann-Whitney Test and CI: SNV_AW, SNV_TC

	N	Median
SNV_AW	13	0.00
SNV_TC	20	0.00

Point estimate for ETA1-ETA2 is 0.00
95.1 Percent CI for ETA1-ETA2 is (0.00,0.00)
W = 202.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.4955
The test is significant at 0.3647 (adjusted for ties)

Mann-Whitney Test and CI: SNV_EC, SNV_TC

	N	Median
SNV_EC	16	0.00
SNV_TC	20	0.00

Point estimate for ETA1-ETA2 is -0.00
95.3 Percent CI for ETA1-ETA2 is (-0.01,-0.01)
W = 275.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.5140
The test is significant at 0.3908 (adjusted for ties)

Mann-Whitney Test and CI: SNV_NW, SNV_TC

	N	Median
SNV_NW	15	4.72
SNV_TC	20	0.00

Point estimate for ETA1-ETA2 is 4.39
95.3 Percent CI for ETA1-ETA2 is (0.55,6.03)
W = 342.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0172
The test is significant at 0.0130 (adjusted for ties)

Mann-Whitney Test and CI: SNV_NW, SNV_EC

	N	Median
SNV_NW	15	4.72
SNV_EC	16	0.00

Point estimate for ETA1-ETA2 is 4.69
95.4 Percent CI for ETA1-ETA2 is (3.29,6.63)
W = 327.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0006
The test is significant at 0.0003 (adjusted for ties)

***Snag Number*:**

Kruskal-Wallis Test: SNN versus ST

Kruskal-Wallis Test on SNN

ST	N	Median	Ave Rank	Z
AW	13	0.000000000	25.7	-1.49
EC	16	0.000000000	24.2	-2.05
NW	15	2.000000000	49.7	4.08
TC	20	0.000000000	30.7	-0.52
Overall	64		32.5	

H = 17.86 DF = 3 P = 0.000
H = 23.42 DF = 3 P = 0.000 (adjusted for ties)

<u>Diameter and Decay Class Analysis</u>

Logs:

Chi-Square Test

Diameter class of logs and stand type:

Chi-Sq = 57.964, DF = 12, P-Value = 0.000

Decay class of logs and stand type:

Chi-Sq = 101.148, DF = 12, P-Value = 0.000

Number of downed logs and their percentage distribution within each stand type for diameter and decay class.

Stand Type	No. pieces		Downed Logs											
			Diameter Class (cm)							Decay Class				
			5-9	10-14	15-19	20-24	25-29	30-34	35+	1	2	3	4	5
Ancient Woodland	63	Count	2	27	11	12	5	3	3	14	26	14	8	1
		Proportion	3	43	17	19	8	5	5	22	41	22	13	2
Native Woodland	46	Count	14	24	6	2	0	0	0	11	19	10	5	1
		Proportion	30	52	13	4	0	0	0	24	41	22	11	2
Thinned Conifer	95	Count	32	42	11	3	2	4	1	23	27	24	16	5
		Proportion	34	44	12	3	2	4	1	24	28	25	17	5
Even-aged Conifer	50	Count	13	20	7	7	3	0	0	1	4	15	18	12
		Proportion	26	40	14	14	6	0	0	2	8	30	36	24

Snags:

Number of snags and their percentage distribution within each stand type for diameter and decay class

Stand Type	No. pieces		Standing Dead Trees - snags											
			Diameter Class (cm)							Decay Class				
			5-9	10-14	15-19	20-24	25-29	30-34	35+	1	2	3	4	5
Ancient Woodland	5	Count	0	1	2	2	0	0	0	2	2	1	0	0
		Proportion	0	20	40	40	0	0	0	40	40	20	0	0
Native Woodland	32	Count	8	10	8	6	0	0	0	9	17	5	0	0
		Proportion	25	31	25	19	0	0	0	28	53	16	0	0
Thinned Conifer	17	Count	3	8	3	2	0	0	1	7	7	2	1	0
		Proportion	18	47	18	12	0	0	6	41	41	12	5.9	0
Even-aged Conifer	3	Count	1	0	1	0	0	0	1	2	0	1	0	0
		Proportion	33	0	33	0	0	0	33	67	0	33	0	0

Total Volume:

Proportion of CWD Volume (%) allocated to decay class by stand type.

CWD Type	Stand Type	Decay Class				
		1	2	3	4	5
Logs	AW	13	68	12	6	1
	NW	10	25	32	30	5
	TC	69	11	15	4	1
	EC	28	29	18	14	11
Stumps	AW	88	0	12	0	0
	NW	21	10	32	27	9
	TC	21	34	29	8	7
	EC	1	6	18	24	51
Snags	AW	46	48	7	0	0
	NW	36	50	14	0	0
	TC	34	34	24	7	0
	EC	17	0	83	0	0

Stand composition

Percentage of sample plots (N=64) containing Mature Trees (MT), Seedlings (Sd) and Saplings (Sp).

	Whole Valley			Conifer Woodlands			Native Woodlands		
Species name	MT	Sd	Sp	MT	Sd	Sp	MT	Sd	Sp
Spruce	39	41	45	92	67	81	0	7	0
Larch	25	22	27	39	31	42	7	11	7
Birch	50	34	31	22	31	25	86	39	39
Oak	38	28	8	0	3	3	86	57	14
Sycamore	3	3	5	3	3	3	4	4	7
Ash	9	8	0	0	3	0	21	14	0
Rowan	48	59	45	22	39	36	82	86	57
Beech	16	17	14	11	14	14	21	21	14
Hazel	13	11	2	6	8	0	21	14	4
Holly	9	20	8	3	8	6	18	36	11

Multivariate Analysis

PCA of mature tree data

	PC1	PC2	PC3	PC4	PC5	PC6			PC1	PC2	PC3	PC4	PC5	PC6
sit1	-0.77276	0.41684	-1.81206	-1.20832	0.45541	-0.91415		sit32	1.07005	0.63057	0.37692	0.149718	0.05363	-0.34812
sit2	-1.02068	0.37618	-0.56103	0.381875	1.86513	0.2028		sit33	1.0284	-0.09258	-0.11504	0.596497	-0.29232	-0.2037
sit3	-1.07372	0.12428	0.96016	1.67306	2.12067	0.30312		sit34	-0.07209	-1.77778	-2.23248	0.960901	-0.35215	0.15882
sit4	-1.49822	0.4334	0.3452	-0.12011	-2.93996	1.5209		sit35	0.06304	1.09705	-0.94782	-0.5607	-0.37003	2.00359
sit5	-1.44224	0.31772	0.82693	0.479037	-2.07861	1.25138		sit36	0.36087	0.85694	-0.50719	0.31421	1.89983	1.1206
sit6	-1.27469	0.31655	0.0689	0.095941	-0.23288	-1.03228		sit37	1.07005	0.63057	0.37692	0.149718	0.05363	-0.34812
sit7	-1.46127	0.5437	-0.70078	-0.73587	-0.94706	-1.23646		sit38	0.77522	0.89249	-0.14796	-0.27491	-0.1711	-0.18861
sit8	-0.93763	0.42895	-1.30755	-0.63999	0.74663	-0.23439		sit39	1.10608	0.81945	0.29024	-0.10149	-0.46093	-0.45453
sit9	-1.64669	0.65528	-0.29905	-0.46227	-2.64805	1.97951		sit40	0.71187	-1.43935	-0.88462	1.238127	-0.37561	-0.24563
sit10	-1.44374	0.30582	0.56623	0.398984	-0.5205	-1.2418		sit41	0.79627	-0.73127	1.33461	-2.53946	1.38418	0.85847
sit11	-1.00451	0.16104	0.99771	1.621937	0.44684	3.45451		sit42	0.71187	-1.43935	-0.88462	1.238127	-0.37561	-0.24563
sit12	-1.15825	0.11891	1.20882	1.824581	1.97686	0.19836		sit43	0.87592	0.3016	0.33143	0.155207	0.36621	-0.49028
sit13	-1.34604	0.2508	0.71205	0.735823	0.44102	-1.27199		sit44	0.22592	-0.12078	-1.92306	0.237377	-0.56679	0.80792
sit14	-1.44199	0.36957	0.18	0.006255	-0.70868	-1.64702		sit45	0.7921	-1.84087	0.54308	-1.8063	0.71311	1.15779
sit15	-1.52122	0.49101	0.14819	0.199039	-0.67893	0.37854		sit46	0.77336	-1.64765	0.69286	-1.94949	0.87567	1.08034
sit16	-0.5445	-0.74429	2.41058	0.727172	-0.22606	-2.03158		sit47	1.16793	0.77404	0.41953	0.132497	-0.08811	-0.26018
sit17	0.02027	-2.95415	1.43556	-0.7803	0.32321	0.53826		sit48	0.54014	-1.54813	0.90722	-2.20142	1.48426	0.74957
sit18	-0.29625	-2.48456	0.53424	-1.52077	-1.74137	-0.71836		sit49	1.2658	0.91751	0.46214	0.115275	-0.22984	-0.17225
sit19	-0.66929	-0.85087	1.62577	-1.83197	-1.39589	-2.1362		sit50	1.2658	0.91751	0.46214	0.115275	-0.22984	-0.17225
sit20	-1.07267	0.03336	1.34197	1.802906	1.7164	-0.07573		sit51	1.2658	0.91751	0.46214	0.115275	-0.22984	-0.17225
sit21	-0.87884	-0.08696	1.23032	1.374048	0.96648	-0.71351		sit52	0.45574	-2.25621	-1.31201	1.576163	-0.27552	-0.35453
sit22	-1.26914	-0.20753	1.22481	-0.82926	-0.84978	1.73222		sit53	0.58137	0.71404	-0.24602	0.478207	0.03651	2.95161
sit23	-1.44479	0.39673	0.18442	0.269137	-0.11623	-0.86294		sit54	1.2658	0.91751	0.46214	0.115275	-0.22984	-0.17225
sit24	-1.2015	-0.22009	0.49483	-1.51294	1.11004	0.45991		sit55	1.16793	0.77404	0.41953	0.132497	-0.08811	-0.26018
sit25	-0.89227	0.5305	-2.06346	-1.41101	0.28862	-0.41356		sit56	1.2658	0.91751	0.46214	0.115275	-0.22984	-0.17225
sit26	-0.89025	0.6067	-2.25975	-1.30032	1.86073	-0.37615		sit57	1.2658	0.91751	0.46214	0.115275	-0.22984	-0.17225
sit27	-0.65124	0.37661	-1.81055	-1.04653	1.6183	-0.62577		sit58	1.16793	0.77404	0.41953	0.132497	-0.08811	-0.26018
sit28	-1.12936	0.36743	-0.43228	0.04856	0.68802	-0.35432		sit59	1.28454	0.72428	0.31235	0.258461	-0.3924	-0.0948
sit29	0.437	-2.06298	-1.16223	1.432977	-0.11297	-0.43198		sit60	1.20123	-0.72201	-0.67158	1.152019	-1.08429	0.19403
sit30	0.47448	-2.44943	-1.4618	1.719349	-0.43808	-0.27708		sit61	0.98239	0.91027	0.03166	-0.56947	-1.20656	-0.84322
sit31	0.28632	0.40914	-1.58088	-0.06622	-0.38341	0.74096		sit62	1.07005	0.63057	0.37692	0.149718	0.05363	-0.34812
								sit63	1.07005	0.63057	0.37692	0.149718	0.05363	-0.34812
								sit64	0.19271	0.98077	-1.15545	-1.21488	-0.01348	-0.92046

CCA analysis of whole valley – tested for significance

	Df	Chisq	F	N.Perm	Pr(>F)	
CCA1	1	0.5269	16.7935	999	0.001	***
CCA2	1	0.2744	8.747	999	0.001	***
CCA3	1	0.1966	6.2665	999	0.001	***
CCA4	1	0.1072	3.4158	999	0.001	***
CCA5	1	0.0666	2.1239	999	0.025	*
CCA6	1	0.0554	1.7651	4999	0.0594	.
CCA7	1	0.0426	1.359	999	0.163	
CCA8	1	0.0226	0.7217	999	0.731	
CCA9	1	0.0192	0.6118	999	0.847	
CCA10	1	0.0138	0.4399	999	0.951	
CCA11	1	0.0087	0.2786	999	0.993	
CCA12	1	0.0042	0.1344	999	1	
CCA13	1	0.0026	0.0841	999	1	
CCA14	1	0.0003	0.0105	999	1	
CCA15	1	0.0003	0.0091	999	1	
Residual	44	1.3805				

	CCA1	CCA2	CCA3	CCA4	CCA5	CCA6
MT1	0.879019	0.02709	-0.02859	0.06256	-0.09718	0.1089
MT2	-0.24617	0.82417	0.100916	-0.17179	-0.31166	0.02605
ELV	0.628916	-0.01416	0.059069	-0.07673	-0.48912	-0.31035
CPY	0.428826	0.28311	0.039744	-0.51395	0.041319	0.47423
STV	0.521569	-0.18576	-0.01807	0.08288	0.268968	-0.05461
SNV	-0.0654	-0.09914	0.002757	0.11433	0.151484	-0.12448
SLP	-0.28743	-0.33413	0.082162	-0.13519	-0.09984	-0.15771
RCK	-0.6506	-0.2552	0.231113	-0.30903	-0.09631	-0.24938
COWY	0.293823	-0.1366	0.011727	0.5385	-0.10768	-0.16008
SHPY	-0.49678	0.15204	-0.73891	-0.10521	-0.12048	-0.06357
LGV	-0.00381	0.05328	-0.18036	0.25754	0.000984	-0.13726
TV	0.047495	0.02112	-0.18083	0.28209	0.125786	-0.21331
ASPS	0.126075	-0.30935	0.485212	-0.17609	0.171202	0.22274
STEC	0.526388	0.28879	0.125685	-0.40899	-0.32208	0.02055
STNW	-0.5599	-0.2943	0.58401	-0.05796	0.127483	-0.10615
	CCA1	CCA2	CCA3	CCA4	CCA5	CCA6
COWN	-0.1668	0.07705	-0.00551	-0.30422	0.06127	0.09061
COWY	0.5188	-0.23968	0.017153	0.94633	-0.19059	-0.28187
SHPN	0.202	-0.06355	0.304815	0.04522	0.05029	0.02548
SHPY	-1.1956	0.3762	-1.80428	-0.26768	-0.29767	-0.15079
ASPN	-0.1467	0.36934	-0.58087	0.20342	-0.20498	-0.26275
ASPS	0.104	-0.26171	0.411595	-0.14414	0.14525	0.18618
STEC	1.1232	0.61839	0.251935	-0.87576	-0.68822	0.04538
STNW	-0.8076	-0.42662	0.846569	-0.07662	0.18604	-0.15405
STTC	0.6643	-0.07802	-0.17079	0.63298	0.3049	0.18186

CCA of Native Woodland –tested for significance:

	Df	Chisq	F	N.Perm	Pr(>F)	
CCA1	1	0.5269	16.7935	999	0.001	***
CCA2	1	0.2744	8.747	999	0.001	***
CCA3	1	0.1966	6.2665	999	0.001	***
CCA4	1	0.1072	3.4158	999	0.001	***
CCA5	1	0.0666	2.1239	999	0.025	*
CCA6	1	0.0554	1.7651	4999	0.0594	.
CCA7	1	0.0426	1.359	999	0.163	
CCA8	1	0.0226	0.7217	999	0.731	
CCA9	1	0.0192	0.6118	999	0.847	
CCA10	1	0.0138	0.4399	999	0.951	
CCA11	1	0.0087	0.2786	999	0.993	
CCA12	1	0.0042	0.1344	999	1	
CCA13	1	0.0026	0.0841	999	1	
CCA14	1	0.0003	0.0105	999	1	
CCA15	1	0.0003	0.0091	999	1	
Residual	44	1.3805				

Biplot scores for constraining variables						
	CCA1	CCA2	CCA3	CCA4	CCA5	CCA6
SHPY	-0.69151	0.27572	-0.46097	0.09347	-0.21664	0.14945
COWY	-0.33952	-0.27013	0.71132	0.03956	-0.16588	-0.16997
ELV	-0.19696	0.02749	0.68644	0.40329	0.009276	-0.18511
CPY	0.19218	0.06106	-0.29242	-0.30687	0.124673	0.4782
SLP	-0.01192	0.09554	0.06716	0.06236	0.504616	-0.03818
RCK	0.43216	-0.32581	-0.11264	0.13833	-0.40408	0.29585
LGV	-0.4181	-0.14098	0.10364	-0.18464	-0.10741	0.17482
ASPS	0.88678	0.05143	0.12374	0.29264	0.10521	-0.20762
MT1	0.61815	0.64325	0.23191	0.01821	0.211956	0.11619
MT2	0.02425	-0.3486	-0.4468	0.44089	0.280469	0.51466
Centroids for factor constraints						
	CCA1	CCA2	CCA3	CCA4	CCA5	CCA6
SHPN	0.4655	-0.19032	0.3074	-0.06123	0.14851	-0.10713
SHPY	-1.0466	0.42791	-0.6913	0.13767	-0.33391	0.24087
COWN	0.1562	0.12378	-0.3281	-0.01826	0.07683	0.07775
COWY	-0.7316	-0.57989	1.5372	0.08554	-0.35995	-0.36424
ASPN	-0.8975	-0.03814	-0.1293	-0.2928	-0.11331	0.21913
ASPS	0.8805	0.03741	0.1268	0.28725	0.11117	-0.21498

CCA of Coniferous Woodland – tested for significance:

	Df	Chisq	F	N.Perm	Pr(>F)	
CCA1	1	0.3437	7.4833	999	0.001	***
CCA2	1	0.232	5.0518	999	0.001	***
CCA3	1	0.1481	3.2245	999	0.004	**
CCA4	1	0.099	2.1545	999	0.023	*
CCA5	1	0.0736	1.6019	999	0.091	.
CCA6	1	0.0295	0.6414	999	0.704	
CCA7	1	0.0205	0.447	999	0.9	
CCA8	1	0.0091	0.1984	999	0.992	
CCA9	1	0.0045	0.0981	999	1	
CCA10	1	0.0008	0.0171	999	1	
Residual	21	0.9645				

	CCA1	CCA2	CCA3	CCA4	CCA5	CCA6
ELV	-0.35284	-0.4876	-0.12134	0.38153	-0.57223	-0.02042
CPY	0.11762	-0.4546	-0.65282	0.18059	0.40304	-0.14915
RCK	-0.3713	0.30328	-0.07858	0.41389	-0.03909	-0.35689
MT1	0.43442	-0.11014	-0.64703	0.1065	-0.36371	0.22124
MT2	0.77184	-0.37902	0.26666	-0.2643	0.11011	-0.20513
STTC	-0.07781	0.50424	0.56516	0.06707	0.40929	-0.04913
ASPS	0.07059	0.20421	-0.32923	-0.60431	0.13808	-0.20434
LGV	-0.26933	-0.02152	0.36689	0.21942	-0.04848	0.05196
COWY	-0.50532	-0.09064	0.34102	-0.02612	0.3174	0.12319
LGN	-0.30092	-0.16732	0.28269	-0.07627	-0.14188	-0.31684

Centroids for factor constraints

	CCA1	CCA2	CCA3	CCA4	CCA5	CCA6
STEC	0.10386	-0.69408	-0.7776 -	-0.09148	0.5571	0.06895
STTC	-0.05537	0.37006	0.4146	0.04877	-0.297	0.03676
ASPN	-0.09594	-0.27696	0.4459	-0.82134	0.1876	0.27771
ASPS	0.05194	0.14993	-0.2414 -	0.44462	-0.1016	0.15033
COWN	0.33853	0.06114	-0.227	-0.01748	-0.2127	0.08264
COWY	-0.75461	-0.13629	-0.506	0.03897	0.4741	0.18422

APPENDIX 3.

- *Raw data*

Native woodland environmental parameter sample plot data

Stand Type	Plot	Co_ordinates X	Co_ordinates Y	Grazing Sheep	Grazing Cattle	CWD Intentory Logs No.	Logs Vol. m^3ha^{-1}	Stumps No.	Stumps Vol. m^3ha^{-1}	Snags No.	Snags Vol. m^3ha^{-1}	Total Vol. m^3ha^{-1}	Environmental Parameters Elevation m	Aspect	Slope ^{0}	Canopy Cover %	Rock Cover %
AW	30	310780	514354	Y	N	5.00	50.91	0.00	0.00	3.00	23.62	74.52	159	N	31	25	40
AW	31	311202	514198	Y	N	6.00	52.50	0.00	0.00	2.00	18.18	70.67	125	N	32	10	80
AW	32	311466	514144	Y	N	6.00	24.48	0.00	0.00	0.00	0.00	24.48	136	N	20	25	35
AW	33	311506	414118	Y	N	10.00	53.93	0.00	0.00	0.00	0.00	53.93	145	N	24	50	70
AW	34	311590	514096	Y	N	6.00	64.60	0.00	0.00	0.00	0.00	64.60	140	N	19	85	80
AW	35	311759	514008	Y	N	10.00	233.16	0.00	0.00	0.00	0.00	233.16	155	N	25	5	90
AW	36	311913	513847	Y	N	1.00	5.14	0.00	0.00	0.00	0.00	5.14	141	N	14	30	10
AW	37	312066	513844	Y	N	2.00	9.18	1.00	2.75	0.00	0.00	11.93	161	N	26	55	40
AW	38	312206	513914	Y	N	1.00	24.42	1.00	0.38	0.00	0.00	24.79	182	N	26	60	80
AW	63	312188	513783	Y	N	7.00	39.63	0.00	0.00	0.00	0.00	39.63	169	N	48	30	80
AW	64	311885	513965	Y	N	5.00	283.04	0.00	0.00	0.00	0.00	283.04	146	N	20	10	20
AW	65	312059	513887	Y	N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	146	N	36	35	60
AW	66	311466	514144	Y	N	6.00	24.48	0.00	0.00	0.00	0.00	24.48	136	N	20	25	35
NW	14	312860	514390	N	N	12.00	37.79	2.00	8.91	7.00	23.05	69.76	153	N	39	70	75
NW	15	312573	514451	N	N	5.00	18.87	1.00	1.24	2.00	4.72	24.83	130	S	46	75	80
NW	17	311658	515080	N	N	6.00	8.20	1.00	1.62	2.00	3.92	13.73	187	S	52	65	95
NW	49	313182	514324	N	N	3.00	2.90	1.00	1.88	0.00	0.00	4.78	144	S	28	35	75
NW	50	313045	514388	N	N	4.00	16.46	2.00	2.46	2.00	6.63	25.54	174	S	32	30	20
NW	51	313059	514324	N	N	4.00	10.63	0.00	0.00	3.00	4.39	15.02	175	S	28	40	95
NW	52	312974	514341	N	N	0.00	0.00	0.00	0.00	2.00	25.25	25.25	163	S	36	35	45
NW	53	312780	514449	N	N	1.00	14.47	0.00	0.00	2.00	18.82	33.30	177	S	44	25	95
NW	54	312668	514443	N	N	3.00	17.34	3.00	6.64	2.00	4.69	28.67	155	S	34	35	90
NW	55	312517	514503	N	N	1.00	2.34	0.00	0.00	2.00	6.02	8.36	137	S	18	25	95
NW	56	312568	513577	N	Y	5.00	16.75	3.00	0.00	2.00	41.11	57.86	234	S	33	20	60
NW	57	312435	513651	N	Y	2.00	10.60	1.00	6.91	2.00	5.29	22.79	197	N	43	30	70
NW	58	312516	513652	N	Y	1.00	3.22	2.00	8.56	1.00	3.28	15.07	191	N	30	20	60
NW	59	312721	513595	N	Y	0.00	0.00	0.00	0.00	1.00	0.70	0.70	178	N	28	40	60
NW	60	312788	513546	N	Y	2.00	0.96	0.00	0.00	1.00	0.54	1.51	196	N	14	25	60

Coniferous woodland environmental parameter sample plot data

Stand Type	Plot	Co_ordinates		Grazing		CWD Intentory							Environmental Parameters				
		X	Y	Sheep	Cattle	Logs No.	Logs Vol. m^3ha^{-1}	Stumps No.	Stumps Vol. m^3ha^{-1}	Snags No.	Snags Vol. m^3ha^{-1}	Total Vol. m^3ha^{-1}	Elevation m	Aspect	Slope ^{0}	Canopy Cover %	Rock Cover %
TC	1	313866	515044	N	N	6.00	207.50	3.00	7.15	0.00	0.00	214.64	292	N	19	15	20
TC	4	314466	514744	N	N	9.00	96.37	8.00	20.67	2.00	4.78	121.82	280	S	21	70	5
TC	7	312069	515110	N	N	8.00	14.13	8.00	11.56	0.00	0.00	25.69	203	S	13.5	95	10
TC	8	312966	515044	Y	N	8.00	15.52	10.00	23.57	2.00	131.03	170.11	225	S	27	70	85
TC	9	312666	514744	N	N	5.00	64.21	1.00	0.82	3.00	80.35	145.38	224	S	57	10	15
TC	10	311160	515182	N	N	7.00	8.06	2.00	4.57	0.00	0.00	12.63	145	S	20	5	15
TC	12	308766	515644	N	N	0.00	0.00	8.00	9.74	2.00	10.35	20.09	131	S	13	75	5
TC	13	308166	515644	N	N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	125	S	1	80	0
TC	16	312066	514744	N	N	0.00	0.00	3.00	7.98	0.00	0.00	7.98	120	S	3	60	15
TC	18	311413	515032	N	N	7.00	26.45	4.00	11.11	0.00	0.00	37.56	134	S	25	45	25
TC	20	311065	515859	N	N	8.00	17.61	3.00	2.67	0.00	0.00	20.28	160	N	40	85	20
TC	39	313266	513544	N	Y	11.00	41.71	4.00	25.50	0.00	0.00	67.21	186	N	12	40	0
TC	40	314687	513381	N	N	11.00	172.88	2.00	13.82	5.00	28.82	215.52	257	N	51	50	80
TC	41	312966	513844	N	Y	5.00	8.89	10.00	35.83	0.00	0.00	44.72	134	N	2	25	15
TC	43	313640	513607	N	Y	4.00	2.82	8.00	14.48	2.00	4.94	22.25	183	N	11	65	10
TC	44	313871	513819	N	Y	0.00	0.00	0.00	0.00	0.00	0.00	0.00	129	S	0	10	0
TC	45	315208	514199	N	Y	3.00	8.07	9.00	18.33	0.00	0.00	26.41	188	S	32	35	10
TC	46	315309	514109	N	Y	1.00	1.76	4.00	3.46	0.00	0.00	5.21	191	S	22	45	45
TC	47	315258	514307	N	Y	3.00	5.57	7.00	5.34	0.00	0.00	10.91	219	S	19	60	7
TC	48	315162	514226	N	Y	1.00	3.90	4.00	17.46	0.00	0.00	21.36	200	S	21	30	10
EC	2	313551	514693	N	N	0.00	0.00	6.00	9.53	0.00	0.00	9.53	260	S	8	90	10
EC	3	314166	514744	N	N	6.00	4.83	8.00	10.05	0.00	0.00	14.88	271	S	12	90	5
EC	5	313866	514444	N	N	4.00	5.69	2.00	4.89	0.00	0.00	10.57	254	S	38	50	5
EC	6	314212	514224	N	N	12.00	27.95	7.00	20.30	0.00	0.00	48.24	183	S	32	90	10
EC	11	308286	515897	N	N	3.00	10.38	16.00	13.25	0.00	0.00	23.64	146	S	4	85	5
EC	19	315499	514353	N	Y	9.00	38.41	6.00	11.09	1.00	0.60	50.10	231	S	26	95	10
EC	21	317167	513366	N	N	3.00	30.44	0.00	0.00	1.00	34.54	64.98	214	S	16	95	15
EC	23	318419	512748	N	Y	2.00	4.69	6.00	7.99	0.00	0.00	12.69	259	S	4	90	30
EC	24	317315	513330	N	N	1.00	0.52	8.00	6.98	0.00	0.00	7.49	212	S	27	90	10
EC	25	318925	512054	N	N	2.00	2.23	6.00	3.24	0.00	0.00	5.47	337	N	50	75	30
EC	26	317975	512526	N	N	0.00	0.00	0.00	0.00	1.00	6.48	6.48	351	N	50	80	70
EC	27	317766	512944	N	Y	0.00	0.00	0.00	0.00	0.00	0.00	0.00	236	N	22	75	30
EC	28	315666	513244	N	N	6.00	28.12	1.00	0.42	0.00	0.00	28.54	296	N	19	70	5
EC	42	314112	513417	N	N	1.00	1.93	0.00	0.00	0.00	0.00	1.93	251	N	48	80	5
EC	61	315182	513119	N	N	0.00	0.00	1.00	1.22	0.00	0.00	1.22	314	N	13	15	10
EC	62	315313	513457	N	N	1.00	1.65	0.00	0.00	0.00	0.00	1.65	216	N	12	10	15

Stand composition data – Native woodland: trees and saplings

Stand Type	Plot	Trees (Domin Value)										Saplings (Domin Value)									
		Spruce	Larch	Birch	Oak	Sycamore	Ash	Rowan	Beech	Hazel	Holly	Spruce	Larch	Birch	Oak	Sycamore	Ash	Rowan	Beech	Hazel	Holly
AW	30	0	0	7	0	0	4	7	0	0	0	0	0	0	0	0	0	0	0	0	0
AW	31	0	0	9	4	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0
AW	32	0	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AW	33	0	0	6	8	0	0	8	0	6	0	0	0	0	0	0	0	0	0	0	0
AW	34	0	0	6	9	0	0	6	0	5	0	0	0	0	0	0	0	0	0	0	0
AW	35	0	0	7	7	0	0	6	0	0	0	0	0	4	0	0	0	7	0	0	0
AW	36	0	0	8	6	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0
AW	37	0	0	8	2	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0
AW	38	0	0	8	7	0	0	9	0	6	0	0	0	0	0	0	0	5	0	0	0
AW	63	0	0	7	9	0	0	6	0	0	0	0	0	1	0	0	0	0	0	0	0
AW	64	0	0	7	7	0	0	0	0	6	0	0	0	6	0	0	0	4	0	0	0
AW	65	0	0	8	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AW	66	0	0	7	9	0	2	4	0	0	2	0	0	0	0	0	0	0	0	0	0
NW	14	0	0	7	8	0	3	7	0	0	0	0	0	3	2	3	0	0	0	0	2
NW	15	0	0	8	8	0	2	6	0	3	2	0	0	0	0	0	0	3	0	0	0
NW	17	0	0	0	9	0	2	1	2	0	0	0	0	0	0	0	0	2	0	0	0
NW	49	0	7	0	5	6	0	0	8	0	0	0	0	0	0	4	0	0	5	0	0
NW	50	0	7	0	5	0	0	5	7	0	0	0	0	0	0	0	0	2	4	0	0
NW	51	0	0	0	7	0	0	6	5	0	1	0	2	0	0	0	0	2	0	0	0
NW	52	0	0	7	9	0	0	0	0	0	0	0	0	4	5	0	0	4	0	0	0
NW	53	0	0	5	8	0	0	1	0	0	0	0	0	0	5	0	0	6	0	0	0
NW	54	0	0	6	8	0	0	5	4	4	0	0	0	2	0	0	0	4	2	2	6
NW	55	0	0	8	8	0	0	6	0	0	0	0	3	0	3	0	0	8	0	0	8
NW	56	0	0	8	6	0	0	5	5	0	0	0	0	4	0	0	0	5	2	0	0
NW	57	0	0	8	0	0	0	8	0	0	0	0	0	6	0	0	0	6	0	0	0
NW	58	0	0	9	0	0	0	6	0	0	6	0	0	6	0	0	0	7	0	0	0
NW	59	0	0	7	0	0	0	5	0	0	5	0	0	6	0	0	0	7	0	0	0
NW	60	0	0	8	5	0	0	5	0	0	0	0	0	3	0	0	0	4	0	0	0

Stand composition – Native woodland: seedlings

Stand Type	Plot	Seedlings (Domin Value)									
		Spruce	Larch	Birch	Oak	Sycamore	Ash	Rowan	Beech	Hazel	Holly
AW	30	0	0	5	2	0	6	4	0	0	0
AW	31	0	0	0	0	0	2	4	0	0	0
AW	32	0	0	0	0	0	0	6	0	0	0
AW	33	0	0	0	0	0	0	6	0	0	0
AW	34	0	0	0	7	0	0	0	0	0	0
AW	35	0	0	0	3	0	0	5	0	0	0
AW	36	0	0	4	2	0	0	6	0	0	0
AW	37	0	0	0	3	0	0	5	0	0	0
AW	38	0	0	3	3	0	0	4	0	0	0
AW	63	0	0	5	4	0	0	7	0	0	0
AW	64	0	0	6	3	0	0	0	0	0	0
AW	65	0	0	0	5	0	0	8	0	0	0
AW	66	0	0	3	3	0	2	5	0	0	3
NW	14	0	0	5	2	4	2	3	0	3	3
NW	15	1	1	2	0	0	0	0	0	2	3
NW	17	0	0	0	0	0	0	5	0	0	0
NW	49	0	0	0	0	0	0	7	4	0	0
NW	50	0	2	0	4	0	0	8	5	0	4
NW	51	0	5	0	2	0	0	8	2	0	7
NW	52	0	0	2	2	0	0	7	4	0	7
NW	53	0	0	0	6	0	0	9	0	0	4
NW	54	0	0	0	3	0	0	8	4	3	5
NW	55	2	0	0	5	0	0	3	0	4	8
NW	56	0	0	0	0	0	0	7	4	0	0
NW	57	0	0	0	0	0	0	5	0	0	0
NW	58	0	0	3	0	0	0	6	0	0	0
NW	59	0	0	3	0	0	0	5	0	0	3
NW	60	0	0	0	0	0	0	0	0	0	0

Stand composition – Conifer woodlands: trees and saplings

Stand Type	Plot	Trees (Domin Value)										Saplings (Domin Value)									
		Spruce	Larch	Birch	Oak	Sycamore	Ash	Rowan	Beech	Hazel	Holly	Spruce	Larch	Birch	Oak	Sycamore	Ash	Rowan	Beech	Hazel	Holly
TC	1	0	8	0	0	0	0	0	0	0	0	5	4	0	0	0	0	0	0	0	0
TC	4	0	10	0	0	0	0	0	0	0	0	6	5	0	0	0	0	0	0	0	0
TC	7	7	4	6	0	0	0	4	0	0	0	7	4	2	0	0	0	4	0	0	0
TC	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TC	9	7	3	0	0	0	0	0	0	0	0	3	5	1	0	0	0	3	0	0	0
TC	10	0	9	4	0	0	0	3	0	0	0	2	0	2	0	0	0	5	2	0	0
TC	12	6	0	6	0	0	0	4	0	3	0	5	0	6	0	0	0	4	0	0	0
TC	13	6	0	6	0	0	0	0	0	0	0	4	0	6	0	0	0	0	0	0	0
TC	16	8	0	0	0	0	0	0	0	0	0	4	0	5	0	0	0	4	0	0	0
TC	18	8	0	2	0	0	0	2	0	0	0	0	0	4	2	3	0	3	0	0	0
TC	20	9	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
TC	39	3	7	0	0	0	0	0	0	0	0	5	5	0	0	0	0	0	0	0	0
TC	40	5	0	0	0	0	0	0	8	0	0	5	0	0	0	0	0	4	5	0	0
TC	41	3	7	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0
TC	43	6	0	0	0	2	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
TC	44	6	6	6	0	0	0	4	0	0	0	3	3	0	0	0	0	3	0	0	0
TC	45	4	5	0	0	0	0	0	8	0	0	3	2	0	0	0	0	0	2	0	0
TC	46	4	4	0	0	0	0	0	8	0	0	5	5	0	0	0	0	0	2	0	0
TC	47	9	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0	0
TC	48	2	2	0	0	0	0	0	8	0	0	3	0	0	0	0	0	0	5	0	1
EC	2	10	0	0	0	0	0	0	0	0	0	7	4	0	0	0	0	0	0	0	0
EC	3	10	0	0	0	0	0	0	0	0	0	8	2	0	0	0	0	0	0	0	0
EC	5	10	0	0	0	0	0	0	0	0	0	8	5	2	0	0	0	3	0	0	8
EC	6	0	9	0	0	0	0	0	0	0	0	3	7	0	0	0	0	0	0	0	0
EC	11	7	1	4	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
EC	19	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EC	21	9	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	1	0	0	0
EC	23	10	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
EC	24	10	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
EC	25	9	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
EC	26	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EC	27	8	7	0	0	0	0	0	0	0	0	7	5	0	0	0	0	0	0	0	0
EC	28	9	0	0	0	0	0	3	0	0	0	6	0	0	0	0	0	2	0	0	0
EC	42	8	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
EC	61	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0
EC	62	6	0	4	0	0	0	5	0	0	5	8	0	4	0	0	0	4	0	0	0

Stand composition – Conifer woodlands: seedlings

Stand Type	Plot	Seedlings (Domin Value)									
		Spruce	Larch	Birch	Oak	Sycamore	Ash	Rowan	Beech	Hazel	Holly
TC	1	6	5	0	0	0	0	5	0	0	0
TC	4	5	3	0	0	0	0	0	0	0	0
TC	7	4	2	4	0	0	0	0	0	0	0
TC	8	0	0	0	0	0	0	0	0	0	0
TC	9	5	6	2	0	0	0	3	0	0	0
TC	10	1	1	2	0	0	0	4	3	0	0
TC	12	6	0	4	0	0	2	2	0	2	0
TC	13	5	0	6	0	0	0	0	0	2	0
TC	16	3	0	4	0	0	0	4	0	0	0
TC	18	0	0	2	6	2	0	0	0	0	0
TC	20	0	0	0	0	0	0	0	0	0	0
TC	39	5	7	0	0	0	0	0	0	0	0
TC	40	5	0	0	0	0	0	4	4	0	0
TC	41	3	5	0	0	0	0	2	0	0	0
TC	43	4	0	0	0	0	0	7	0	0	0
TC	44	0	5	7	0	0	0	3	0	0	0
TC	45	0	0	0	0	0	0	1	6	0	0
TC	46	5	0	0	0	0	0	0	2	0	2
TC	47	0	0	0	0	0	0	0	0	0	0
TC	48	4	2	0	0	0	0	2	6	0	0
EC	2	2	0	0	0	0	0	0	0	0	0
EC	3	0	0	0	0	0	0	0	0	0	0
EC	5	5	4	1	0	0	0	3	0	0	2
EC	6	0	0	0	0	0	0	0	0	0	0
EC	11	2	0	2	0	0	0	0	0	0	4
EC	19	0	0	0	0	0	0	0	0	0	0
EC	21	0	0	0	0	0	0	0	0	0	0
EC	23	7	0	0	0	0	0	0	0	0	0
EC	24	0	0	0	0	0	0	0	0	0	0
EC	25	3	0	0	0	0	0	0	0	0	0
EC	26	0	0	0	0	0	0	0	0	0	0
EC	27	6	4	0	0	0	0	0	0	0	0
EC	28	2	0	0	0	0	0	0	0	3	0
EC	42	3	0	0	0	0	0	0	0	0	0
EC	61	4	0	0	0	0	0	2	0	0	0
EC	62	4	0	6	0	0	0	3	0	0	0