An assessment of dead wood habitat management & ancient oak conservation in Sherwood Forest National Nature Reserve

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Abstract

The following report is a historical overview and an assessment of dead wood habitat management & ancient oak conservation in Sherwood Forest National Nature Reserve. The following survey report provides the first dead wood survey and results completed for Sherwood Forest NNR, along with a detailed assessment of ancient oak response to the conservation practice of haloing. Line-transect sampling was used in order to predict total volume m^3/ha for four study areas and then combined to provide a total overall estimate for Sherwood Forest NNR. Four study areas were chosen in which ten 50 metre transect lines were randomly chosen. The study areas were chosen based on past and present management practices of grazing, non-grazing, and the introduction of oak plantations. A total average volume 211.17 m^3/ha of dead wood for logs, snags, and stumps were estimated from the four study areas within Sherwood Forest NNR. There were significant differences between grazed and non-grazed study areas for ancient oak and oak volumes. Significant difference was also found between study area 4 when compared to study areas 1, 2, and 3 for ancient oak dead wood volumes. Study areas 2 and 4 for oak dead wood volume also showed significant difference. These differences can be explained by the past and present management practices within the Park. Of the 211.17 m^3/ha of estimated dead wood, 66% (139.96 m^3/ha) of total dead wood came from snags and stumps. This was an expected find with the abundance of ancient oak snags and stumps throughout the forest. Compared to previous dead wood surveys performed throughout the UK and Europe Sherwood Forest NNR contains a substantial amount of deadwood habitat. Results of total volume, rot class, and species volume for each individual study area have been displayed within the appendices upon the Sherwood Forest site manager's request. A total of twenty-six ancient oaks were surveyed separately using information from previous surveys performed in 2005 and 2011. Assessments were made for each oak found alive to determine whether there was any obvious positive or negative response to haloing practices since 2005 using assessment recommendation keys provided within the 2011 survey. Of the twenty-six ancient oaks surveyed sixteen showed positive response, three moderate, six no response at all, and one found dead since the 2010 survey. Epicormic buds, leaf appearance, and overall tree structure provided the basis of comparison from previous surveys to determine the trees response to the haloing method. Overall Sherwood Forest NNR shows very high levels of deadwood based on line-intersect estimates for an old growth forest. Even though the line-intersect method is known to overestimate snag volume and stump volume; with a total of 71.21 m3/ha for just log volume, Sherwood Forest NNR is within the higher third of previous studies.

Table of Contents

Abstract……...Page i

1. **Introduction……...Page 1**

2. **Introduction……Page 6**

3. **Methodology……Page 12**

3.1. Deadwood……..Page 14

3.2. Haloing

3.3. Haloing Practice……

3.4. Ancient Oak Field Survey…….Page 20

4. Data Analysis……...Page 23

5. Results……Page 23

5.1. Dead Wood Results……..…Page23

5.2. Statistical Results……...Page 39

5.3. Ancient Oak Survey Results……Page 42

6. Discussion……..Page 43

7. Conclusion……Page 50

8. Acknowledgements……Page 52

9. Appendices……...Page 52

9.1. Study Area 1 Transects and Individual Results……..Page 53

9.2. Study Area 2 Transects and Individual Results…….….Page 64

9.3. Study Area 3a Transects……..Page 75

9.4. Study Area 3b Transects……...Page 76

9.5. Study Area 3a and 3b Individual Results……...Page77

9.6. Study Area 4 Transects and Individual Results……..Page 88

9.7. Ancient Oak Haloing Survey……...Page101

9.8. Haloing assessment Notes…….Page 102

10. References……Page 106

1. Introduction

Most of Britain is thought to have been bare of trees during the height of the last glaciation between 100,000 and 12,000 B.C. It is believed that the glacial ice had swept the land clean with the exception of some bays along the coasts of Great Britain and Ireland, where sheltered flora may have survived. Birch and willow scrub along with patches of pine may have persisted along the lower margins of the ice line (Rush, 2009). After the Ice age plants and animals began to quickly colonise the British landscape (Rackham, 1980; Yalden, 2010). Natives pioneer trees, such as Scots pine, birch, willow and rowan, colonised the bare land vacated by the retreating glaciers (Tickell et al., 2000). Following the retreating ice during the Palaeolithic and Mesolithic period's man began to colonize Great Britain. Since the introduction of man, the woodlands of Great Britain have played host, providing raw material in order to sustain life. Management by coppicing, grazing, and pollarding was common throughout Britain before and after the Roman period.

Birklands (the area containing present Sherwood Forest NNR), is an old Viking word meaning 'birch land', and was first mentioned in documents in 1251 and is likely to be at least one thousand years old according to Natural England. Sherwood first received its name in 958 AD. After the Norman Conquest, the area of Sherwood became known as "Sherwood Forest". Forest during medieval times did not hold the same meaning as it does today. Forest or Royal Forest was land controlled by the crown and used as royal hunting grounds. According to a royal inspection, Sherwood Forest once covered over 50,000 hectares of Nottinghamshire back in the 11th century (Rackham, 1986). By the 1200's Sherwood Forest is estimated to have covered roughly 100,000 acres. From the 13th century onwards the royal boundary of Sherwood Forest claimed land from the River Trent in the south to the River Meden in the north (Nottinghamshire County Council, 2015). While spreading roughly between Dover Beck and the King's Highway (now the A614 roughly) in the East, to the River Leen in the West" according to the Mercian Archaeological Services CIC. The forest was comprised mainly of Birch and Oak, while also containing large areas of sandy heath and large grasslands. Three deer parks are on record, which were located near what is today Nottingham Castle, Bestwood, and Clipstone Park. The current area of Sherwood represented in **Figure 1** was once completely covered in a mixture of broadleaved forests and lowland heath. By the late 20th century Sherwood had been reduced to only 250 hectares of lowland heath. The drastic decline in lowland heath and woodland began noticeable within the 17th century. Upkeep of Sherwood Forest remained within high regard until the execution of King Charles in 1649. This led to poor management of the Forest during the English Civil Wars between

1642 and 1651. By the 18th century Sherwood Forest had undergone a complete transformation. Large portions of the Forest were sold and awarded into the Newstead, Rufford, Thoresby, Welbeck, and Wollaton estates; while other portions of forest were felled during times of war and sold to the public for grazing, housing, timber, and charcoal.

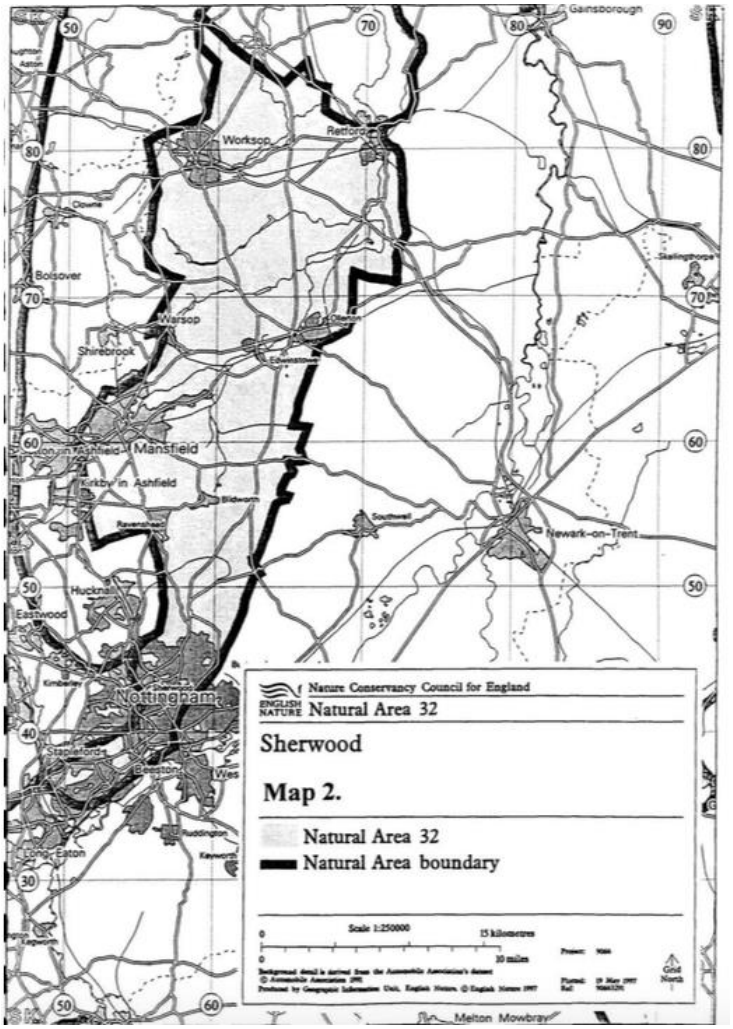


Figure 1: *Above is the Sherwood Natural Area Profile map provided by English Nature (1997). The Natural Area boundary represents 20th century Sherwood which has been outlined for recognition of its natural habitats.*

The high demand supply and demand for timber led to 80% of Sherwood's oaks being cut (Nottinghamshire County Council. 2015). Leading up to the late 18th century Sherwood began to disappear and lose recognition amongst the public. It wasn't until 1790 when Major Hayman Rooke wrote a book titled "The Remarkable Oaks in the Park at Welbeck", that Sherwood became of interest to the public once again. This book shed some much needed light on this dying forest, bringing more popularity to the area and the now named Major Oak within. This book along with Robin Hood's tale prevented the forest from falling into shadow and drew in much needed interest and support. However, Sherwood Forest still would have much more to endure. Due to the collapse of the Royal Forest administration in the eighteenth century local estates began to dominate the woodlands. **Figure 1** and **2** provide an ideal of just how small the Birklands area is to what was once entirely covered by heathland and woodland. The area in **Figure 2** shows the impact of clearing for farmland and living areas.

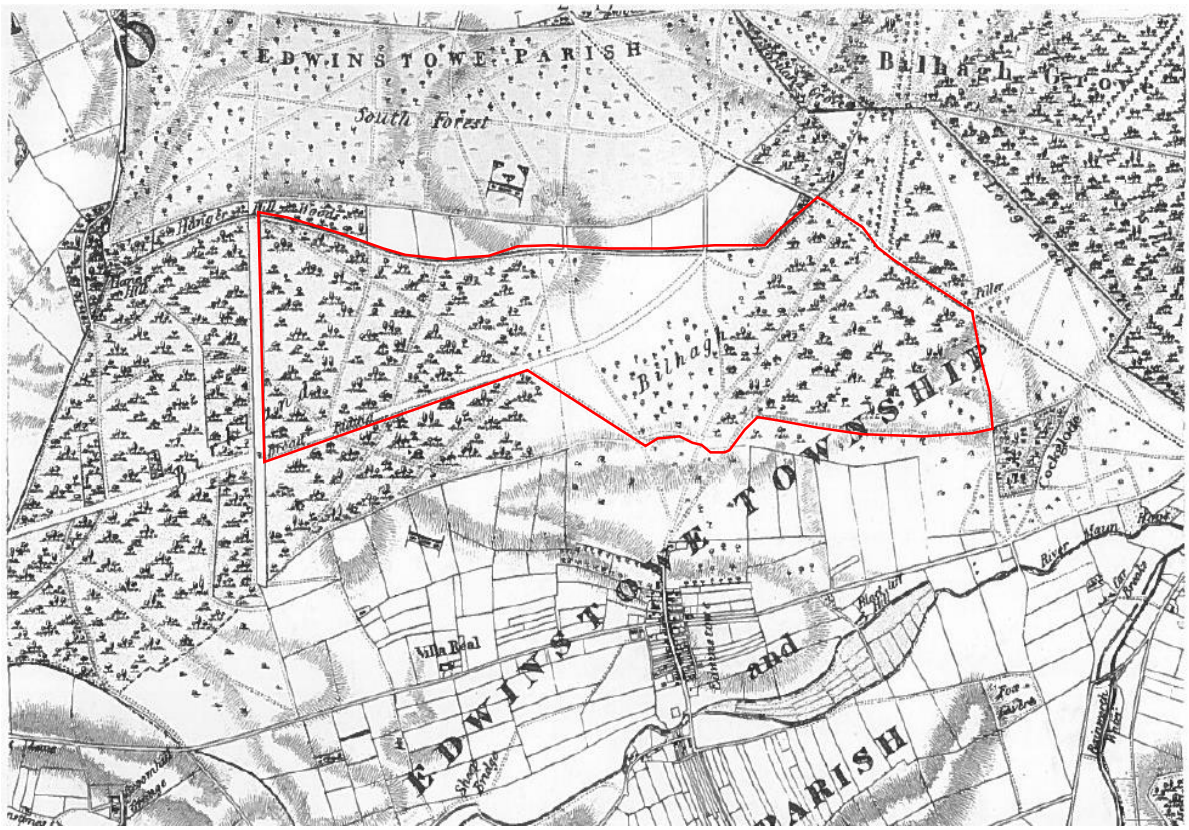


Figure 2: *Above is a map of Birklands from 1835 with Sherwood Forest NNR outlined in red. Map by George Sanderson Twenty Miles around Mansfield (1835).*

The 20th century produced some of the more drastic changes within a shorter period of time throughout the British landscape. Changes throughout the twentieth century for Sherwood can be broken down into five periods. The 1900-14, picturesque tradition and the new forestry; 1914-39 war and stagnation; 1939-45 Second World War timber demands; 1945-80 post-war intensification; and 1980-2000 consolidation and rise of conservation (Kottler et al,. 2005). During the picturesque tradition of new forestry management of the ancient oak, birch, and heathland continued to be supported for aesthetic and sporting landscapes (Tsouvalis and Watkins, 1999). The ancient woodlands continued to receive priority while in 1902 birch restoration began in order to preserve a picturesque affect. Birch was considered in high regard as an aesthetically pleasing element of the landscape. Experimental plantations from nineteenth century influenced implantation of conifer and pine stand management. Grazing was being incorporated during this time in order to maintain the ancient oak and birch land. During this short time frame land owners and managers were seeking to produce landscapes that were of

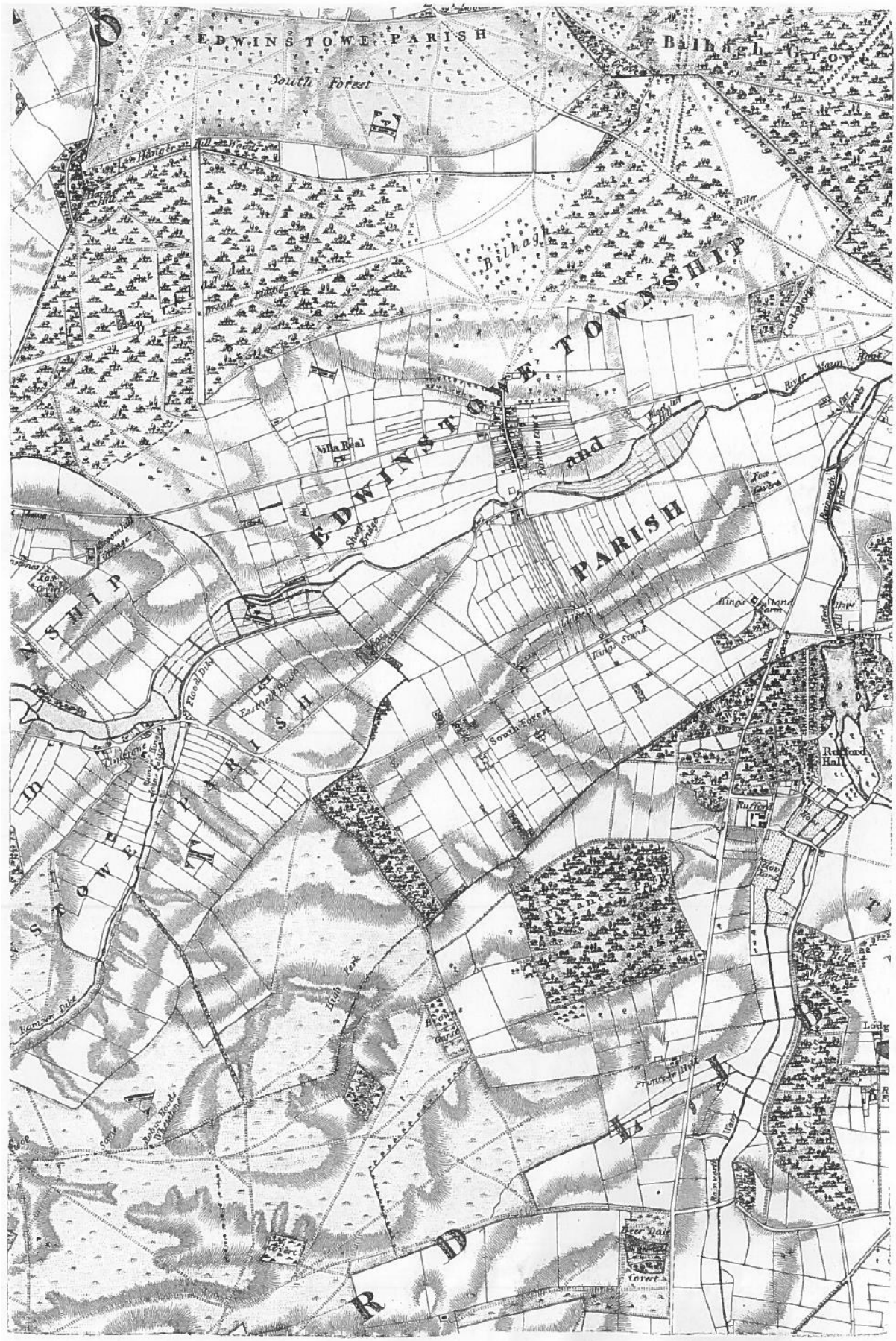


Figure 3: *Above is a map of Midlands from 1835 with Sherwood Forest NNR outlined in red. Map by George Sanderson Twenty Miles around Mansfield (1835).*

benefit to the eye and not necessarily to the natural landscape itself. The 19th and 20th century industrialization period along with the World Wars brought along with it a major impact on Sherwood. Particularly felling and clearing for coal mining, mining, villages, factories, farms, military camps, ammunition stores, training areas, and timber. National request and need for softwood alone changed the landscape on a very large scale during the First World War through the felling of broadleaf stands for these softwood plantations. This trend occurred specifically during 1915 and 1917 according to notes reviewed by (Kottler et al., 2005; from Hopkinson (1927)). After the First World War game conservation as well as grazing through ancient woodlands continued. The estate also experienced its greatest loss of woodland through the creation of the Thoresby Colliery in 1925, with the assistance of heavy post-war economic influence. Following the start of the Second World War felling and timer production increased rapidly to meet war demands. Luckily the oaks and birch of Sherwood experienced little felling; softwood in the immediate area was in high demand for pit-props within the colliery. Following the war, different trends of management arose like the eradication of birch which had obtained the label of a ‘’pest species’’. The area of Birklands however remained relatively unchanged. It wasn’t until the 1950’s when Birklands woodland management had ceased entirely as a part of the Thoresby estate. In response to this neglect, woodland flourished until it eventually became recognized as a Site of Special Scientific Interest (SSSI) in 1954 by English Nature. Part of the forest was opened as a country park to the public in 1969 by Nottinghamshire County Council, which manages a small section of the forest under lease from the Thoresby Estate. Sherwood County Park was then created and had grown to 448 acres by 1978. The County Park was included as a Grade 1 site for its ancient woodland and heathland in a Nature Conservation Review in 1977; as well as re-notified as an SSSI under the 1981 Wildlife Countryside Act In 2002 a portion of Sherwood Forest was designated a National Nature Reserve by English Nature. Nottinghamshire County Council and Forest Enterprise now manage the woodland as a NNR in partnership with English Nature and the Thoresby Estate. The area of Sherwood has gone under rapid transformations over the last century through interventions by land agents and landowners through social, economic, and government pressures. The woodlands themselves experienced many phases, playing major game, timber, war and coal amenities, and aesthetic landscape roles. The area of Birklands however received little repercussions from the surrounding pressures as far as the rest of Sherwood is concerned; allowing the ancient woodland to persist. Considering that ancient woodlands are said to produce some of the richest habitats with high levels of biodiversity, along with being reduced to just ten percent of Britain’s land area (Tickel et al., 2000); it is no surprise to see how much attention the area of Birklands receives today.

2. Literature Review

Native woodlands have experience huge losses over the past 2–3000 years as a result of clearance for agriculture and conversion to plantations (Spencer and Kirby, 1992). Today 13% (3.08 million hectares) of the total land area in Great Britain is estimated to be covered by woodland according to the UK Forestry commission. Of the 3.08 million hectares of woodland, the Forestry Commission and Forest Service only own .087 million hectares. Roughly sixty-nine percent of all woodland in the UK is now owned by private land owners (Kottler et al., 2005). This can prove troublesome when attempting to coordinate management plans for the restoration of natural habitats. The area of Birklands and Bilhaugh for example is currently under the management of Nottinghamshire County Council, The Forestry Commission, and the Thoresby Estate.

Today, within Birklands and Bilhaugh is the last surviving section of the Royal Sherwood Forest. The study area of Birklands and Bilhaugh covers 797 hectares; 326 of which are Sites of Special Scientific interest (Clifton, 2000). Management has been implemented to restore a number of historically characteristic landscapes native to Birklands and Bilhaugh for improved biodiversity. These include dry and wet heathland, broadleaved native woodland, wetland, acid grassland, and pasture woodland (Stander, 2003). Within this survey the broadleaved woodlands were of interest; in particular the ancient oak population along with dead wood diversity and abundancy found in Sherwood Forest NNR within the Birklands and Bilhaugh boundaries. The area of study chosen for this survey was the Birklands area which is made up of Sherwood Forest NNR covering roughly 450 acres today. This area of Special Scientific Interest is labelled by the Joint Nature Conservation Committee (JNNC) and UK Government as Habitat Class 9190: Old acidophilous oak woods with Quercus robur on sandy plains. This habitat type is further explained as being comprised of ancient lowland oak on acidic, sandy, or gravely substrates. Sherwood Forest NNR shown in **Figure 4** according to the National Soil Resources Institute at Cranfield University sits on free draining permeable soils in unconsolidated sands or gravels with relatively high permeability due to permo-triassic reddish sandstone parent material; which in turn produces a sandy topsoil layer which the ancient oaks and birch stands of Sherwood can be found on. .

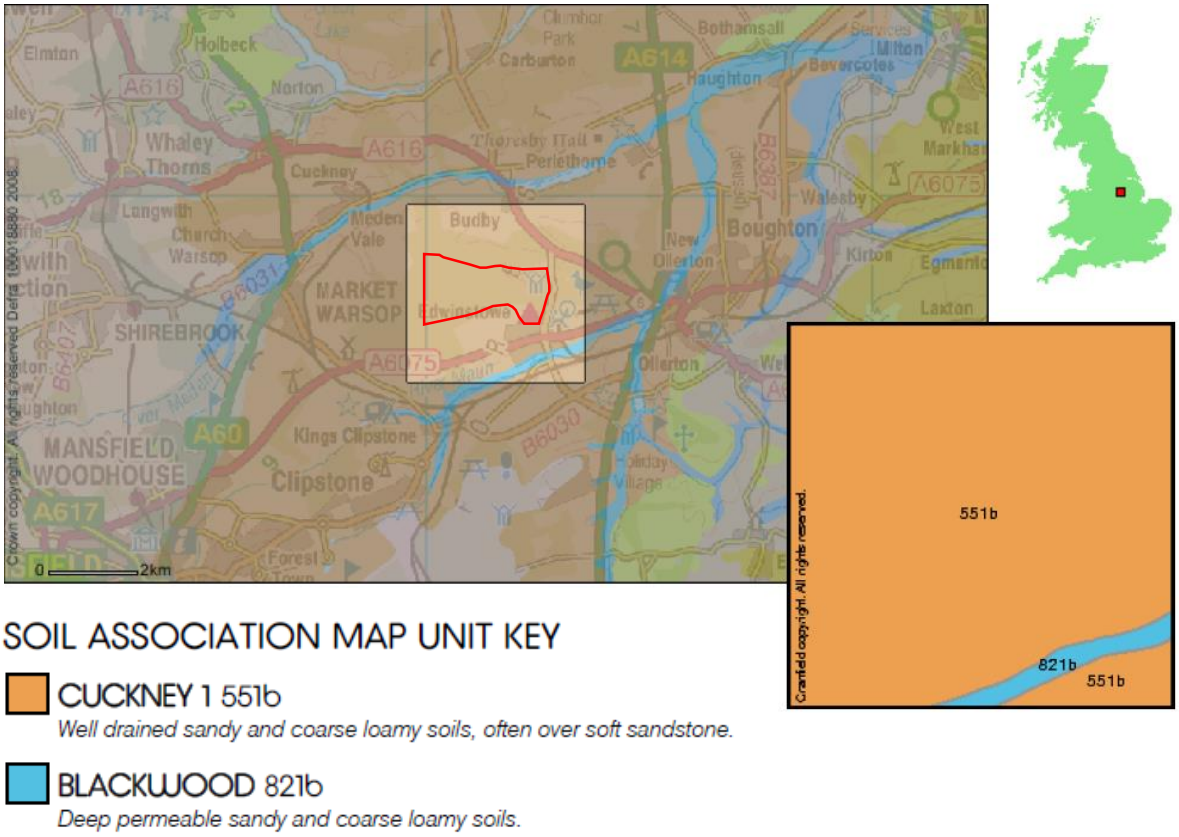


Figure 4*: Above is a soils-spatial distribution map of the area of Sherwood Forest (Outlined in red) provided by Cranfield University (NSRI) 2008. For further description of area (Hydrogeological Rock Type, Hydrology, Simple Topsoil Texture, Typical Habitats, and Soil Parent Material) please refer to Appendix.*

These stands are normally associated with combinations of notable lichens, fungi and invertebrates. Birkland's ancient woodland is dominated primarily by pedunculated oak *Quercus robur,* sessil oak *Q. petraea*, and birch *Betula pendula*. Other species such as rowan *Sorbus aucuparia*, holly *Ilex aquifolium*, hawthorn *Crataegus monogyna;*, and other non-native like sycamore *Acer pseudoplatanus*, and beech *Fagus sylvatica* can be found throughout these woods. The common underlay throughout is considered species-poor; formed predominantly by *Galium saxatile, Melampyrum pratense, Holcus mollis*, *Pteridium aquilinum*, and *Rubus fruticosus* otherwise known as bramble and bracken. The area has been given a National Vegetation Classification (NVC) type W16 *Quercus* spp. – *Betula* spp. –*Deschampsia flexuosa* woodland and some stands of W10 *Quercus robur* – *Pteridium aquilinum* – *Rubus fruticosus* woodland; a community of base-poor brown earths located mainly in the lowlands of southern Britain according to the Joint Nature Conservation Committee (Hall et al., 2004). Birklands and Bilhaugh is the most northerly site selected for old acidophilous oak woods and is renowned for its rich invertebrate fauna, particularly spider and beetles, as well as a diverse fungal assemblage, including *Grifoa suphurea* and *Fistulina hepatica*. The ground vegetation have been managed primarily by non-intervention, grazing and rolling; while dead wood is constantly being

influenced by felling, naturally dead and dying trees. Each of these management practices produces its own microhabitat in which dead wood volume, species richness, and geographical make up varies significantly amongst them. In order to be selected as a SSSI an area must contain lacking geographical and ecological variation shown by the habitat type in the UK. Selection for the Birklands is centered on the large ancient woodlands, particularly veteran trees that are important for their lichen, fungi or invertebrate assemblages.



Figure 5: *Above Laetiporus Sulphureus shelves on oak dead wood within Sherwood Forest NNR. Photo by: Tyler Wilcox, June 2015.*

"Dead wood is an integral and often substantial component of natural forests. It provides wildlife habitat, maintains ecosystem health and influences geomorphological processes" (Hodge and Peterken, 1998). Dead wood plays a variety of roles in woodland systems through its influence on biological, physical, and chemical processes (Kirby et *al.*, 1998). The importance of dead wood in promoting invertebrate biodiversity has been recognized in the last 20 years, after the protection of sparoxylic invertebrates and their habitats has been recommended by the European Council (Speight, 1989). The Ministerial Conference on the Protection of Forest in Europe currently incorporates the presence of dead wood as one of the nine sustainability indicators (Sands, 2013). Dead wood in habitats is a long term indicator of biodiversity as suggested by The European Environmental Agency (Kristensen, 2003). The biodiversity provided by dead wood environments places a high value and priority for maintaining them. According to (Humphrey et *al.*, 2002) at UK Forestry and Natural England one in every five of all woodland species depend on dead or dead wood at some point within their life. Dead wood abundancy and diversity has been labeled as a main driver for fungal communities (Ylisirniö et al., 2012). The ancient native semi-natural woodlands found in Britain provide significant habitats for lichens and bryophytes (Hodgetts, 1996). These different types of fungi have a very important relationship with dead wood in turn playing a vital role for saproxylic invertebrates, impacting the habitat diversity through speeding up the decay rate of dead wood (Humphrey et al., 2005). Previous works have proven that a more

diverse scale of dead wood decay classes and size produce higher levels of diversity in lichen and bryophyte communities (Humphrey et al,. 2003; Humphrey et al., 2002; Hodge and Peterken, 1998) and saproxylic invertebrates (Gossner et al., 2013; Lassauce et. al. 2011; Hodge and Peterken 1998). Sherwood Forest NNR is well known for its abundant saproxylic invertebrates, many of them red listed, this alone places high value on the conservation of dead wood (Lassauce et. al. 2011) as well as obtaining the Site of Special Scientific interest. In particular Sherwood Forest is home to a total 1,169 species of *Coleopteran*. Of the 1,169 species 217 are currently classified as Red-listed (RDB) species on a nationally noticeable status (Pendleton, T.A. and Pendleton, D.T. 2013). Forty-nine of these species such as the *Poecilus kugelanni, Ptenidium turgidum*, and *Eutheia linearis* for example*;* have all been red listed since before 1994. Records show that 315 of the 1,169 species have not been found since 1914; a list of all species can be found on the Earkingbirds website. Saproxylic beetles are known for being used as good indicator species for the quality of a surrounding ecosystem (Franc et al., 2007). An investigation completed by (Gibb et al., 2006) found that snags (standing dead trees) provided the highest diversity of beetle species, including a higher count of red listed species. While a contrary finding by (Hjältén et al., 2007) found that 16 out of 11 red listed beetles preferred logs as opposed to snags. The majority of rare and endangered saproxylic species are poor colonizers, and are restricted to specific patches of dead wood within forests (Humphrey et *al.*, 2002). These findings emphasize the importance of having a wide range of dead wood types to obtain optimal diversity by catering for all species requirements. A strategy for dead wood should therefore serve primarily for the maintenance and enhancement of biodiversity. Snags and downed dead wood varying amongst different states of decay, indicates the level of diversity within the woodland (Humphrey and Bailey, 2012). Knowledge of the association between stumps and saproxylic assemblages is still relatively incomplete (Brin et al., 2013) and in earlier



Figure 6: *Above are a cluster of ancient oak and birch snags taken while surveying ancient oak #2 from within Sherwood Forest NNR. Photo by: Tyler Wilcox, July 2015.*

studies were sometimes not included. Results from (Brin et al., 2013; Abrahamsson and Lindbladh 2007; Hedgren, 2007; and Hjalten et al., 2010)) show that stumps are relatively long lasting forms of dead wood compared to logs. Stumps provide substantial habitats for not only living, but breeding conditions for saproxylic species. Surveying for multiple types of dead wood such as logs, stumps, and snags can provide estimates for the abundance of dead wood and spread through the different stages of decay, allowing for a clear understanding the quality of biodiversity within a forest ecosystem. Specific findings such as tree species, rot scale, and dead wood spread can also be used for helping manage specific types of habitats for specific woodland species.

In managed forests, however, potential dead wood volumes are reduced by felling and extraction of timber to a small fraction of the volume found in natural forests. This impairs biodiversity and can affect some aspects of ecosystem health and geomorphological processes" (Hodge, S.G. and G.F. Peterken, 1998). Unfortunately dead wood was removed from managed forests up until the 20th century from the misconception that it would sanitise woodland for secured forest health and a "tidy" look (Humphrey, J. and S, Bailey 2012). The age-class structure of most managed forests has broken down, creating gaps between veteran and ancient trees, in turn leaving low levels of dead wood volume and variety. This is problematic for species that depend on the saproxylic habitat to survive (Bell, 2003). Birklands woodland in particular has a diverse mixture of age-classes, so there is good potential for maintaining the structure and function of the woodland system and a continuity of dead-wood habitats according to JNCC. Determining the amount of dead wood within Sherwood will give a better understanding to whether or not specific areas are in need of management; along with determining what approaches should be taking when doing so.

The oaks of Sherwood have played many roles for the forest and still do today. Not only have they provided the landscape with giant ascetically pleasing natural structures, giving Birklands the popularity and exposure leading to the restoration of this area. These ancient relics provide an extremely rare and valuable large dead wood habitat that is ever changing as it decays over the years, providing the specialized micro habitats that can only be created through the prolonged process of decay. According to (Widerber et al., 2012) the oaks found in northern Europe supports the richest diversity of saproxylic invertebrates, including many red listed species. Since dead oak trees may persist for centuries (McFee and Stone 1966; Triska and Cromack 1980) they can influence ecosystems as long as living trees, making them just as important when considering conservation methods and forest biodiversity. "The richest biodiversity often occurs where

there is extensive dead wood in an advanced state of decay" (Høiland and Bendiksen 1996). For example, as oaks being to slough off dead and dying bark, pockets begin to form between the sapwood and bark. Studies have shown that beetle species rely on high levels of insulation that are often associated with shade intolerant tree species such as oak (Widerber et al., 2012; Lindhe et al., 2005). Maintaining and preserving ancient oaks through the prolonged decay process especially for partially dead or dying trees provides suitable habitats for many species, from which they can breed and disperse to similar trees in the surrounding area (Franklin et al., 1997). When standing trees dead, partially dead, or alive are looked at as dead wood structures, the longer the structure ages, the more diverse of a structure it becomes (Widerber et al., 2015; Lindhe et al., 2005). Sherwood Forest NNR is home to 987 Ancient oaks, 576 of which are dead trees. Estimates of their age vary but most trees are believed to die between 400 – 600 years of age, with some exceptions such as the Major Oak which is estimated to be 800 - 1000 years old, still standing and alive today. Having such a high density of ancient trees is especially crucial for species with limited dispersal capacity (Widerber et al., 2012; Ranius et al., 2011; Svensson et al., 2011; and Lo¨bel et al., 2006). Dead wood spatial distribution is therefore crucial for the survival of these insects and should be considered in forest management plans (Schiegg, 2000). When considering future generations of veteran and ancient trees it is important to take into account their spatial distribution within a managed area.

As oaks begin to age their crown begins to collapse as part of a natural process, making it easier for younger more vigorous trees to outcompete ancient oaks for sunlight. The ancient oaks of Sherwood Forest NNR are especially known for their exceptionally thick trunks and disproportionally small crowns. One such conservation technique for this problem is to remove the surrounding competition to allow adequate sunlight for the ancient trees to sustain life if not rejuvenate. This process is known as haloing and has been put into practice for many of the ancient oaks found in Sherwood Forest NNR. Oak is seen as the UK's important dead wood provider, due to its large size, long lived, slow decay rate, and being a native tree. Birch may be seen as the opposite of oak, since it is short lived compared to oak species, with wood which decays rapidly once dead, however birch still plays a very important role within dead wood biodiversity. Not only introducing a new type of wood, but also wood decay rate. Birch decays at a rapid pace compared to oak, helping fill in the generation gaps of different stages of wood decay (Ferris – Kaan et *al.* 1993). Increased openness around shade intolerant species such as oak has been found to positively affect species richness and abundance of oak associated saproxylic invertebrates (Widerberg., 2012). Due to the multiple positive results of haloing for both

the conservation of ancient oaks and the saproxylic invertebrates that reside inside them it is important to monitor the responses of the oaks over time for continual success.

3. Methodology

A field survey of dead wood was conducted within different sections of the Sherwood National Nature Reserve. Four sections based on current management and previous management plans were chosen in order to compare dead wood abundancy, diversity, and status for sustainability between different management practices. The dead wood survey provided evidence of what practice of land management yields the optimum variety of tree species abundancy and dead wood volume depending on wood removal and placement practices. The four study areas were chosen based on a previous 1975 – 1986 oak regeneration plan map (**Figure 7**).

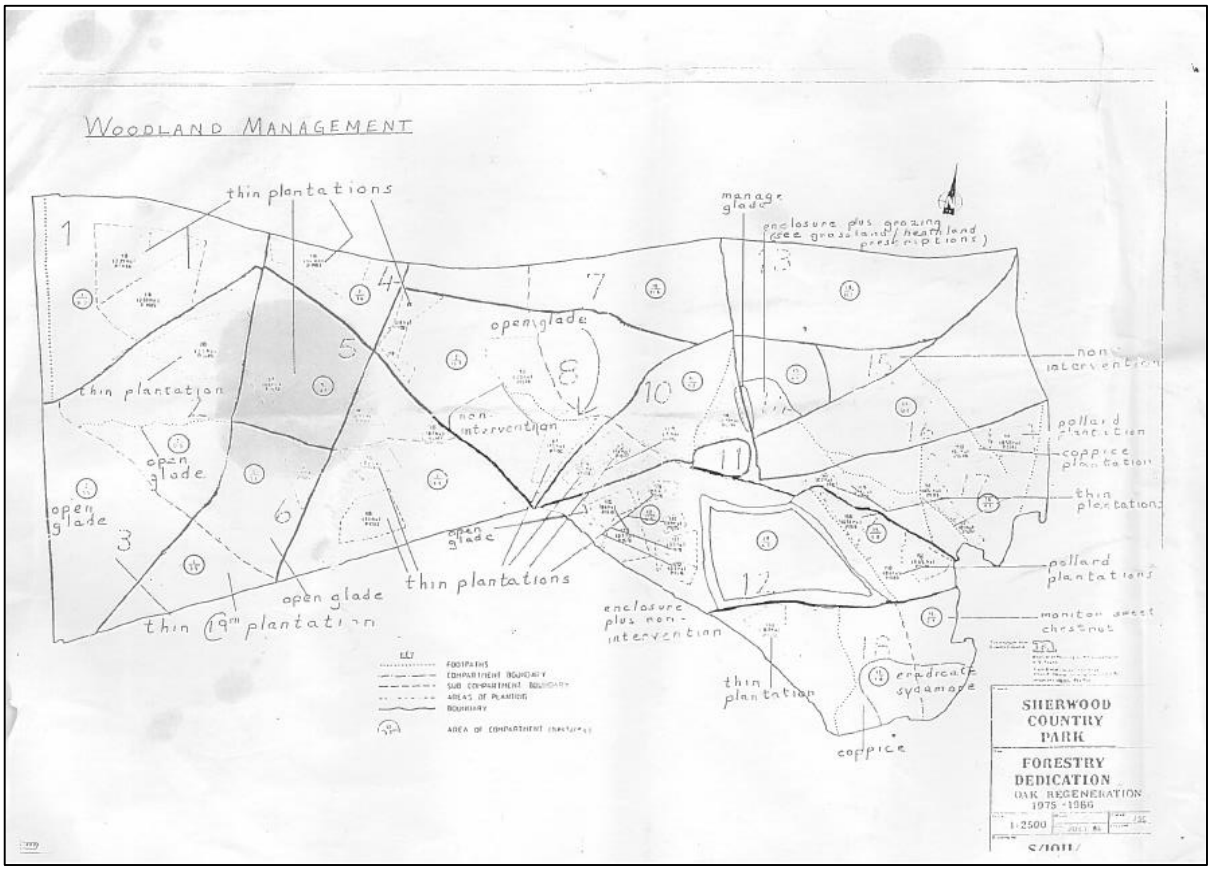


Figure 7: *Above is a map with site specific management plans for oak regeneration between 1975 – 1986 within Sherwood Forest NNR.*

Study areas 1 and 2 both have been implementing phases of grazing practices within recent years. During this survey, English Longhorn Cattle were introduced during July and August of 2015 for grazing management within study area 1, while study area 2 remained un-grazed for this year. The 1975 oak regeneration map shows several small

plantations were established and these were planned to be thinned over time and some glades created. Both study areas have noticeable recent management practices for dead wood, with multiple log stacks and felled pockets. Woodland grazing is considered an important practice in the creation and maintenance of diverse woodlands (Rotherham 2013) and promoting biodiversity and tree regeneration (Mayle., 1999). Disturbance and

Study Area 1: Grazing light oak regeneration 2015
Study Area 2: Grazing Moderate oak regeneration 2015
Study Area 3a: Heavy oak regeneration, heavy tourism
Study Area 3b: Heavy oak regeneration, low tourism
Study Area 4: Diverse underlay and woodland

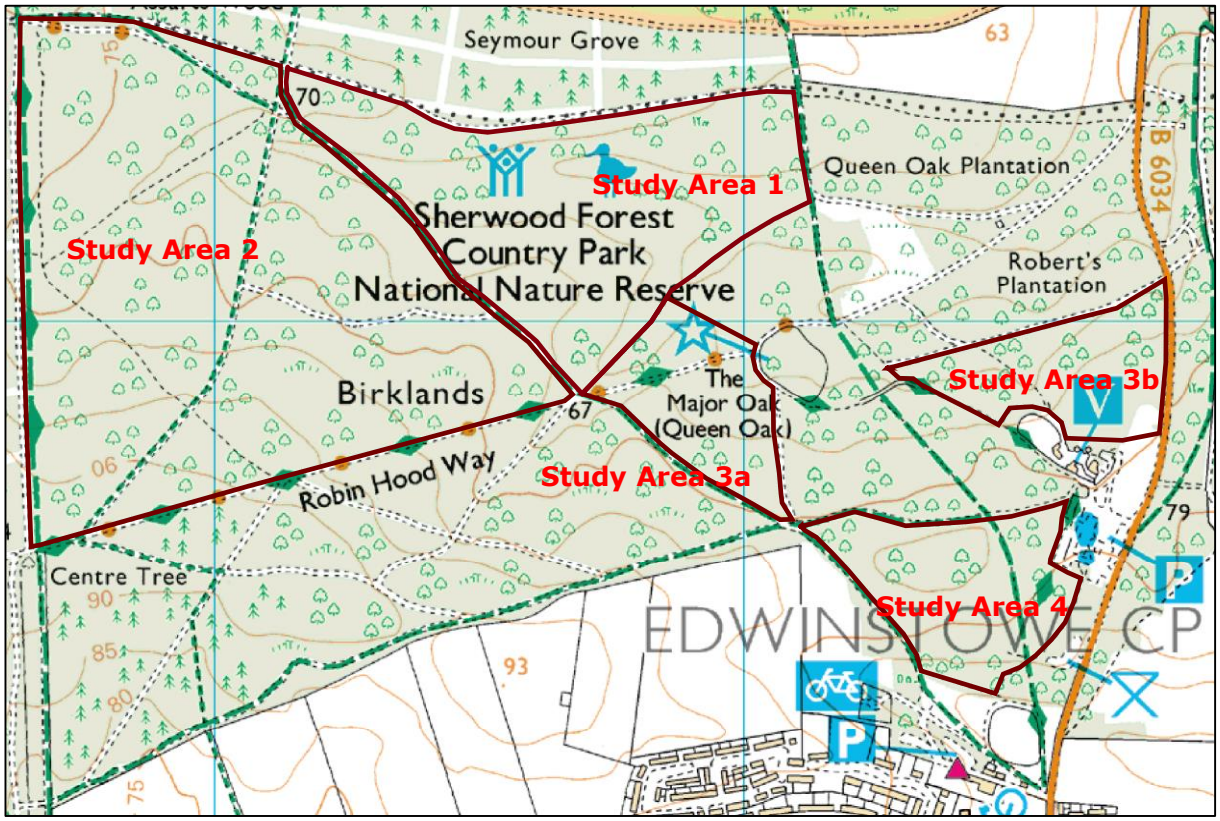


Figure 8: *Above is a 2015 map of Sherwood Forest NNR provided by Edina Digimap. Study aras 1 through 4 are outlined with their represented labled above.*

reduction of competitive ground vegetation and shrub layers by large herbivores is considered important for the regeneration of future generations of light sensitive vegetation (Hester et al. 1996; Thompson et al., 2003). Study areas 1 and 2 contain a considerable amount of *Deschampsia flexuosa and Holcus mollis.* Area 3 was split into two sections (3a and 3b) due to public pathways and interference as compared to the park map 1975 oak regeneration map. Section 3b of the park has an extremely thick underlay

of *Urtica dioica* with thick pockets of *Pteridium aquilinum* and *Rubus fruticosus* positioned throughout the boundary with very little ground exposure. 3a which had similar management plans labelled on the 1975 oak regeneration map, now has had a large portion converted into a recreational area in front of the Major Oak for visitors, along with various make-shift paths winding throughout the study area. The section of the study area that has not been converted contains a mixture of *Pteridium aquilinum* and *Rubus fruticosus* bordering the tourist area. Towards the back of section 3a furthest from the Major oak, ground vegetation becomes sparse with much of the ground exposed compared to 3b.. The final section surveyed, section 4, looked to eradicate the sycamore *(Acer pseudoplatanus)* population within this area while incorporating the one thin plantation as seen in **Figure 7**. Today the area is completely covered in a very thick underlay of *Urtica dioica, Digitalis purpurea*, *Pteridium aquilinum* and *Rubus fruticosus*. Some Scotts pine *(Pinus sylvestris)* is also mixed in amongst the hardwood populations. There is little to no ground exposed within this study area with the exception of walking paths and areas recently downed wood.

3.1. Dead wood:

The term dead wood and CWD (coarse woody debris) is used in this survey to include all types of dead and dying trees of 5 cm or more in diameter. Dead wood quality is determined by several factors: tree species, the part of tree concerned, size of dead wood units, and stage of decay (Ferris – Kaan et al. 1993). Line-intercept sampling has been widely referred to and recommended for measuring the volume of dead wood. It was first introduced by (Warren and Olsen 1964) for the measuring of logging waste; and then further developed by (Van Wagner, 1968) and (Brown, 1974). In order to prevent bias, ten plot points were selected by random within each section of particular interest using ArcMap and ArcGis with a minimum of a fifty metre buffer between each starting point. Easting and Northing coordinates for each transect line provided by ArcMap were located in field by the 2004 Garmin eTrex Summit. Ten transect lines were laid and measured between the two random points for each transect line within



Figure 9: *Above is a pile of dead wood encountered within study area 2. Many of these deadwood pieces were ignored due to having a diameter < 5cm. Photo by: Tyler Wilcox, May 2015.*

the four sections chosen for Sherwood Forest NNR as seen in F**igure 10** below. For sections 3a and 3b the ten random transect lines were cut to five for the two part section. to form the fifty metre line for a precise transect line. Field measuring tape was used and staked into the ground at each random transect point

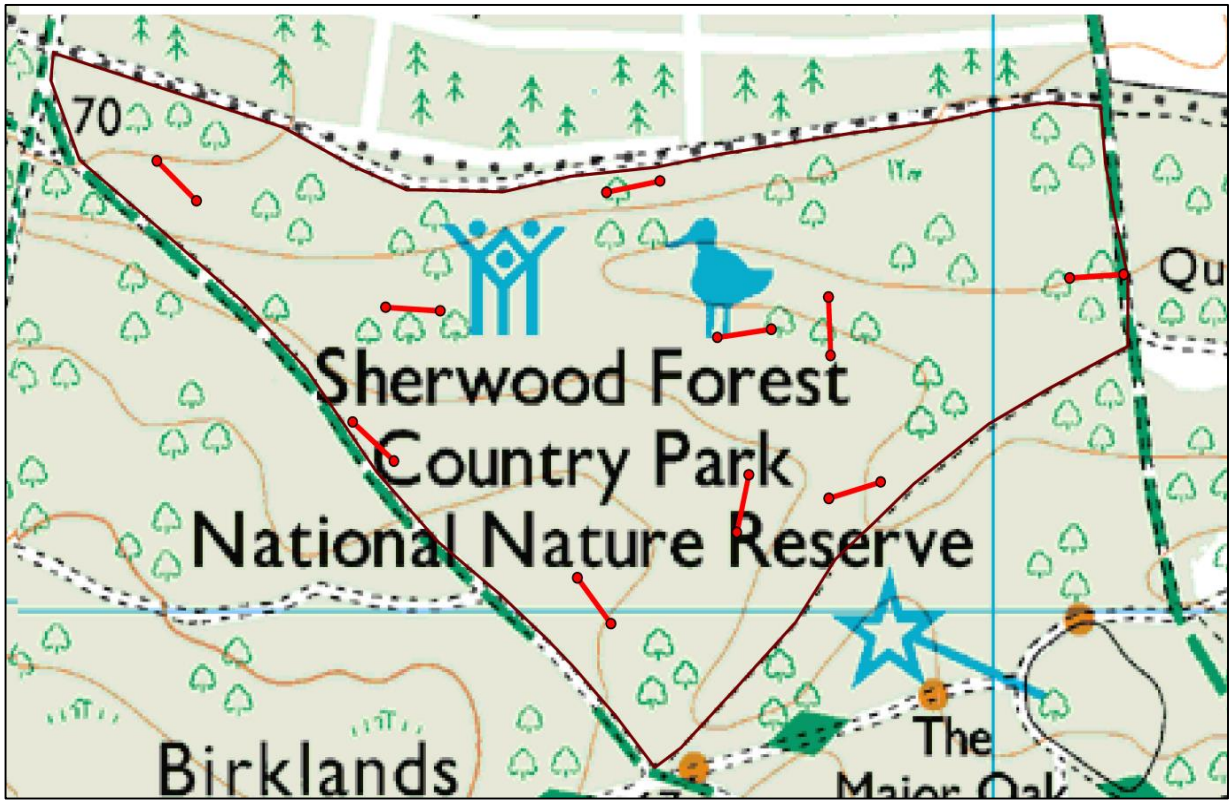


Figure 10: *Above is the result of ArcMap GIS random sampling and the 50 meter transect lines between the groups of random points. All five study areas along with British National Grid coordinates can be found in Appendix for each transect line.*

Dead wood with a diameter < 5cm was ignored. Any dead wood ≥ 5cm in diameter that fell into contact with the transect line was measured and recorded. The reason 5cm was chosen as a minimum, is because for dead wood to be considered a suitable microhabitat for lichens, bryophytes and a variety of invertebrates; wood must be at least 5 cm in diameter (Humphrey et al, 2002). A diameter between 5 – 9cm is considered the low end when measuring diameter of dead wood before discarding it as fine woody debris, however it was included within this survey for it has been found to play just as much of a role in dead wood biodiversity as wood with 10cm or greater Diameter. It is important not to view small woody debris as insignificant, for it plays a major role for specific fungal species, balancing woodlands carbon cycle, and returning nutrients back into the soil within a short time frame (Kruys and Jonsson 1999).

For the calculation of dead wood volume, the line-transect method from (Harmon and Sexton, 1996), (Van Wagner, 1968), and (Brown, 1974) was used. This method has

been commonly used in Britain for the measurement of fallen dead wood since 1988 (Kirby et al., 1998). According to (Ritter and Saborowski et al., 2012) the Line-intersect sampling method is superior to fixed area sampling, achieving higher precision at lower cost of required precision.



Figure 11: *Above 50 metre transect line number 1 for study area 2.*

Referring to the (Harmon and Sexton, 1996), (Van Wagner, 1968), and (Brown, 1974) formula below, the length of dead wood can be estimated when placing a transect line within a stand of trees.

$$L = \pi\, 10^4\, N\, (2t)^{-1}$$

Where ***L*** is the total length of dead wood per hectare (metres), ***N*** is the total number of dead wood intersections with the transect line, and ***t*** is the length of the transect line in metres. The conversion factor 10^4 is needed in order to produce results as metres per hectare and not metres per square. This method was adopted from (Kirby et al., 1998). It is important to take note and avoid confusion when viewing the length and volume instructions for these formulas. The original use for this formula was for estimation of the total length and volume of wood for logging and harvesting timber. The length estimate

formula was used for estimation and statistical purposes for lumber production of volume by length. The volume estimate formula is completely separate from the length estimate formula.

Volumes for each transect line were estimated using the Diameter of the CWD measured where the piece intersects the transect line. Log, snag, and stump intersections were placed into diameter classes and the mean cross-sectional area for that class was calculated. The volume for each Diameter class then equals the length for that class multiplied by the cross sectional area that is:

$$V = nd^2 \pi^2 10^4 / 8t$$

Where ***V*** is the total volume of Diameter class ***d*** (the Diameter being measured at the intersection with the transect line), ***n*** is the number of intersections for logs of Diameter ***d***, and ***t*** is the length of the transect line. For each study area as a whole the volume per hectare is the sum of volumes per Diameter class. This layout was adopted from (Kirby et al., 1998).

Index	**Dead wood Category**
Log	Downed dead wood
Wind Thrown	Standing dead tree < 45^0
Snag	Standing dead trees ≥ 45^0
Stump	height ≤ 2m
Attached	Dead wood still attached to a living or partially living tree

Figure 12: *Classifications of dead wood according to Humphrey and Bailey (2012).*

Dead wood was divided into five categories following Humphrey and Bailey (2012) to help determine the differences between logs, snags, and stumps (**Figure 12**). All CWD were classed as log, standing dead tree (snag), and stump depending on their current status. Dead wood habitat also occurs on living trees in the form of rot holes, dead limbs, decay columns and heart rot; these features all have their own associated flora and fauna. It was therefore important to make note of and measure deadwood that intersected the transect line even if still attached to a living tree. Standing dead trees (snags) were also included within this survey for the dead wood volume assessment by measuring the diameter at breast height (l.5 metres from ground level) of snags ≥ 5cm. The centre of the standing dead tree had to lie within 2 metres of the transit line as recommended by (Kirby, 1998) in order to be included within the survey. Diameter ≥ 5cm was measured from the top of stumps <5 metres where the cut or break occurred.

Results were added to provide a new overall estimate for the dead wood volume of m^3 per hectare found within Sherwood Forest NNR. Dead wood was also placed into species classes, length and Diameter classes by intervals of five, and assessed for scale of rot which can be viewed in more detail through Fig. 5 below.

Index Scale	**Description**
1	Bark intact, small branches present
2	Bark loose or sloughing off, no sapwood degradation
3	No bark, sapwood degradation
4	No bark, considerable sapwood degradation
5	Sapwood and heartwood degradation

Figure 13: *Suggested scale for estimating decay state of dead wood provided by (Hunter, 1990) as recommended by UK Forestry*.

The reason for multiple categories is in order to provide a thorough analysis of the different varieties and classifications of dead wood that lies within Sherwood, and to help determine if there are any gaps within the rot time scale. Throughout Sherwood Forest NNR a significant amount dead wood that has been created through felling is stacked, while other naturally occurring dead wood is scattered. A supply of dead wood such as the construction of wood stacks is a recommended practice in conservation management strategies for forest ecosystems (Kirby, 2001). The volume of dead wood found in each individual survey section was calculated as well as stacked wood vs. scattered wood to determine which management plan approach will best suit the needs of Sherwood Forest and overall dead wood requirements for immediate and future conservation plans. This should help to determine what types of management practices should be implemented to help strengthen the biodiversity within the NNR.

3.2. Haloing

Haloing is still relatively new considering the first trial methodology to knowledge, had taken place in 2003-4 at Windsor Forest according to (Alexander *et al*. 2010).



Figure14: *Ancient oak # 10379 in Sherwood Forest NNR with obvious signs of haloing practice for surviving vertical limbs on north facing side. Birch snags present on south facing side as a result of felling from halo practice.*

Papers describing surveys and discussing their outcomes such as this are seldom published (Rotherham 2013). At Sherwood Paul Barwick introduced this management plan for the first time alongside the Forestry commission within Birklands for ancient oaks of interest (Thompson et al., 2003). This had become an established practice by the mid-2000s (Notts Biodiversity Action Group, 2007) as well as part of the ancient oak management plan for Sherwood Forest NNR starting in 2005 according to (Banton, 2015).

3.3. Haloing Practice

Haloing is implicated for veteran trees in order to release them from the competition of other younger, more vigorous trees for sunlight and in some cases in order to promote ideal conditions for saproxylic invertebrates as discussed previously. This form of management has and is still being practiced by many such as UK Forestry and the Forestry Commission today. Specifically, the shade intolerant ancient oaks found throughout the U.K receive this treatment. Based off the 2003-4 survey by Alexander et *al.* and the Forestry Commission haloing provided positive responses from 27 of the 29 oaks surveyed in Windsor forest. The practice of haloing involves the removal of younger, more vigorously growing trees that are of less conservational interest or concern, away from the crown layer of veteran trees through felling and/or coppicing techniques. The removal of the invasive trees should be done with care and consideration for species that rely on the surrounding trees as well as keeping in mind the success of future tree generations. When haloing, much care and consideration must be taken to ensure the veteran trees do not react negatively. Too much exposure too quickly can apply additional stress, leading to death within a year or two of treatment (Read, 2000). After having adapted to living within a shaded woodland situation for decades veteran oaks are more susceptible to sun scorched leaves, increased transpiration, dehydrated bark, and wind damage when exposed to quickly. This makes immediate, complete clear-felling undesirable (Harmer and Thampson, 2013) and too risky for trees more susceptible to these negative responses such as ancient oaks. Epicormic buds are important defects of oak timber which originate from suppressed buds that develop in early life and sprout into epicormic shoots depending on light availability (Colin et al., 2008) and were used as a form of assessment during the 2003-4 Windsor Forest assessment. An example of reiterative growth are these epicormic shoots or buds previously mentioned, which are a form of investment for the veteran or ancient trees providing a lower canopy, and enhancing the ability of the trees to naturally retrench, while maintaining photosynthetic vigor (Steer, 2011). The method of haloing will be recorded as in practice or not in practice for live trees only. Stacked logs and clean cut stumps/snags within immediate proximity provide evidence of whether or not haloing has taken place. Referring back to specific notes for

competition felling will also be analyzed on site to determine if the recommended treatment was carried out fully. Trees that have not had any signs of the recommended haloing will be visually assessed using past records along with current observation to determine if the tree has been negatively affected and is in need of immediate or future haloing management. Individual notes shall be taken for concerns such as invasive branches, major overshadowing by surrounding trees, or over-exposure due to natural occurrence. Records of haloing dates and responses will be used for reference when recording visual assessments of any noticeable change both negative and positive.

Again to reiterate on a major influence for these methods, all measurements and data being collected are for the use of Sherwood Forest National Nature reserve. The methods are fixed in order to collaborate with past studies for easy comparison when following the status of each individual ancient oak. Fuller files and additional work such as photographs and halo assessments will be implemented for future reference.

3.4. Ancient Oak Haloing Field Survey

A field assessment survey was conducted in order to record the overall status and sustainability of the ancient oaks chosen for the haloing survey. Data that has been collected and recorded in previous years was made available thanks to (Steer, L. 2011), Nottinghamshire County Council, and the Sherwood Forest National Nature Reserve, and was used as a reference and starting point for this survey. The juxtaposition of the 2005 and 2011 surveys were assessed in order to determine if any management is recommended to ensure the conservation of these crucial environmental contributors. In particular the first section of the 2005 survey recommends immediate haloing treatments to twenty seven ancient oaks within Sherwood Forest NNR. These trees were chosen as the subjects of study, for they have had the most time to react to the prescribed haloing treatments which can be seen in the Appendices. Visual assessment will be conducted using the assessment steps and guidelines discussed within the 2011 survey produced by Luke Steer. The purpose for following the guidelines and descriptions used by Steer 2011 is for familiarity; helping to eliminate any confusion or discrepancy between findings and terminology used during this assessment survey.

Locating the ancient oaks by the 2010 tag number was the first step in collecting data by using the Easting and Northing GIS British National Grid coordinates provided by the 2005 and 2011 surveys. The two sets of coordinates were compared and if identical, imputed into the 2004 Garmin eTrex Summit which was used for locating each individual tree. Pictures from the North, South, East, and West were taken of the tree for visual assessment and future reference. Comparison of the trees from the 2005 and 2011

survey to now were compared, evaluated and gauged, in order to spot any major changes in the shape, health, and overall composition of the tree. Any obvious major changes were duly noted.

Each tree was assessed for age class based on the guidelines discussed within the Sherwood Forest National Nature Reserve Higher Level Scheme Special Capital Project: re-survey and assessment of veteran trees of Sherwood Forest NNR. The likelihood of any variation from the 2011 age class survey was deemed very unlikely, with the exception of any windblown, dead or dying trees. Health was evaluated for each tree based on visual observation using the health classification scale found in the 2011 survey report. The ancient oaks are classified by vitality; focus will be set on crown size, branch growth, twig extension, epicormic shoots, dead wood, decay, and cavities; with a full description adopted from the 2011 survey report found below.

The Tree Health classifications are described as:

- **Normal Vitality**: normal growth and twig extension
- **Moderate Vitality**: reduced twig extension but other than that few signs of ill-health
- **Early Decline**: reduced twig extension and some dead twigs on outer canopy
- **Mid Decline**: small internodes, the canopy may be thinning and contain dead twigs and/or in the outer canopy, older branch wounds that haven't occulated may be decaying and forming cavities
- **Severe Decline**: sparse crown, numerous dead twigs and branches in the outer canopy, older branch wounds likely to be decaying and forming cavities
- **Dead**
-

Structural condition of live and dead trees will be recorded by visual assessment. Any immediate, obvious structural concerns are noted for immediate attention. The trees are ranked from A-E depending on their structural durability. The following descriptions were borrowed from the Steer 2011 survey.

Structural Condition of the live trees:

- **A**: no significant structural defects;
- **B**: some minor structural defects that are unlikely to comprise its mechanical integrity at this time but could develop in the future;
- **C**: one or more moderate defects that could lead to failure during severe weather conditions;
- **D**: contains significant structural defects that could lead to failure during weather events expected in this locality;

- **E**: significant structural defects that have led to partial failure and catastrophic failure could be imminent.

Sustainability of each tree is ranked A-C with the description good-poor, based on a combination of the health and structural condition adopted from the Steer 2011 survey report.

The sustainability of the live trees based on a combined subjective assessment of their health and structural condition:

- **A:** healthy trees in good condition that do not require maintenance work
- **B:** some work may be required to enable these trees to survive
- **C:** these trees are in poor condition and are unlikely to survive for a significant period

The presence of epicormics shoots was also surveyed and recorded through the label classes used by Steel 2011. The ability for a tree to grow epicormics shoots differs between species and individuals of the same species.

- **The epicormics classifications are described as:**
- **Superabundant:** dense epicormic shoots
- **Abundant:** some epicormic shoots, may produce more if light levels increase or if their own crowns are reduced by storm damage or tree surgery
- **Present:** few epicormic shoots, may produce if light levels are increased or if their crowns are reduced by storm damage or tree surgery but this may be slow and the volume physiologically functional, live, sapwood may decrease rapidly as a consequence
- **None:** no epicormic shoots

The competition from other tree classes were used as guidelines, rather than placing each individual into one of the three classes. Measurement of the drip line for each tree was also incorporated into this survey. As simply making an observation is usually the case when surveying and assessing trees, and even less common are picture records, there is little to no solid information to determine approximate estimations. To help in future surveying and assessments the drip line was recorded at four points of the three. A standard field measuring tape is attached to the main stem of the tree at breast height and walked out from under the tree. The distance from the main stem, to where the leaves of the tree being measured end, were recorded. This was performed on four sides of the tree; measurements were taken from the north, east, south and west sides of the tree. A compass was used in order to provide accurate spacing around the tree. These numbers can then be referenced to see if there in indeed gradual crown reduction or

regeneration. This can be especially helpful for trees that are of immediate and or prolonged interest.

4. Data Analysis

Data collection for the dead wood survey took place during May and June of 2015, while survey data for the haloing conservation technique between the 20th and the 27th of July 2015. Data was compiled and analyzed using IBM SPSS Statistics 22, while total volume for each rot class and species was tested for normality between each study area. None of the data was normally distributed even after using multiple SPSS transformation functions. Due to data that is not normally distributed the non-parametric Kruskal–Wallis one-way analysis of variance test was used. Since the Kruskal–Wallis test is a non-parametric test, normal distribution is not assumed, allowing for the comparison of multiple groups of data and to determine whether or not there is a significant difference between the means of these groups. Bar graphs and their represented charts are also shown from excel in order to better interpret the distribution and spread of data amongst the Diameter classes.

5. Results

5.1. Dead wood Results

Total volume was added from the ten line-intersects for each individual study area and added to provide a total estimate for each of the four individual study areas. The total volume was then divided by the number of transect lines in order to provide an overall estimate for Sherwood Forest NNR. The average total volume of dead wood for Sherwood Forest NNR was 211.17 m^3/ha. Average log volume was 71.21 m3/ha, with 83.84 m^3/ha average snag volume, and average stump volume of 56.12 m3/ha. The following results are a combined total of stump, snag, and log volumes from all four study areas**.** Dead wood was then categorized by total volume for each species, and then divided into individual Diameter classes. Throughout the four study areas, dead wood was found for ancient oak, birch, hawthorn, holly, oak, sycamore, as well as unidentified pieces. Ancient oak produced 123.93 m3/ha average volume, birch with an average total of 31.25 m3/ha, hawthorn with an average of 0.53 m3/ha, holly 0.03 m3/ha, oak with an average total of 49.53 m3/ha, sycamore with an average total of 0.62 m3/ha, and unidentified dead wood producing an average total volume of 5.27 m3/ha. For the species total volume charts and graphs below holly is not included, due to the fact that only two logs both with a diameter

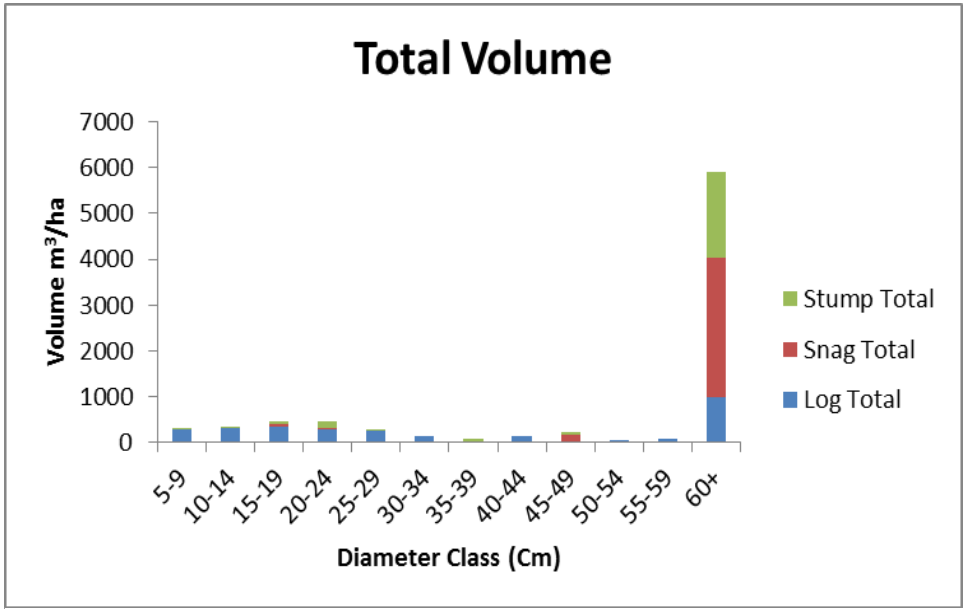


Figure 15: *Above presents the total volume of all dead wood within each Diameter class for Sherwood Forest NNR.*

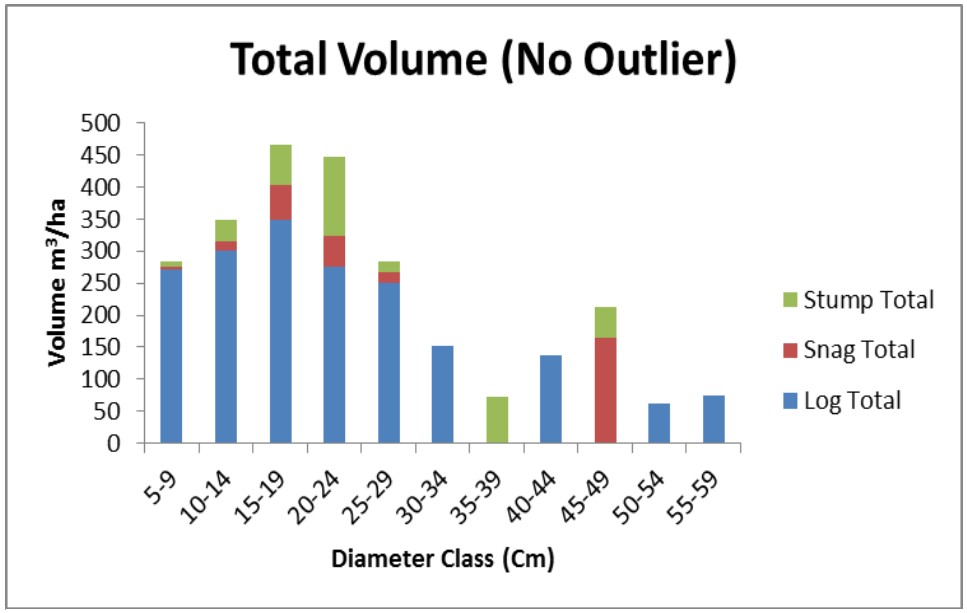


Figure 16: *Left presents the total volume of all dead wood within each Diameter class for Sherwood Forest NNR, with the exception of Diameter class 60+*

Diameter Class (Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Total	Average
Log Total	270.9	299.99	348.74	275.21	251.16	151.84	0	136.91	0	61.69	74.64	977.14	2848.22	71.21
Snag Total	5.26	14.61	53.86	48.98	15.42	0	0	0	163.67	0	0	3051.73	3353.52	83.84
Stump Total	8.09	35.04	63.36	123.39	17.99	0	73.16	0	49.96	0	0	1873.87	2244.87	56.12
Total	284.25	349.63	465.97	447.59	284.57	151.84	73.16	136.92	213.63	61.69	74.64	5902.74	8446.61	211.17

Chart 1: *Above shows total volume m^3/ha for each individual Diameter class for Sherwood Forest NNR rounded to the second decimal place. The following results produced* ***Figure 9*** *and* ***10****.*

of five centimeters was recorded for a total volume of 1.23 m3/ha. The difference between oak and ancient oak was determined by physical characteristics and a representative tag number that was recorded in either of the 2005 or 2011 assessments.

Finally dead wood volume was assigned to rot categories based on **Figure 5**. Rot category 1 produced a total average of 21.23 m3/ha, rot category 2 with an average total of 21.78 m3/ha, rot category 3 with a total average of 12.1 m3/ha, rot category 4 produced a total average of 83.07 m3/ha, and finally rot category 5 with a total of 72.99 m3/ha. Due to the wide range of volumes within each Diameter class it is important to pay attention to the scale bars representing the Y-Axis when comparing Figures.



Figure 17: Above is an ancient oak snag encountered during dead wood survey in study area 1 within Sherwood Forest NNR. Picture by: Tyler Wilcox, June 2015.



Figure 18: Above shows a clean cut stump left over from an oak felled by haloing management for ancient oak #10982 in Sherwood Forest NNR. Picture by: Tyler Wilcox, July 2015



Figure 19: Above is a birch dead wood pile with a rot classification of 1. This pile was encountered within study area 2 of Sherwood Forest NNR. Picture by: Tyler Wilcox, May 2015.

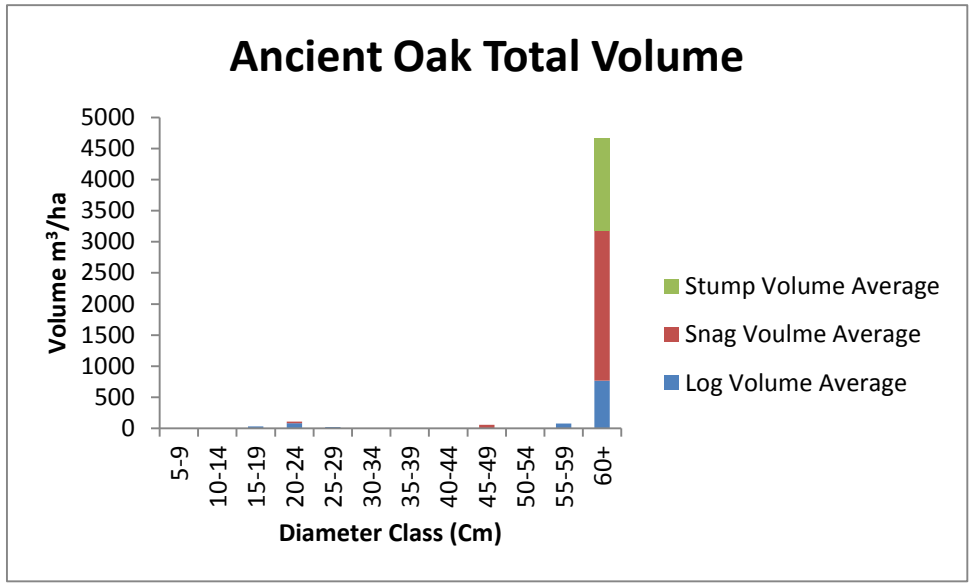


Figure 20: *Above represents total volume of ancient oak dead wood from all four study areas within Sherwood Forest NNR.*

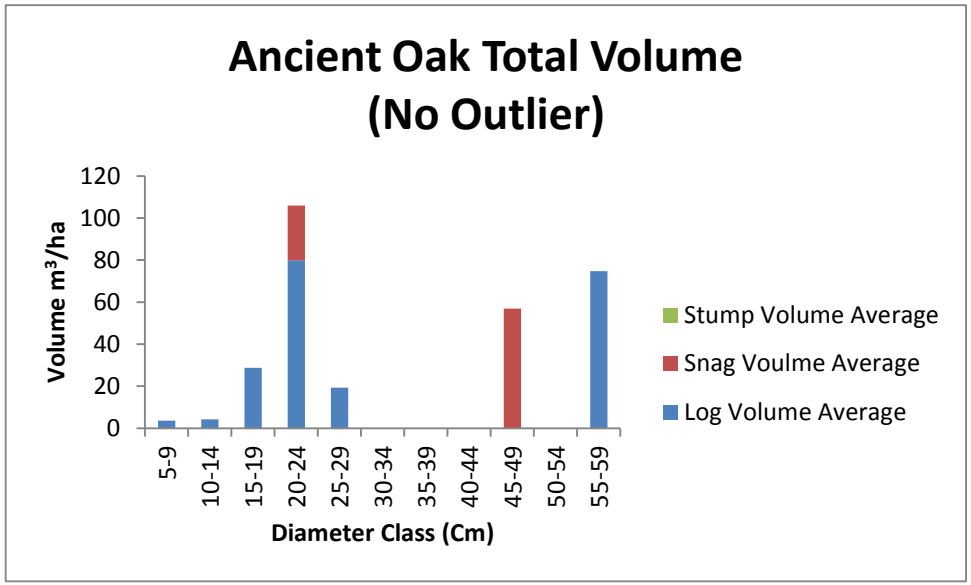


Figure 21: *Above represents total volume of ancient oak dead wood from all four study areas within Sherwood Forest NNR, with the exception of Diameter class 60+.*

Diameter Class(Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	3.58	4.17	28.77	79.85	19.34	0	0	0	0	0	74.64	768.3	978.65	24.47
Snag Volume Average	0	0	0	26.15	0	0	0	0	56.85	0	0	2409.79	2492.79	62.32
Stump Volume Average	0	0	0	0	0	0	0	0	0	0	0	1485.87	1485.87	37.15
Total Volume Average	3.58	4.17	28.77	106	19.34	0	0	0	56.85	0	74.64	4663.97	4957.31	123.93

Chart 2: *Above shows total volume of ancient oak dead wood for Sherwood Forest NNR in m^3/ha for each individual Diameter class. The following results produced* ***Figure 20*** *and* ***21.***

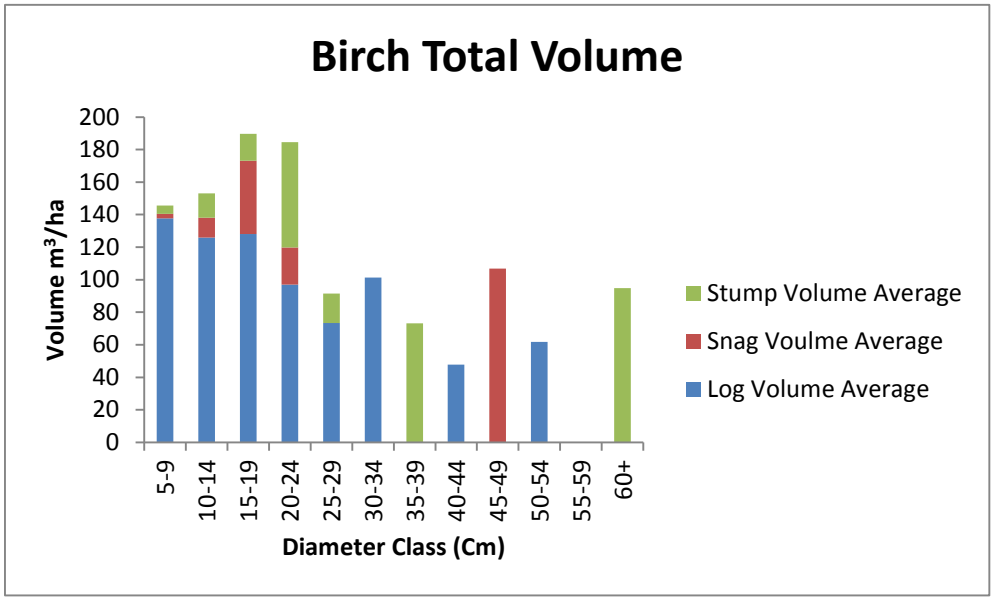


Figure 22: *Left represents total volume of birch dead wood from all four study areas within Sherwood Forest NNR.*

Chart 3: *Below shows total volume of ancient oak dead wood for Sherwood Forest NNR in m^3/ha for each individual Diameter class. The following results produced* ***Figure 22.***

Diameter Class (Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	137.79	125.91	128.18	96.99	73.45	101.26	0	47.77	0	61.69	0	0	773.04	19.33
Snag Volume Average	2.79	12.14	44.96	22.82	0	0	0	0	106.81	0	0	0	189.52	4.74
Stump Volume Average	4.93	15.03	16.66	64.7	17.99	0	73.16	0	0	0	0	94.85	287.3	7.18
Total Volume Average	145.51	153.08	189.79	184.51	91.44	101.26	73.16	47.77	106.81	61.69	0	94.85	1249.87	31.25

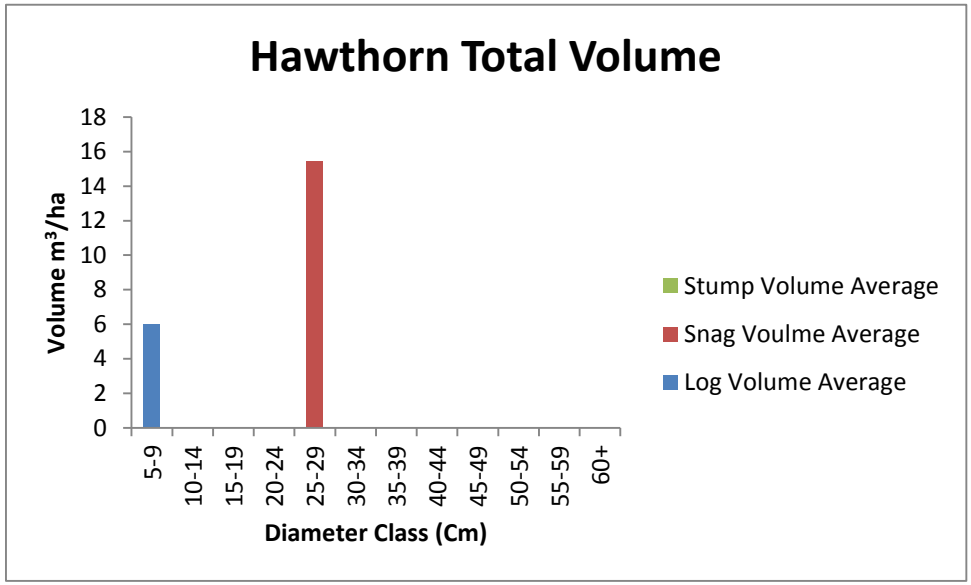


Figure 23: *Left represents total volume of hawthorn dead wood from all four study areas within Sherwood Forest NNR.*

Chart 4: *Below shows total volume of hawthorn dead wood for Sherwood Forest NNR in m^3/ha for each individual Diameter class. The following results produced* ***Figure 23.***

Diameter Class (Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	5.97	0	0	0	0	0	0	0	0	0	0	0	5.97	0.15
Snag Volume Average	0	0	0	0	15.42	0	0	0	0	0	0	0	15.42	0.39
Stump Volume Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Volume Average	5.97	0	0	0	15.42	0	0	0	0	0	0	0	21.39	0.53

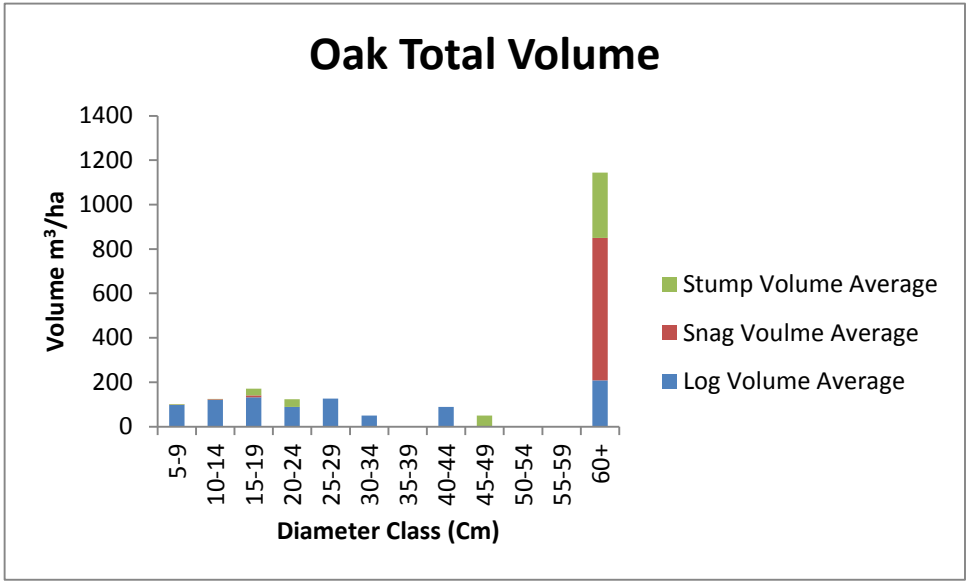


Figure 24: *Above represents total volume of oak dead wood from all four study areas within Sherwood Forest NNR.*

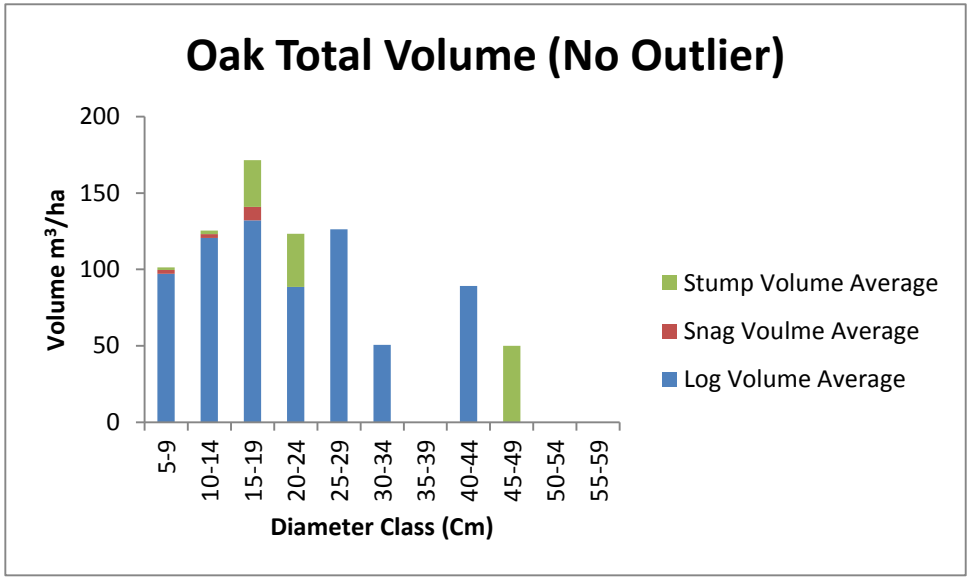


Figure 25: *Above represents total volume of oak dead wood from all four study areas within Sherwood Forest NNR, with the exception of Diameter class 60+.*

Diameter Class(Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	97.19	120.56	132.1	88.51	126.26	50.58	0	89.15	0	0	0	208.84	913.19	22.83
Snag Volume Average	2.47	2.47	8.91	0	0	0	0	0	0	0	0	641.94	655.79	16.39
Stump Volume Average	1.58	2.47	30.45	34.77	0	0	0	0	49.97	0	0	293.15	412.38	10.31
Total Volume Average	101.24	125.49	171.46	123.27	126.26	50.58	0	89.15	49.97	0	0	1143.94	1981.35	49.53

Chart 5: *Above shows total volume of hawthorn dead wood for Sherwood Forest NNR in m^3/ha for each individual Diameter class. The following results produced* ***Figure 24*** *and* ***25.***

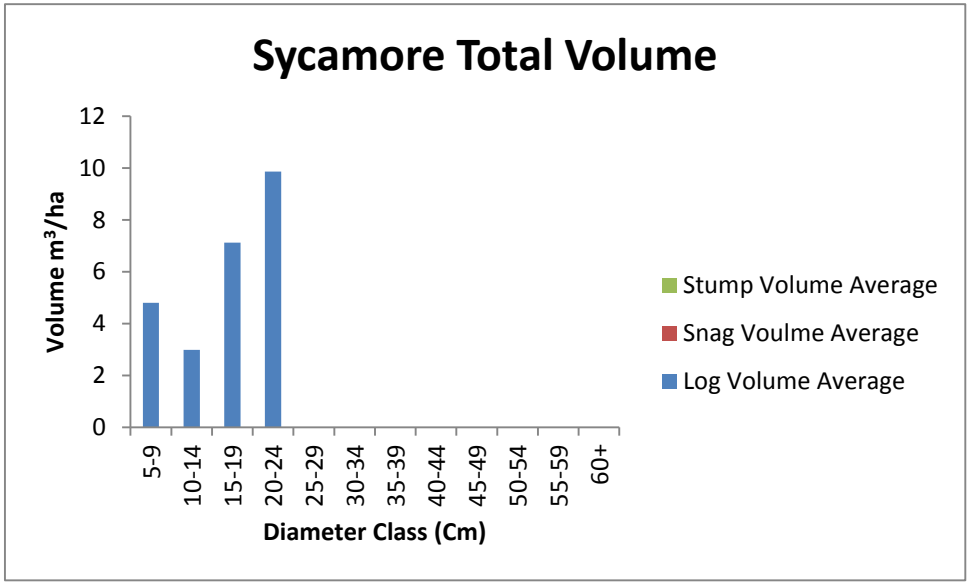


Figure 26: *Left represents total volume of sycamore dead wood from all four study areas within Sherwood Forest NNR.*

Chart 6: *Below shows total volume of sycamore dead wood for Sherwood Forest NNR in m^3/ha for each individual Diameter class. The following results produced* ***Figure 26.***

Diameter Class(Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	4.81	2.99	7.13	9.87	0	0	0	0	0	0	0	0	24.8	0.62
Snag Volume Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stump Volume Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Volume Average	4.81	2.99	7.13	9.87	0	0	0	0	0	0	0	0	24.8	0.62

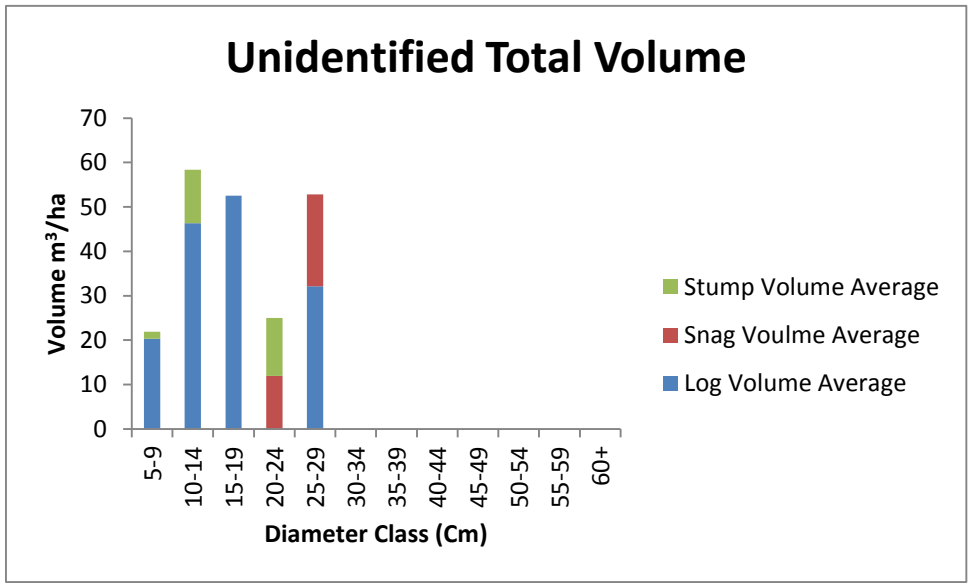


Figure 27: *Left represents total volume of unidentified dead wood from all four study areas within Sherwood Forest NNR.*

Chart 7: *Below shows total volume of unidentified dead wood for Sherwood Forest NNR in m^3/ha for each individual Diameter class. The following results produced* ***Figure 27.***

Diameter Class(Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	20.33	46.36	52.56	0	32.1	0	0	0	0	0	0	0	151.35	3.78
Snag Volume Average	0	0	0	11.94	20.75	0	0	0	0	0	0	0	32.69	0.81
Stump Volume Average	1.58	11.99	0	13.05	0	0	0	0	0	0	0	0	26.62	0.67
Total Volume Average	21.91	58.35	52.56	25	52.85	0	0	0	0	0	0	0	210.67	5.27

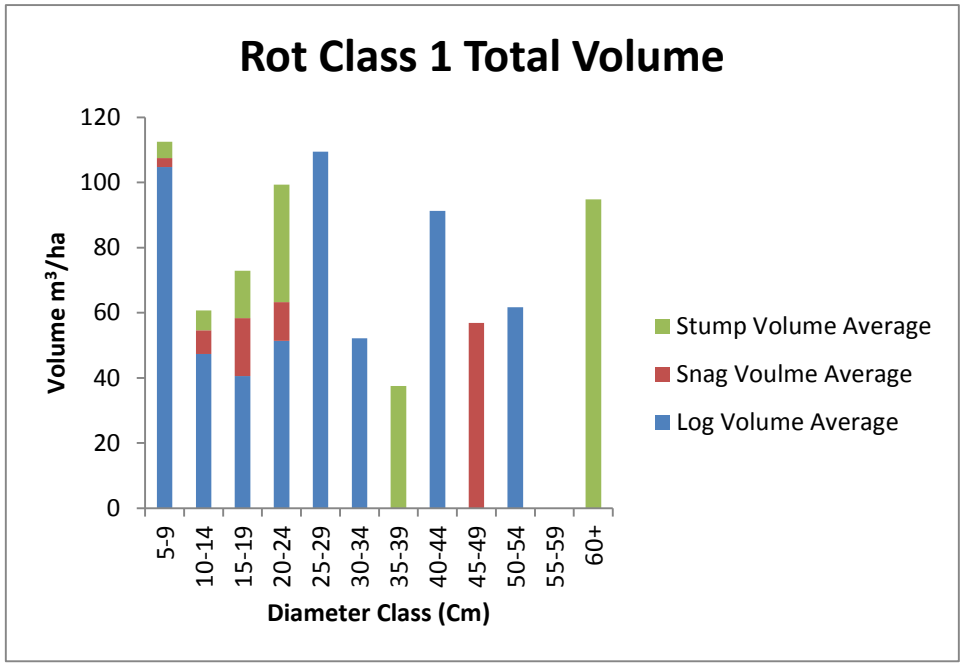


Figure 28: *Left represents total volume of dead wood that fell within rot 1 classification from all four study areas within Sherwood Forest NNR.*

Chart 8: *Below shows total volume of dead wood that fell within rot 1 classification for Sherwood Forest NNR in m^3/ha for each individual Diameter class. The following results produced* ***Figure 28.***

Diameter Class(Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	104.74	47.35	40.59	51.37	109.43	52.14	0	91.29	0	61.69	0	0	558.6	13.96
Snag Volume Average	2.79	7.31	17.81	11.94	0	0	0	0	56.85	0	0	0	96.7	2.42
Stump Volume Average	4.93	60.02	14.59	35.97	0	0	37.53	0	0	0	0	94.85	193.77	4.84
Total Volume Average	112.46	60.67	72.86	99.29	109.43	52.14	37.53	91.29	56.85	61.69	0	94.85	849.06	21.23

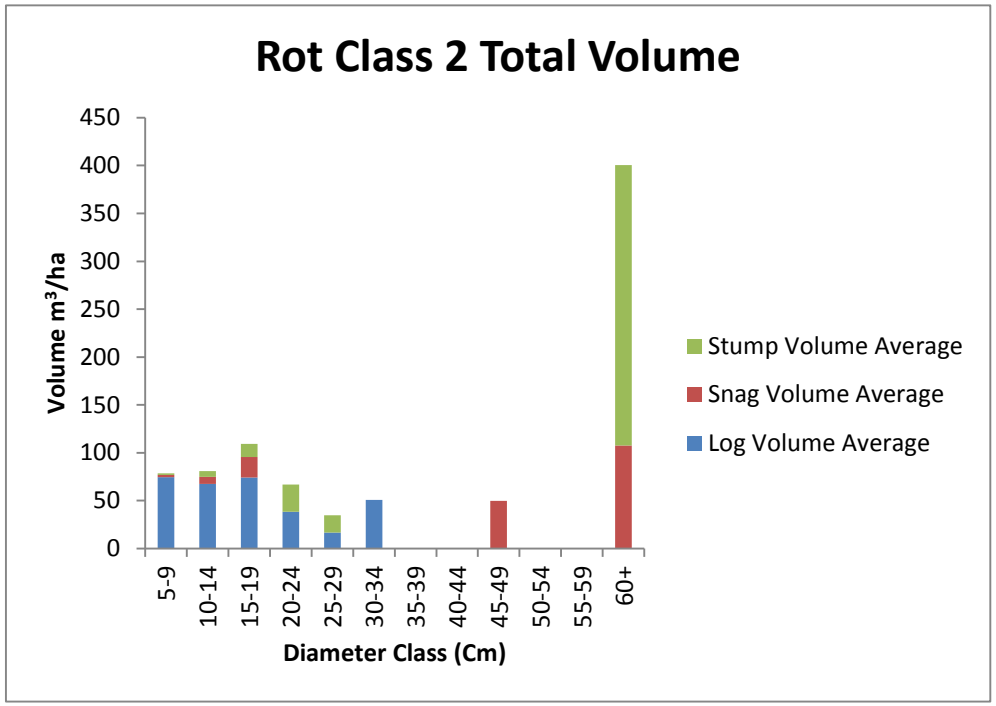


Figure 29: *Above represents total volume of dead wood that fell within rot 2 classification from all four study areas within Sherwood Forest NNR.*

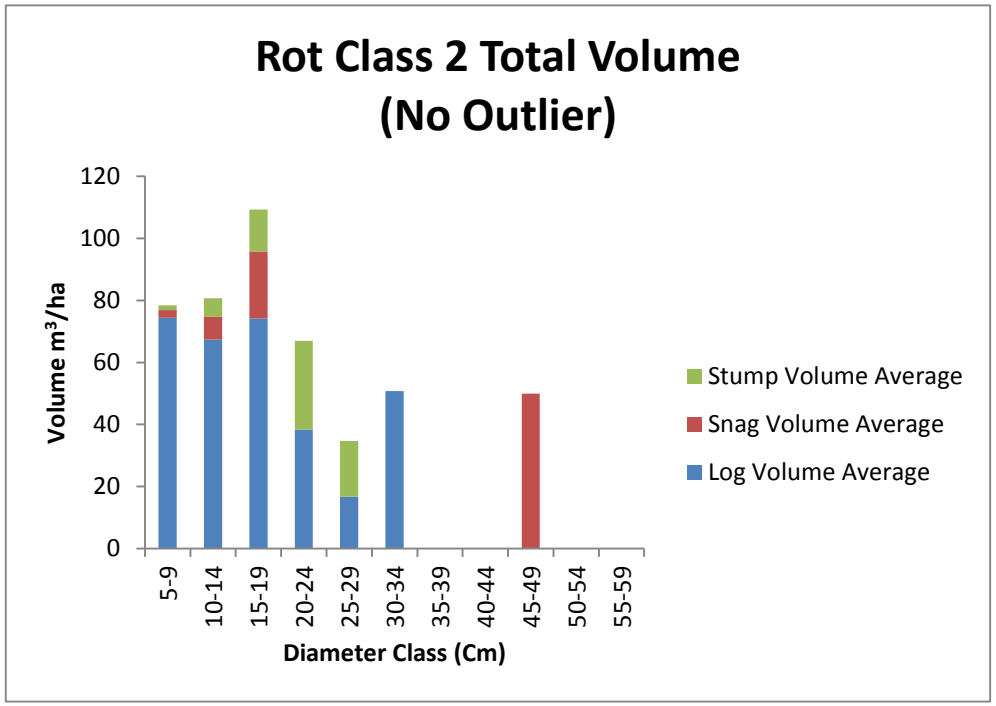


Figure 30: *Above represents total volume of dead wood that fell within rot 2 classification from all four study areas within Sherwood Forest NNR, with the exception of Diameter class 60+.*

Diameter Class(Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	74.38	67.41	74.15	38.29	16.68	50.73	0	0	0	0	0	0	321.64	8.04
Snag Volume Average	2.47	7.3	21.59	0	0	0	0	0	49.97	0	0	107.48	188.81	4.72
Stump Volume Average	1.58	6.02	13.55	28.62	17.99	0	0	0	0	0	0	293.15	360.91	9.02
Total Volume Average	78.43	80.73	109.28	66.92	34.67	50.73	0	0	49.97	0	0	400.63	871.35	21.78

Chart 9: *Above shows total volume of dead wood that fell within rot 2 classification for Sherwood Forest NNR in m^3/ha for each individual Diameter class. The following results produced* ***Figure 29*** *and* ***30.***

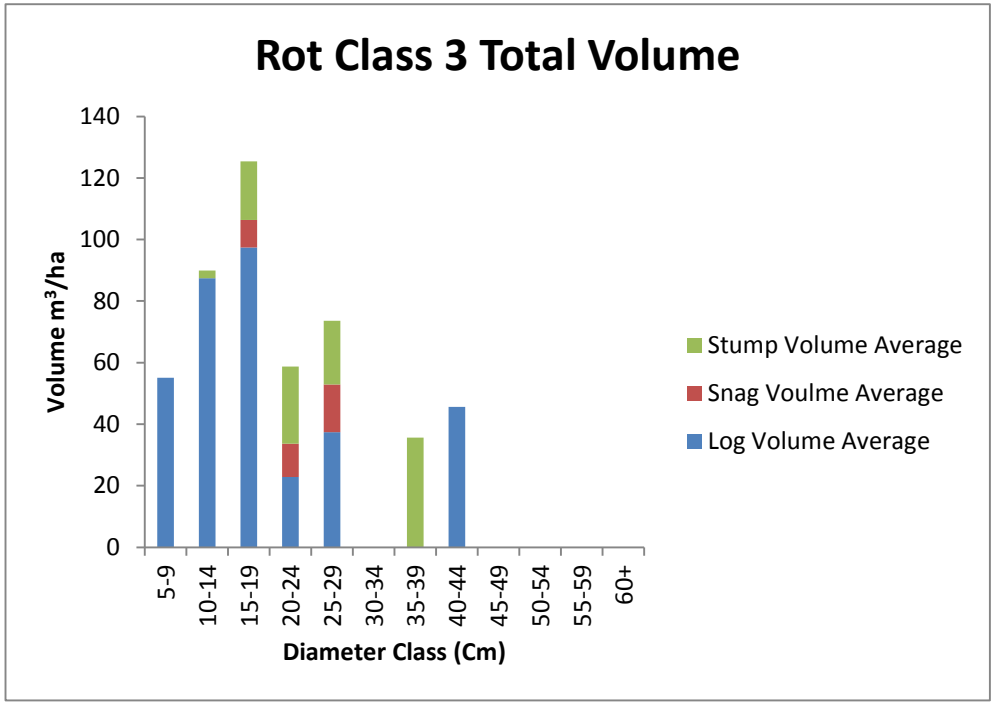


Figure 31: *Left represents total volume of dead wood that fell within rot 3 classification from all four study areas within Sherwood Forest NNR.*

Chart 10: *Below shows total volume of dead wood that fell within rot 3 classification for Sherwood Forest NNR in m^3/ha for each individual Diameter class. The following results produced* ***Figure 31.***

Diameter Class(Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	55.09	87.42	97.44	22.82	37.43	0	0	45.62	0	0	0	0	345.82	8.65
Snag Volume Average	0	0	8.91	10.88	15.42	0	0	0	0	0	0	0	35.21	0.88
Stump Volume Average	0	2.47	19.1	25	20.75	0	35.63	0	0	0	0	0	102.94	2.57
Total Volume Average	55.09	89.89	125.44	58.7	73.6	0	35.63	45.62	0	0	0	0	483.97	12.1

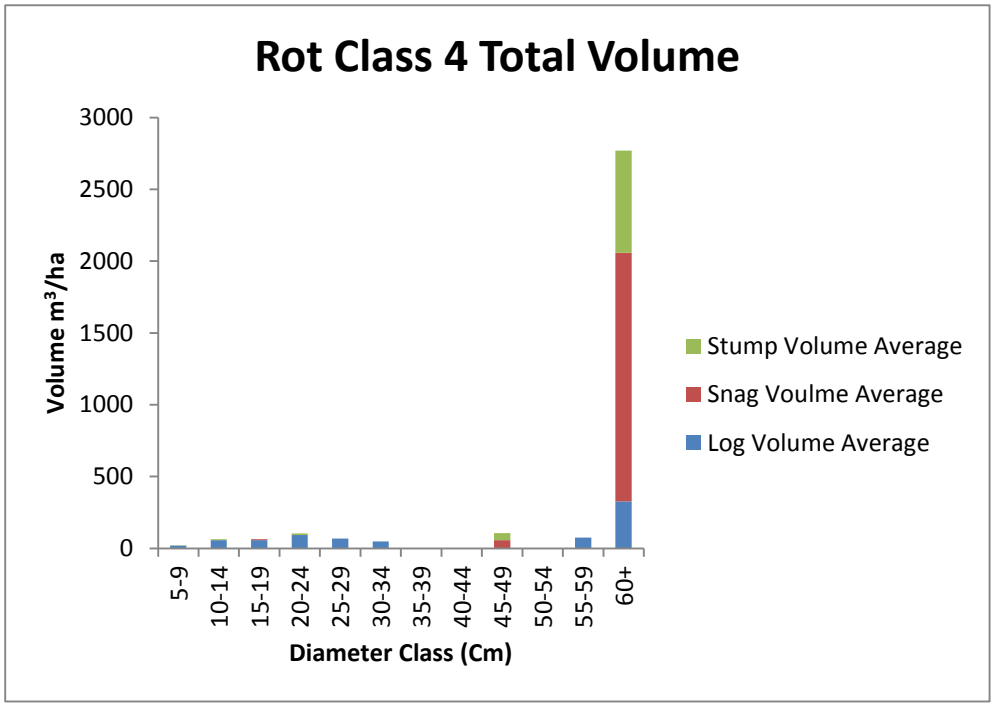


Figure 32: *Above represents total volume of dead wood that fell within rot 4 classification from all four study areas within Sherwood Forest NNR.*

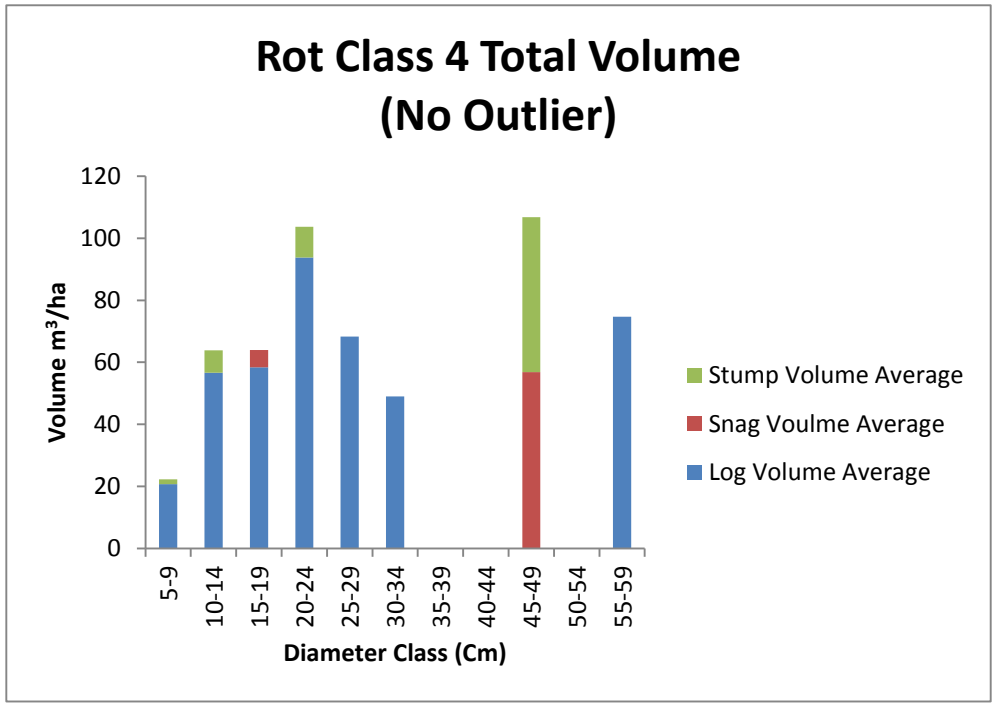


Figure 33: *Above represents total volume of dead wood that fell within rot 5 classification from all four study areas within Sherwood Forest NNR, with the exception of Diameter class 60+.*

Diameter Class(Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	20.73	56.65	58.35	93.81	68.27	48.98	0	0	0	0	74.64	326.31	747.75	18.69
Snag Volume Average	0	0	5.55	0	0	0	0	0	56.85	0	0	1732.44	1794.84	44.87
Stump Volume Average	1.58	7.16	0	9.87	0	0	0	0	49.96	0	0	711.45	780.02	19.5
Total Volume Average	22.31	63.81	63.91	103.68	68.27	48.98	0	0	106.81	0	74.64	2770.2	3322.6	83.07

Chart 11: *Above shows total volume of dead wood that fell within rot 4 classification for Sherwood Forest NNR in m3/ha for each individual Diameter class. The following results produced* ***Figure 32*** *and* ***33.***

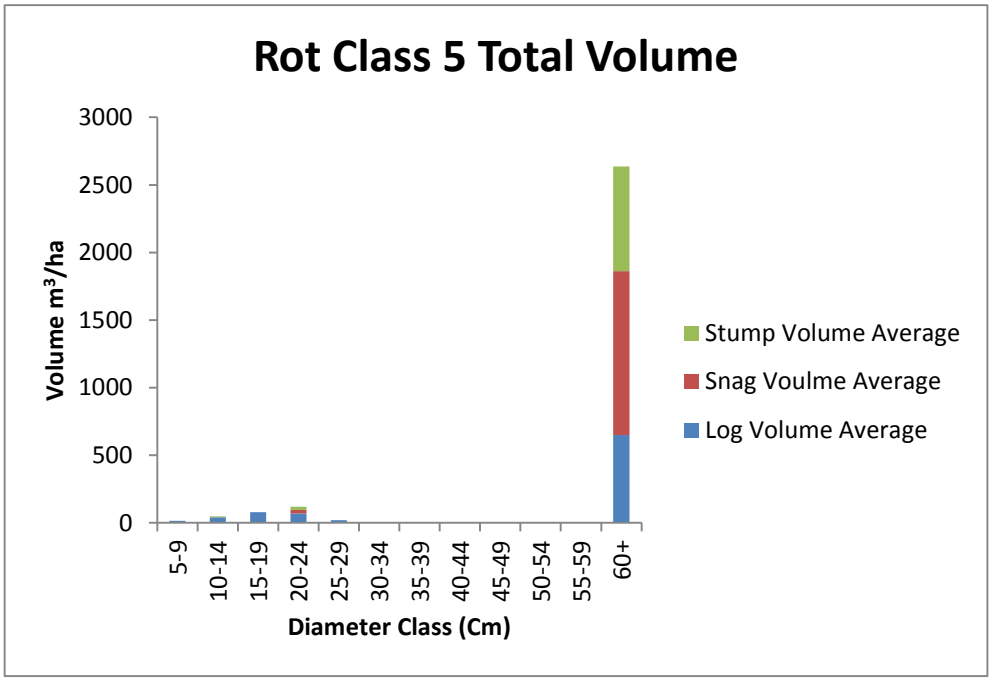


Figure 34: *Above represents total volume of dead wood that fell within rot 5 classification from all four study areas within Sherwood Forest NNR.*

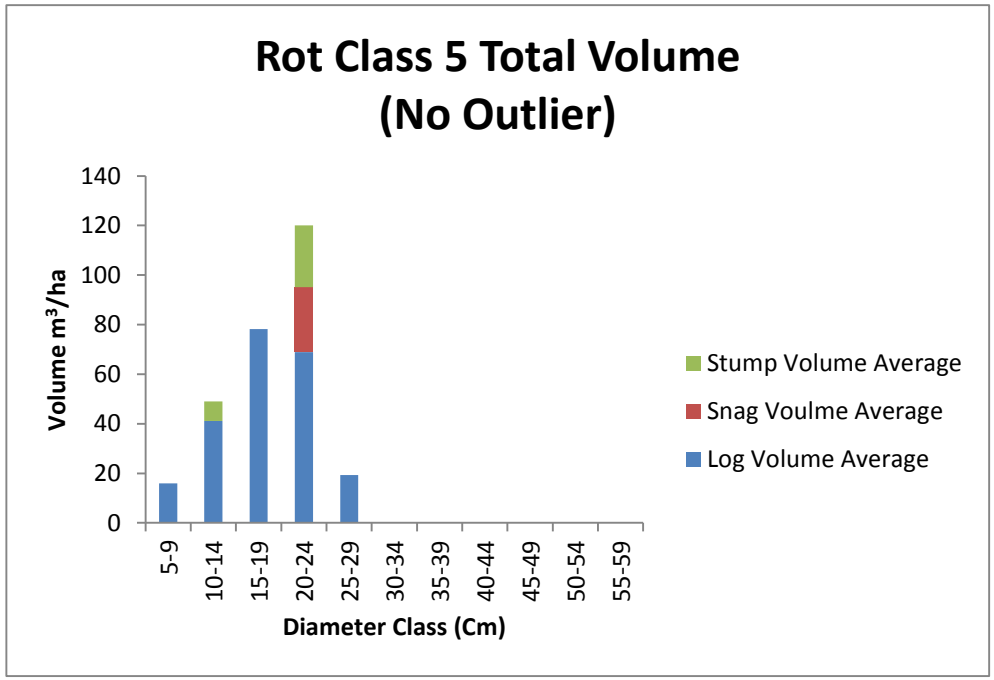


Figure 35: *Above represents total volume of dead wood that fell within rot 5 classification from all four study areas within Sherwood Forest NNR, with the exception of Diameter class 60+.*

Diameter Class(Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	15.96	41.16	78.22	68.92	19.34	0	0	0	0	0	0	650.83	874.42	21.86
Snag Volume Average	0	0	0	26.16	0	0	0	0	0	0	0	1211.81	1237.97	30.95
Stump Volume Average	0	7.82	0	25	0	0	0	0	0	0	0	774.72	807.24	20.18
Total Volume Average	15.96	48.98	78.22	120.06	19.34	0	0	0	0	0	0	2637.06	2919.63	72.99

Chart 12: *Above shows total volume of dead wood that fell within rot 5 classification for Sherwood Forest NNR in m3/ha for each individual Diameter class. The following results produced* ***Figure 34*** *and* ***35.***

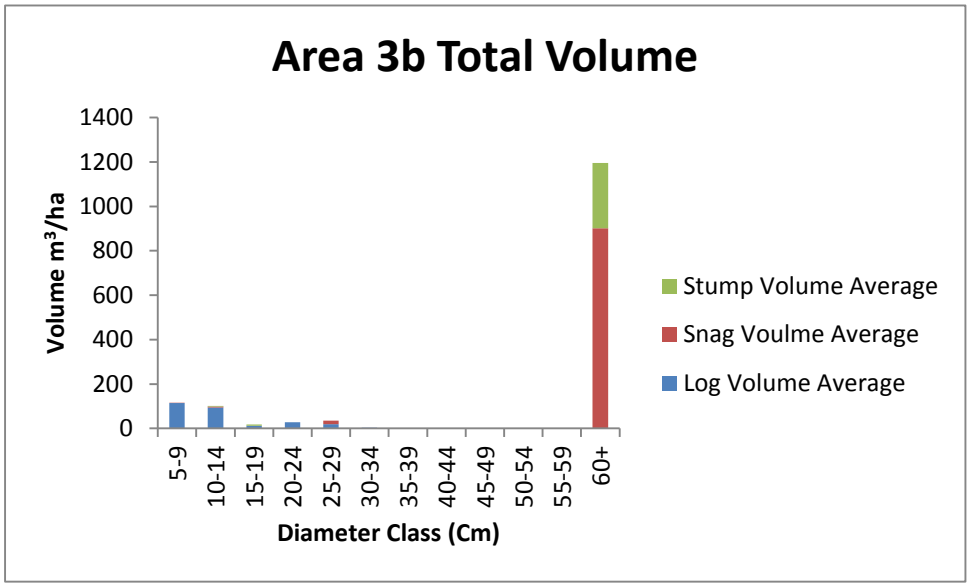


Figure 36: *Above represents total volume of dead wood for each Diameter class that fell within study area 3b within Sherwood Forest*

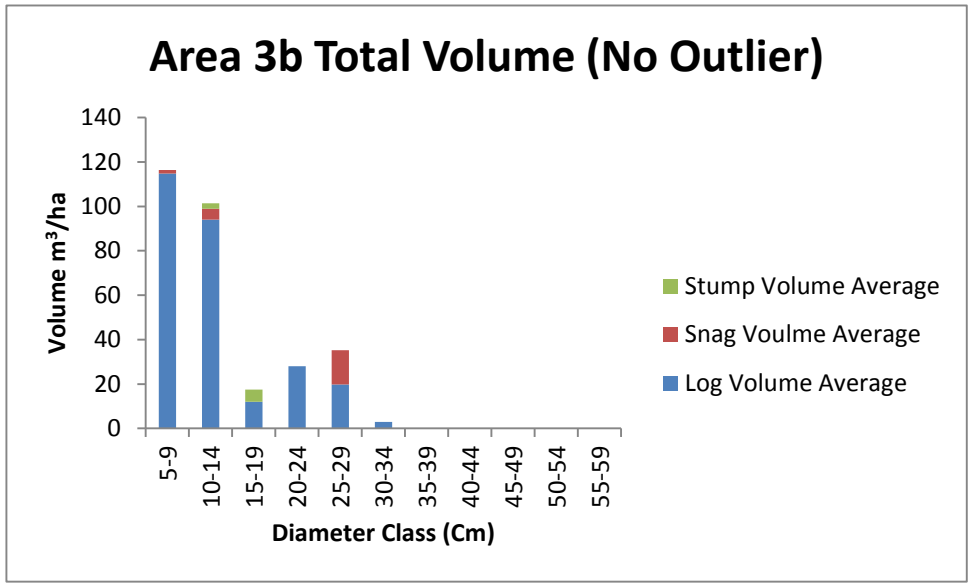


Figure 37: *Above presents the total volume within each Diameter class that fell within study area 3b for Sherwood Forest NNR, with the exception of Diameter class 60+.*

Diameter Class(Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	114.78	94.01	12.02	27.96	19.76	2.99	0	0	0	0	0	0	271.51	54.3
Snag Volume Average	1.58	4.93	0	0	15.42	0	0	0	0	0	0	902.3	924.24	184.85
Stump Volume Average	0	2.47	5.55	0	0	0	0	0	0	0	0	293.15	301.17	60.23
Total Volume Average	116.36	101.41	17.57	27.96	35.19	2.99	0	0	0	0	0	1195.46	1496.92	299.38

Chart 13 *Above shows total volume of dead wood within study area 3b for Sherwood Forest NNR in m3/ha for each individual Diameter class The following results produced* ***Figure 36*** *and* ***37.***

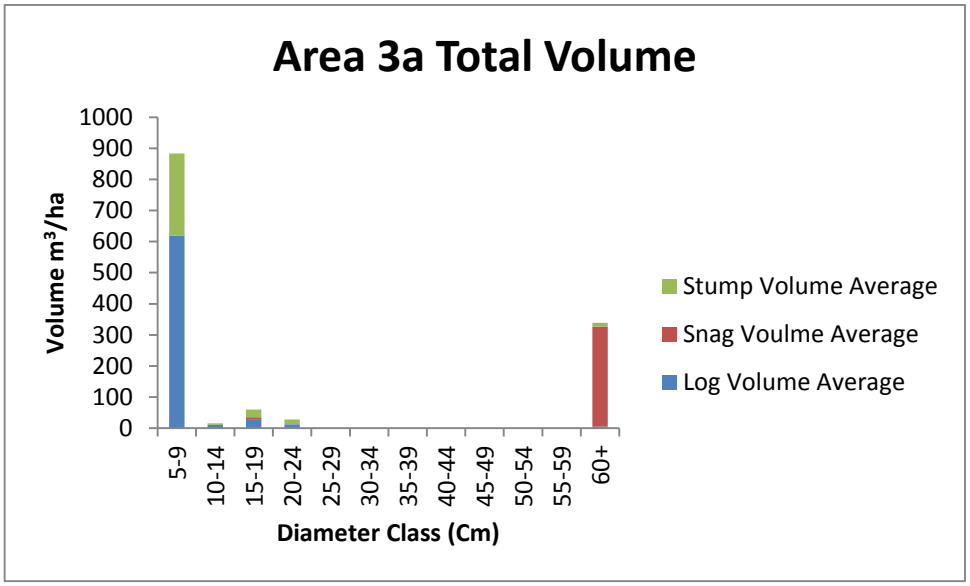


Figure 38: *Above represents total volume of dead wood for each Diameter class that fell within study area 3a within Sherwood Forest NNR.*

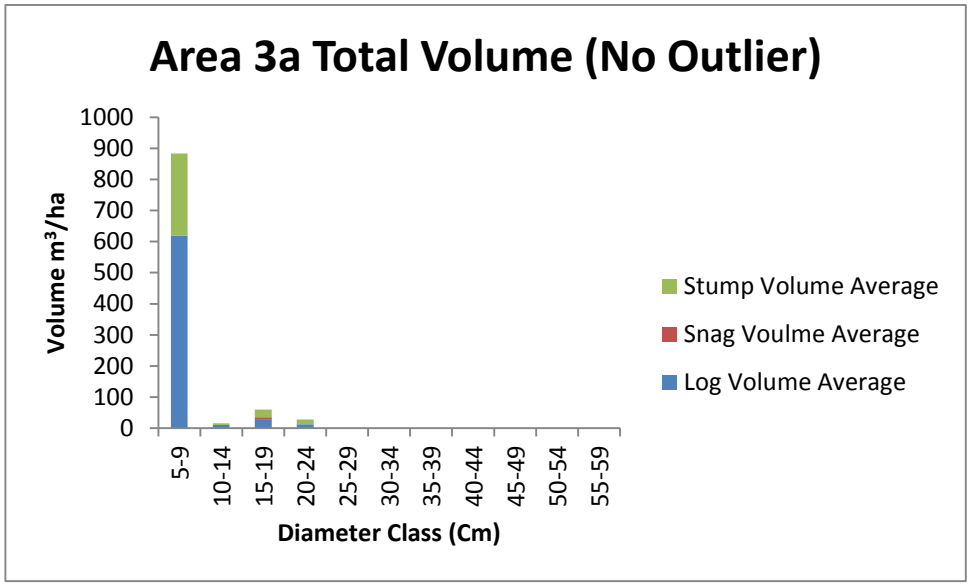


Figure 39: *Above presents the total volume within each Diameter class that fell within study area 3a for Sherwood Forest NNR, with the exception of Diameter class 60+.*

Diameter Class(Cm)	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+	Totals	Average
Log Volume Average	618.62	9.94	26.35	12.86	0	0	0	0	0	0	0	5.55	673.33	134.67
Snag Volume Average	1.21	0	8.91	0	0	0	0	0	0	0	0	320.66	330.78	66.16
Stump Volume Average	263.35	5.13	24.9	14.93	0	0	0	0	0	0	0	13.05	321.35	64.27
Total Volume Average	883.18	15.08	60.155	27.78	0	0	0	0	0	0	0	339.27	1325.46	265.09

Chart 14: *Above shows total volume of dead wood within study area 3a for Sherwood Forest NNR in m3/ha for each individual Diameter class. The following results produced* ***Figure 38*** *and* ***39.***

5.2. Statistical Results

Comparisons between total volume and individual species total volume for grazed and non-grazed study areas were performed using SPSS to determine whether or not there was a significant difference between the management practices. Study areas 1 and 2 are the grazed areas while study areas 3 and 4 are non-grazed.

Ranks

	Graze v. Non-Graze	N	Mean Rank
Volume	A. Oak: G	12	23.13
	A. Oak: N	22	14.43
	Total	34	

Test Statistics[a,b]

	Volume
Chi-Square	5.933
df	1
Asymp. Sig.	.015

a. Kruskal Wallis Test

b. Grouping Variable: G_N

Chart 15: *Above is Kruskal Wallis Test results from SPSS for the comparison of ancient oak dead wood volumes between grazed (study areas 1 and 2) and non-grazed (study areas 3 and 4).*

Ranks

	Graze v. Non-Graze	N	Mean Rank
Volume	Oak: G	87	91.97
	Oak: N	81	76.48
	Total	168	

Test Statistics[a,b]

	Volume
Chi-Square	4.279
df	1
Asymp. Sig.	.039

a. Kruskal Wallis Test

b. Grouping Variable: G_N

Chart 16: *Above is Kruskal Wallis Test results from SPSS for the comparison of oak dead wood volumes between grazed (study areas 1 and 2) and non-grazed (study areas 3 and 4).*

The Kruskal wallis Test produced a P-value of .015 for ancient oak dead wood volumes and a P-value of .039 for oak dead wood volumes between grazed and non-grazed study areas. With P-values ≤ .05 for the following comparisons, it can be said with 95% confidence that there is a significant difference in ancient oak and oak dead wood volumes between grazed and non-grazed study areas. Birch with a P-value of .987 showed no significant difference between grazed and non-grazed study areas.

When comparing the total volume amongst species between study areas, ancient oak dead wood volume between study area 1 and 4, 2 and 4, as well as 3 and 4 produced P-values ≤ .05. Oak dead wood volume between study area 1 and 4 along with area 3 and 4 showed significant difference as well; all of which can be viewed in the **Charts 17** through **19**. Comparisons between total volume and rot showed no significant difference between any of the four research areas.

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Volume	15	96.3027	155.89047	1.58	476.73
Study-Area	15	31.0000	14.63850	11.00	41.00

Ranks

	Study Area	N	Mean Rank
Volume	A.Oak: 1	5	12.80
	A.Oak: 4	10	5.60
	Total	15	

Test Statistics[a,b]

	Volume
Chi-Square	8.702
df	1
Asymp. Sig.	.003

a. Kruskal Wallis Test

b. Grouping Variable: Study Area

Chart 17: *Above are Kruskal Wallis Test results from SPSS for the comparison of ancient oak dead wood volumes between study area 1 and 4.*

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Volume	17	89.9124	126.97661	1.58	409.59
Study-Area	17	32.7647	10.14599	21.00	41.00

Ranks

	Study Area	N	Mean Rank
Volume	A.Oak: 2	7	12.86
	A.Oak: 4	10	6.30
	Total	17	

Test Statistics[a,b]

	Volume
Chi-Square	6.986
df	1
Asymp. Sig.	.008

a. Kruskal Wallis Test

b. Grouping Variable: Study Area

Chart 18: *Above are Kruskal Wallis Test results from SPSS for the comparison of ancient oak dead wood volumes between study area 2 and 4.*

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Volume	22	102.1395	170.40181	1.58	592.79
Study-Area	22	35.5455	5.09647	31.00	41.00

Ranks

	Study Area	N	Mean Rank
Volume	A.Oak: 3	12	14.42
	A.Oak: 4	10	8.00
	Total	22	

Test Statistics[a,b]

	Volume
Chi-Square	5.372
df	1
Asymp. Sig.	.020

a. Kruskal Wallis Test

b. Grouping Variable: Study Area

Chart 19: *Above are Kruskal Wallis Test results from SPSS for the comparison of ancient oak dead wood volumes between study area 3 and 4.*

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Volume	91	9.6410	25.81220	.62	208.84
Study-Area	91	31.3516	9.91786	23.00	43.00

Ranks

	Study Area	N	Mean Rank
Volume	Oak: 2	53	51.20
	Oak: 4	38	38.75
	Total	91	

Test Statistics[a,b]

	Volume
Chi-Square	4.939
df	1
Asymp. Sig.	.026

a. Kruskal Wallis Test

b. Grouping Variable: Study Area

Chart 20: *Above are Kruskal Wallis Test results from SPSS for the comparison of oak dead wood volumes between study area 2 and 4.*

With P-values ≤ .05 for the following comparisons it can be said with 95% confidence that there is a significant difference between study areas 1 and 4, 2 and 4, 3 and 4 for total ancient oak volume; as well as study areas 2 and 4 for total oak volume. Comparisons between total volume and rot between grazed and non-grazed study areas showed no significant difference. All other comparisons between total volume and rot between each individual study area did not show any significant difference.

5.3. Ancient Oak Survey Results

Of the twenty-six ancient oaks surveyed sixteen showed positive response to haloing; with three showing only moderate signs, and six showing no signs at all. Tree #10173 was found dead while tree #10998 could not be confidently confirmed by tag number and was not included within the final results. All sixteen of the oaks that showed positive responses contained superabundant,, to abundant classification levels of epicormic shoot activity. Trees #10485 and #10367 appeared to be completely relying on epicormics shoots in order to sustain life. The three ancient oaks (#10058, #10971, and #10285) showing moderate response placed in the present classification for epicormic activity. Two of these trees were in the process of structural failure within their root system. Heavy heart rot, limited vertical branches, and unstable root systems. Incomplete haloing accompanied two of the three ancient oaks, where younger trees were overshadowing the only live sections remaining.



Figure 40: *Tree #10485 relying completely on epicormics buds. Also flattened underlay from heavy longhorn activity due to placement of the water trough. Picture by: Tyler Wilcox, August 2015*

Tree #10173 could not be classified as negatively affected by haloing because it appeared to have been moved and placed along the Major Oak visitors path for picturesque purposes. Tree #10998 was unable to be identified because the coordinates provided did not lead to the immediate vicinity of the oak. The closest ancient oak had blown over and was completely covered in vegetation; for this reason no tag number was found and the tree could not be positively identified. Surrounding oaks were checked for conformation and none of the tags matched. Trees that showed moderate to no response still remained in competition with younger trees due to incomplete felling. Many of the trees that were observed as overshadowing live sections of ancient oaks appeared to be marked for felling in the future, however some trees are in need of immediate felling and

have been noted within the **Appendix 9.8**. A common trend found in all trees was the positioning of epicormics shoots. Ancient oaks with main stems that have been snapped at the top sprouted epicormic shoots as if to replace lost crown volume that would normally be exposed to easily accessible sunlight. Another trend was epicormic shoots filling out the base of the lower stem. This mainly occurred in trees that had a complete halo felled, allowing sunlight to reach lower sections of the tree. A noticeable control factor to how prominent the epicormics shoots became, was the surrounding ground vegetation. Although exposed to light during early months of spring and summer, vegetation such as *Urtica dioica,* and *Pteridium aquilinum*, and *Rubus fruticosus* begin to overshadow lower levels of the main stem and the epicormic shoots on them. Finally, many of these ancient oaks showed signs of retrenchment; which is a natural phase that normally occurs in oak due to lack of sunlight and or nutrients (Fay, 2002). Epicormic shoots also sprouted along vertical branches, in what can be seen as a response to renewed exposure to sunlight due to haloing management. With the exception of the two dead trees found within the survey, all of the trees produced epicormics shoots since the 1996 survey in which the first instructions for haloing were placed. Since then all trees experienced this practice even if just partially. For reference, pictures for each ancient oak surveyed are available of north, east, west, and south facing sides. These pictures can be viewed in the attached USB drive.

6. Discussion

According to UK Forestry the greater the abundancy or volume of dead wood, the greater the value of the woodland for biodiversity. 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 40-100m3 ha-1 within ancient semi-natural woodlands and 20-40m3 ha-1 within managed plantations and secondary woodlands, and average more than 3 snags per hectare (Humphrey, 2002)

In order to provide reference to the dead wood volumes found during this survey a compilation of previous works has been provided in **Figure 41.** When looking at the Old-Growth column in the Britain section of **Figure 41,** Sherwood Forest NNR with a total average estimate of 211.17 m3/ha contains more deadwood than the highest estimate recorded by any reference provided within Britain since 2010. When compared to Slovenia, the country containing the highest dead wood levels, Sherwood does not even break the lowest estimate threshold. This can be explained by the history of Britain and Slovenian history and current management. During an interview with site manager Izi

Banton on 05/09/2015, she revealed that no all dead wood within Sherwood Forest NNR is left to take its

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

Figure 41: *Above is a compilation of previous dead wood study results adopted from (Woodman and Palmer, 2013).*

coarse. In order to maintain the NNR for public access and future maintenance some a controlled amount of dead wood is moved off site and used/sold for firewood. Other dead wood is kept on site and used for structures throughout the forest such as signs and cattle fencing. Even with high levels of dead wood for an old growth forest locate din Britain, numbers are still being impacted by site management. A larger old growth forest in Slovenia for example experiences less intervention management, as well as larger areas of land that were uninfluenced by man; in turn yielding larger volumes of dead wood.

For all forty transect lines used within this survey a total of 499 intersects occurred. 126 intersections for study area 1, 125 for study area 2, 107 for study area 3a and 3b combined, and 141 intersects encountered in study area 4. Of these total intersects study are 1 encountered seven snags and eight stumps; study area 2 with seven snags and nine stumps; study area 3 had three snags and eleven stumps; 3b with six snags and three stums; finally with study area 4 encountering six snags and three stumps. A large group of low Diameter CWD explains why study area 4 contains the lowest volume of dead wood but contains the highest number of intersects. This is due to the number of fallen trees encountered in study area 4. When the transect-line ran over the crown of a wind-blown tree, specifically birch, multiple recordings of smaller Diameter CWD occurred.

Line-intersect sampling is said to overestimate snag and log volume measurements due to the complex structures snags normally present and short length accompanied by stumps. Even with snag and stump volume removed, Sherwood Forest NNR still produced a total average log volume of 71.21 m3/ha. When compared to the Old-Growth column in Britain and UK Forestry deadwood guidelines; Sherwood still provides an adequate amount of dead wood habitat. As mentioned before snags provide the most diverse deadwood habitat, while stumps provide habitat for some specialist species. Well dispersed amounts of dead wood amongst snags, stumps and logs spread throughout different diameter classes provides adequate habitat for saproxylic invertebrates. Diverse numbers prove consistent throughout study areas 1, 2, 3a, and 3b presenting ideal conditions for poor colonizing invertebrates such as the *Cryptocephalus coryli, a coleopteran* which can only be found in Sherwood within the United Kingdom.

As expected study area 3b produced more deadwood volume than 3a which can be explained by the large section of this area being cleared for public use and access around the Major oak. 3a produced a total average volume of 265.92 m^3/ha and 3b with 299.38 m^3/ha of total average volume. These numbers are high due to the fact that there was only 5 transect lines within each study area to provide the estimates. Study area 3b showed little signs of management for dead wood and received the majority of its volume from naturally occurring small diameter logs and stumps. Study area 3a did show signs of recent management, with stacked logs and snags that have occurred through management practices.

The significant differences produced by the Kruskal-Wallis tests for ancient oaks between study areas 1, 2, and three when compared to study area 4; as well as oak when comparing study areas 2 and 4 can be explained by the lack of snags encountered within study area 4. The low oak volume could possibly be due to the fact that only one small

area had been labeled for oak plantation implementation within the north-west corner of the study area. The low snag density that has arisen can be answered when looking George Sanderson 1835 map of Mansfield. Study area 4 appears to have been lacking tree density and even had sections that were once cleared for farming. Heavy sycamore growth also showed signs of out-competing other species for sunlight. Based on these results it appears that study area 4 has experienced past management practices that have led to a hybrid section of the NNR contain pockets of *Lythrum salicaria, Holcus molis, Pteridium aquilinum,* and *Rubus fruticosus* which when left un-managed prevent the growth of shade intolerant species. Study area 4 does contain some clusters of ancient oaks and snags; however they fall within the norther section of study area 4 near major park paths. Future plans for study area 4 described by Izi banton, are the continuation of sycamore eradication along with the introduction of hazel tree understory mixed in with the current oak population.

When using Kruskal-Wallis (KW), it is important to remember that the KW test does not directly compare the medians of the samples or directly compare the distributions of the samples. Instead, the KW test compares the sums of the ranks. The The KW test assumes that all samples come from the same type of distribution with only a difference in their central locations or the median. That might mean that all of the data sets being compared are skewed in the same way (i.e. skewed left or right). If all data sets share the same type of distribution, then the KW comparisons of the sums of the ranks are equivalent to a comparison of the medians. However, if your samples come from different types of distributions (e.g. some are left skewed, some are symmetric or right-skewed), then the KW test can be very difficult to interpret. This is due to the fact that a significant difference in the sums of the ranks may not imply anything meaningful about the differences in medians. This explains why it is possible to receive a significant P-value of $\leq .05$ when testing all data groups at once; yet receiving no significant P-Values when running tests between the individual study areas. This occurred for rot volumes, which provided no significant differences between any of the study areas when tested separately.

Within the dead wood results large volumes for higher diameter classes is not due to a high number of intersections, but the volume produced due to the sheer size of the dead wood piece from the (Harmon and Sexton, 1996), (Van Wagner, 1968), and (Brown, 1974) formula. Also dead wood labeled as unidentified was the result of high decay, preventing any identification of the dead wood piece and were accompanied by a rot classification of 5.

Stacked dead wood was very common and observed regularly throughout this study, especially within study areas 1 and 2. For this reason deadwood was also recorded as being stacked and non-stacked. However, random line-transect sampling did not intersect with many dead wood piles. Of the total average volume 211.17 m3/ha for the NNR, 200.69 m3/ha was recorded as random with the remaining 10.49 m3/ha as stacked. Snag and stump volume were counted as random for they are technically still randomly placed even if some may have been planted in the past. This explains the large volume of random wood. Stacked wood appeared frequently in sections throughout the NNR. For instance in Study area 1 is a man made “Luxury Home” (Log Pile) found within the centre of the study area sitting roughly ten metres off a major walking path surrounded by tall grass and heath vegetation. Smaller log piles can be found on either side of the “Luxury Home (Log Pile) spacing roughly twenty to thirty metres apart.

This log pile was composed completely of felled birch; the smaller scattered piles were composed completely of felled birch as well. None of the ten transects within study



Figure 42: A*bove shows from left to right smaller individual log piles on the west side of the “Luxury Home (Log Pile), middle is the “Luxury Home” (Log Pile) found in study area 1, and on the right is one of the informative signs found along the “Luxury Home” (Log Pile). Pictures by: Tyler Wilcox, May 2015*

area 1 came into contact with the “Luxury Home (Log Pile). If this structure were to have intersected with any of the ten transect lines, total average dead wood volume for study area 1 and even the total average for the entire NNR would have significantly risen; as well as the overall volume of stacked wood. A detailed study of this particular structure could prove extremely beneficial over time for observing invertebrate diversity. A quick fact to make note of is how Sherwood Forest NNR is incorporating dead wood with educational signs such as the one in **Visual 42** to help the public accept and appreciate the “untidy” look that comes with deadwood.

There were a lack of seedlings and saplings ovserved within Study areas 4 and 3b; which can be explained by the extreme over growth of bracken and bramble, most likely over shading and out-competing the slower growing saplings. Both graze sites had a significantly greater amount of exposed forest floor that allowed seedlings and saplings to be exposed to sunlight. This could be a combination of the grazing impacts as well as ground vegetation that was observed throughout the different study areas. Study area 4 contains the highest density of sycamore trees, which can be compared to the 1970's map of the sycamore eradication plan. Rowan trees were found in pockets within study areas 3a and 3b. These trees are a pioneer species known for their resilience; and appears to be taking advantage of space that other more sensitive species cannot. Study area 4 receives some of the heaviest activity from visitors as it contains one of the main entrances near the car park as well as a horse pass. There are multiple make shift trails as well as a very diverse selection of oak, hawthorn, sycamore, hazel, scots pine, rowan, and birch trees; accompanied by diverse patches of ground vegetation and flora compared to the other study areas. There was a significantly greater abundance of live holly which flourished in study area 1 and 2. Study area one and two provided the largest sections of *Deschampsia flexuosa* , while *Pteridium aquilinum* was seen abundantly throughout the entire forest. Within sections 1 and 2 birch appeared more abundant in the northern sections of the study areas, with oak stand becoming denser heading south. This pattern can be explained by the lack of oak plantations in the past, allowing stands of birch to grow. Overall future generations of deadwood appear abundant thanks to a large number of live ancient and veteran oaks as well as a high density of birch to provide quick short term, fast rotting deadwood.

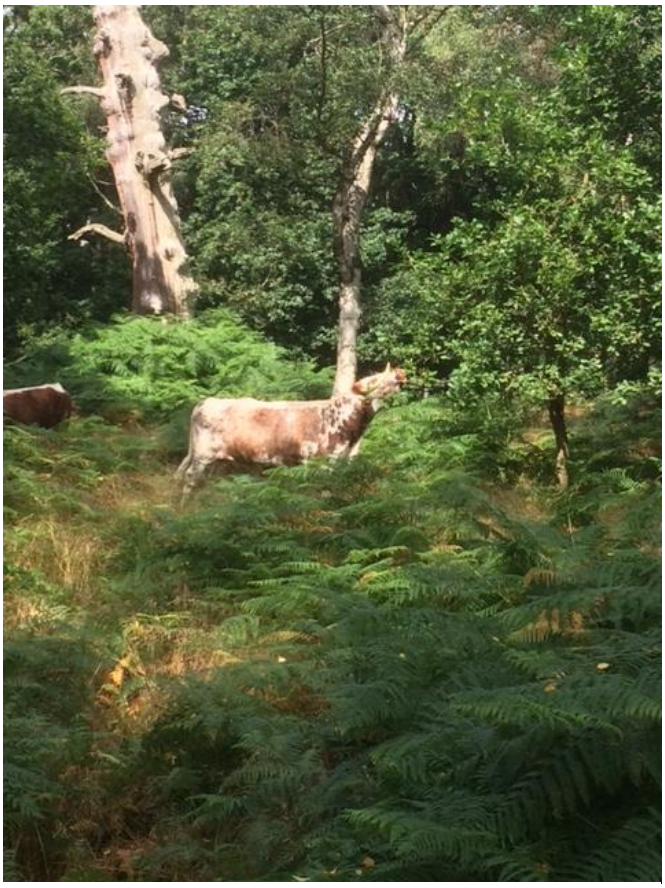


Figure 43: *Above is an English Longhorn grazing on a younger generation oak within study area 2. Photo by: Charles Watkins, August 2015.*

Comparison of the three maps provided in **Figures 1, 4 and 5** provides a timeline to help comprehend how the area of Birklands has changed and developed into present

day Sherwood Forest NNR. Study area 4 appears to be lacking its southern half in the 1835 map compared to the 1975-86 and 2015. This helps understand why study area 4 is lacking dead wood volume; for it most likely is a new growth section of Sherwood. Study area 2 in the 2015 Edina Digi map shows denser tree stands compared to study area 2 in 1835; and also showed less activity with the introduction of oak plantations win the 1975-86 oak regeneration map. Thus, explaining the lower log and snag volumes. The tree stands located in the north-eastern section of study area 1 yields higher birch than oak and is less dense than the rest of the study area which also fits the 1835 map descriptions.

Overall haloing of the ancient oaks produced mostly positive responses from the trees if complete haloing was done before structural failure and crown retrenchment resulted in major permanent damage to the tree. Proof of the haloing technique was easy to confirm by spotting clean cut stumps and dead wood stacked within the immediate area. Comparison of species recommended for felling in the 2006 survey to species of felled tree stumps assisted in confirming haloing management. Another benefit to the haloing practice is the introduction of immediate dead wood. Prescribed cutting helps to reintroduce significant amounts of dead wood while reducing stress on veteran and ancient trees. Logs produced as a result of this management practice was commonly stacked, sometimes at the base of the tree being haloed. When assessing ancient trees it is important to remember that trees of this generation have begun their natural process of decline. When determining whether or not haloing is providing beneficial results, relying on overall health, structural condition, and sustainability may not prove adequate. Rather, compare the trees current appearance and status to previous mentions of the tree. A possible study for the future would be to survey whether or not these stacks harbor invertebrates that might accelerate the decay process of the trees being haloed for extended life.

Izi Banton was concerned about the longevity of the ancient oaks, as well as a generation gap between veteran and ancient oaks within the parks. The next generation of oak does not show promise for succession into the ancient oak generation. Izi predicts that the reaming live ancient oaks have roughly another fifty years of life left in them, with some exceptions showing promise of another two-hundred years. Izi mentioned special interest in genetic testing of the veteran oaks to help understand why they are not advancing into the ancient generation. Dead wood however, has not been affected by this generation gap (Banton, 2015).

Some difficulties did occur during the data collection process of this survey. The accelerated growth of *Urtica dioica,* and *Pteridium aquilinum*, and *Rubus fruticosus* made access to transect-line locations difficult primarily within all study areas. Once the line was laid out there was no problem spotting CWD that intersected the line. For future surveying, it would be more time efficient to perform the dead wood assessment in early spring or even late winter where ground vegetation does not affect accessibility. Bird nesting was also a factor when lying out transect lines; caution was used when laying lines which did slow down efficiency; especially in study area 3b. Study area 2 also produced a natural inconvenience due to Fox monitoring. Within study area 2 transect line number 5 needed to be remarked as its original coordinates ran directly over the Fox den. While surveying ancient oaks 24, 25, and 27, caution was taken to not interfere with monitoring cameras or the Fox den itself. There was also a mix up with tag numbers not matching up on the ancient oak that is labeled as #10368 which was labeled as # 10365. Conformation of the tree was made by matching coordinates and the 1996 tag number. It is recommended that during the next phase of surveying and tagging that the 2006 tags be double checked; the 1996 have considerable rusting and deterioration making them hard to read if not at all and will not be of use for situations such as this one in the near future.

Future interests will be in the succession of the parks area where the visitors centre and parking lot will be removed. A consortium led by the RSPB – the Royal Society for the Protection of Birds – has been named as the preferred bidder to design, build and operate a new visitor centre and to manage the “stunning” natural habitats within Robin Hood’s Sherwood Forest Country Park. The new visitors centre will most likely be moved further into the town of Edwinstowe; while the area previously occupied by the visitor centre and car park will be left for natural regeneration. It is possible to see a trend of succession form that is currently taking place within study area 4.

Sherwood Forest NNR would greatly benefit from plot surveying for dead wood habitat in the future. Plot surveying is ideal for providing more precise estimates for the distorted and sometimes hollow ancient oak snags found regularly throughout the NNR. Considering that snag and stump volume produced approximately 60 percent of the reserve’s deadwood it would be greatly beneficial to produce results that take into consideration the length and dimensions of these invaluable micro habitats.

7. Conclusion

Overall Sherwood Forest provides a variety of dead wood habitats with a large range of different diameters, rot classes, and species abundancy. The combination of ancient oaks, birch, and oaks with the assistance of ongoing management and succession

of the oak plantations is why the dead wood habitat is so varied. Birch provides the forest with a high number of logs and faster rotting wood with smaller diameter pieces. Ancient oaks provide larger long term pieces of dead wood and a high number of snag density and snag volume. The surrounding oak plantations allow for felling in order to fill gaps of larger diameter classes and slower rotting wood, while also ensuring a future ancient oak and snag population. Thanks to these three main types of deadwood the generation gap found in many forests in Britain due to previous practices, is not present within Sherwood Forest NNR. Management practices such as grazing within study areas 1 and 2 exposes soil allowing shade intolerant species such as oak to grow from acorns for future generations; as well as allowing for other underlying vegetation to sprout for improved biodiversity. Having a variety of underlay vegetation and deciduous diversity provides a plethora of potential deadwood habitats throughout them with different stages of succession allowing for high levels of future diversity amongst the NNR.

Though haloing being used as a conservation method is widely known and practiced, there have not been many studies on the long term responses to this method. Based off the results found during this survey, ancient oaks are for the majority, responding positively to the management practice of haloing. There is no clear cut way to determine whether or not a tree is responding to this method because every person will have their own opinion of how a tree is responding, even with the assistance of guidelines and previous work. Detailed notes and records can help provide a timeline in order to provide concreate evidence and results. A photo log can help do this; even though it may seem like a simple procedure, a picture timeline can provide the basis for accurate discussion and debate in determining what management strategies are best not only for a current tree, but future trees of specific interest as well. This is the first dead wood and ancient oak haloing assessment conducted for Sherwood Forest NNR, with the hopes of providing information that may assist in future management plans for the NNR. Haloing of ancient oaks proves as an effective management practice for preserving, if not enabling regeneration and new growth when introduced effectively. Based off information provided by site manager Izi Banton; the oak plantations although a good source of dead wood, present themselves as a nuisance. Since the oak regeneration plan, attention has shifted to thinning the NNR in an attempt to restore once abundant native heathland and grassland throughout the ancient woodland. Thinning as well as a generation gap concern between veteran and ancient oaks within the park naturally places emphasis on maintaining these ancient trees.

Future management plans for the park include rolling, cutting, chemical spraying and grazing in order to push back the bracken and bramble. Thinning of oak plantations

and canopy cover will also be implemented in order to restore native heathland and eventually create an ancient wood pasture system. This plan is in fact the complete opposite of what Sherwood Forest NNR was aiming for just thirty years ago as seen with the oak regeneration plan. Izi is also hoping to incorporate a new form of grazing management; by introducing a large population of grazing mammals into the grazing areas; hitting the areas hard over a. shorter period of time. This management practice is being considered because of an overgrowth of moss interfering with more valued heathland species by the effects of longer grazing periods with smaller populations of grazing mammals. The over abundancy of young generation oaks created by the oak regeneration plan allows room for the thinning process without hindering dead wood habitat quality. Sherwood Forest, one of Britain's only reaming ancient woodlands holds its titles as a National Nature Reserve and Site of Special Scientific Interest with an overwhelming array of biodiversity and large ancient oak population. No surprise to Izi, Sherwood contains a well distributed, healthy amount of dead wood habitat of great diversity which is the basis for providing Sherwood's high levels of biodiversity.

8. Acknowledgements

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Izi Banton for permission to carry out this project and providing useful documents and previous data that made this assessment possible.