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Understanding the Semi-Natural Woodland Diversity at Dunsany Estate, County Meath and Developing a Framework for Future Studies

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Abstract

The cover of forest and semi-natural woodland in Ireland is 11% and 2% respectively. In order to protect and manage woodlands, detailed studies on their structure, dynamics and diversity are required. The site selected for this study was Dunsany estate in County Meath because the landowner, Randal Plunkett asked us to get involved in order to setup baselines, study and survey the fragments of old woodlands and plantations and because it was being rewilded. This study explored sapling regeneration, structure and composition, seedling diversity, number and herbivory in seven semi-natural woodland and three plantation sites at the estate. Thirty-one 10x10 m plots were randomly set up at the ten sites. Stand structure was estimated for all trees with a Diameter at Breast Height (DBH) more than 7 cm. Sapling regeneration (for individuals with DBH <7 cm and height >25 cm) was assessed by categorizing them into four size classes (25-100 cm, 100-200 cm, 200-400 cm and 400+ cm) while seedling diversity and numbers (for individuals <25 cm height) were estimated using five 2x2 m quadrats positioned inside all 10x10 m plots. The thirty-one plots were consolidated into six groups created on the basis of *Rubus*, herb, bare ground, grass, canopy cover and tree species such as *F. excelsior, A. pseudoplatanus, F. sylvatica* etc, using a combination of NMS ordination and cluster analysis. It was found that woodlands had a higher tree, seedling and ground flora diversity compared to plantations. Lower canopy cover, better seed dispersal and seed source as well as no management over a very long time may have contributed to this high diversity. The highest number of seedlings at the estate were recorded for ash and sycamore while highest number of regenerating saplings were recorded for ash in 25-100 cm class, and sycamore in the next three size classes. These two species resist herbivory, grow well under shade and on a variety of soils which probably explained the high numbers. The ash seedlings showed a positive relationship with canopy cover and herbivory while beech seedlings showed a negative relationship with *Rubus* cover and herbivory. It was concluded that increasing canopy and *Rubus* cover may have resulted in an increase in regeneration in the smaller size class. On the other hand, a drop in regeneration in 100-200 cm and 200-400 cm classes was recorded with increasing herbivory. A number of elm seedlings and saplings and yew seedlings were recorded indicating moderate regeneration for the two species that are uncommon in Meath. Species diversity can be improved in plantations by regular thinning of trees, creating small gaps within them so that more light reaches the understory and an availability of a seed source. This initial study forms a baseline for future research in this rewilding project.

Key Words:

1) Semi-natural woodland

2) Plantation

3) Seedling Diversity

4) Herbivory

5) Woodland Regeneration

6) Rewilding

Contents

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Chapter 1

Introduction

1.1 Background

One of the least forested countries in Europe is Ireland. Approximately 11% of its area is covered by forests, 65.5% of which are conifer forests, 20.5% are broadleaved forests and 14% are mixed forests (Department of Agriculture, Food and the Marine, 2020). Semi-natural or native woodlands cover only 2% of Irelands area, which are mostly fragmented and have been transformed to various extents due to human interference and intervention (Perrin *et al.,* 2008).

Ireland is located in the temperate deciduous forest biome and 80% of its land was covered with forests and deciduous woodlands for millennia (Agriculture and Food Development Authority, 2017). But with human interference, the woodland cover reduced quickly to just 1% in the early 20th century. The woodlands that have survived are mostly because of their location which is typically in areas of nutrient-poor soils that cannot be farmed or are within larger estates protected by landowners as they are good hunting sites (Perrin *et al*., 2008). 60% of the semi-natural woodlands are owned by private landowners (Forest Service, 2007). Examples of such woodlands are the Hazel (*Corylus avellana* L.) woodland in the Burren in County Clare, Oak (*Quercus* sp) woodlands in Killarney National Park in County Kerry (Perrin *et al*., 2011), Glen of the Downs in County Wicklow (Rackham, 1987) etc and yew (*Taxus baccata* L.) woodlands in Aughnanure in County Galway (Brian, 2020) and Reenadinna Wood in Killarney National Park, County Kerry (Perrin, 2002).

Any area dominated by trees with an open and well-defined canopy height of 5 m or more is known as a woodland. Areas dominated by shrubs, bramble (*Rubus fruticosus* L. agg.), dwarf and immature trees eg sessile oak (*Quercus petraea* (Matt.) Liebl.), birches (*Betula* spp.), Hazel etc with a canopy height of less than 5 m are called scrub woodlands (Cross *et al*., 2010). In order to be classified as a semi-natural woodland, the area should be abundant with trees that are native with a well-developed underlying layer of vegetation and where timber and fallen trees are not systematically extracted. Tree communities that have grown from an old planting can be included only if they are naturally regenerating. The common native broadleaved trees found in Irish woodlands are oak (*Quercus petraea* and *Quercus robur* L.), ash (*Fraxinus excelsior* L.), birch (*Betula pendula* Roth and *Betula pubescens* L.), alder (*Alnus glutinosa* (L.) Gaertn), wych elm (*Ulmus glabra* Huds.), hazel and the common non-native broadleaves are Beech (*Fagus sylvatica* L.), Sycamore (*Acer pseudoplatanus* L.), Horse chestnut (*Aesculus hippocastanum* L.), Spanish chestnut (*Castanea sativa* L.) and Hornbeam (*Carpinus betulus* L.) (Perrin *et al*., 2008). The only native conifers growing in the semi-natural woodlands are Yew, Scots pine (*Pinus sylvestris* L.) and Juniper (*Juniperus communis* L.*)* (Cross *et al*., 2010).

According to Cross *et al.* (2010) there are five major types of semi-natural woodlands (based on the best indicator species) in Ireland, each with its respective sub-types (based on the two best vascular indicator species) as shown in Table 1.1. These woodlands differ on the basis of tree species, understory, soil type and ground flora.

Table 1.1: Types of Semi-natural woodlands in Ireland

	Type	**Occurrence**	**Tree Species and Understory**	**Ground Flora**
1	Sessile oak – woodrush (*Quercus petraea – Luzula sylvatica*)	On acidic (pH close to 4.5), well-drained mineral soils such as podzols, in upland areas, hillsides or valley sides.	Tree Species: Sessile Oak *(Quercus petraea),* Pedunculate Oak (*Quercus robur*) or their hybrid (*Q. x rosacea*) are dominant species while Downy Birch *(Betula pubescens)* and Rowan *(Sorbus aucuparia)* occur frequently. Understory: Holly (*Illex aquifolium*) and *Rhododendron*	Ling heather *(Calluna vulgaris)*, Bilberry *(Vaccinium myrtillus)*, hard fern (*Blechnum spicant*), common polypody (*Polypodium vulgare*), Bracken *(Pteridium aquilinum)*, Great Wood-rush *(Luzula sylvatica)*, Honeysuckle (*Lonicera periclymenum*) and ivy (*Hedera helix*)

			ponticum are abundant.	
Sub-types				
1.1	Bilberry-holly (*Vaccinium myrtillus – Ilex aquifolium*)			
1.2	Woodrush – broad buckler fern (*Luzula sylvatica – Dryopteris dilatata*)			
1.3	Bramble-Hazel (*Rubus fruticosus agg. – Corylus avellana*)			
2	Ash – Ivy (*Fraxinus excelsior – Hedera helix)*	On dry or moist, fertile, base-rich, mineral soils, in the lowlands (pH 5.9).	Tree Species*:* Ash and Pedunculate Oak are dominant. Birch, rowan, wych elm (*Ulmus glabra*) beech and sycamore occur occasionally. Understorey: Hazel is most common. Hawthorn, holly, blackthorn (*Prunus spinosa*), cherry laurel (*Prunus laurocerasus*) occur frequently.	Bramble, honeysuckle, ivy, wood avens, wood sorrel, wood speedwell (*Veronica montana*), barren strawberry, true strawberry (*Fragaria vesca*), wood-brome (*Brachypodium sylvaticum*), wild arum (*Arum maculatum*), wood sanicle (*Sanicula europaea*) and enchanter's nightshade.
Sub-types				
2.1	Wood avens – wood speedwell (*Geum urbanum – Veronica montana*)			
2.2	Pedunculate oak – bramble (*Quercus robur – Rubus fruticosus*)			
2.3	Hazel – wood sorrel (Corylus avellana – Oxalis acetosella)			
2.4	Holly – Rowan (*Ilex aquifolium – Sorbus aucuparia*)			
2.5	Beech – cherry laurel (*Fagus sylvatica – Prunus laurocerasus*)			
2.6	Sycamore – hawthorn (*Acer pseudoplatanus – Crataegus monogyna*)			
2.7	Yew-carnation sedge (*Taxus baccata – Carex flacca*) - Very rare			

3	Alder-meadowsweet (*Alnus glutinosa – Filipendula ulmaria*)	On poorly drained gleys, flushes, stream and river margins, lake-shores, and water-logged hollows (pH 6.2)	Tree Species: Alder is dominant. Pedunculate oak, ash occur frequently and downy birch is occasional. Understorey: Grey willow (*Salix cinerea*) and ash are dominant. Holly, hazel, hawthorn, blackthorn occur frequently.	Meadowsweet (*Filipendula ulmaria*), remote sedge (Carex remota), marsh bedstraw (*Galium palustre*), angelica (*Angelica sylvestris)*, creeping buttercup (*Ranunculus repens*), water mint (*Mentha aquatica*) and yellow flag (*Iris pseudacorus*).
	Sub-types			
3.1	Ash – remote sedge (*Fraxinus excelsior – Carex remota*)			
3.2	Alder – bramble (*Alnus glutinosa – Rubus fruticosus*)			
3.3	Grey willow-water horsetail (*Salix cinerea – Equisetum fluviatile*)			
3.4	Hawthorn-herb-Robert (*Crataegus monogyna – Geranium robertianum*)			
3.5	Birch – water mint (*Betula pubescens – Mentha aquatica*) - Rare			
3.6	Alder – tussock sedge (*Alnus glutinosa - Carex paniculata*) - Rare			
3.7	Alder – giant horsetail (*Alnus glutinosa – Equisetum telmateia*) - Rare			
3.8	Almond willow-nettle (*Salix triandra – Urtica dioica*) - Rare			
4	Birch – purple moorgrass (*Betula pubescens – Molinia caerulea*)	On degraded or intact raised bogs and peaty hollows and on mineral soils (pH 4.6)	Tree Species: Downy birch and Scots pine are dominant. Understorey: Holly, hawthorn, hazel, rowan are common.	Purple moor-grass, bramble, broad buckler-fern and bracken.
Sub-types				
4.1	Bramble-broad buckler-fern (*Rubus fruticosus – Dryopteris dilatata*)			
4.2	Bilberry-woodrush (*Vaccinium myrtillus – Luzula sylvatica*)			

4.3	Yorkshire fog – bent grass (*Holcus lanatus – Agrostis capillaris*)			
4.4	Ivy – ash (*Hedera helix – Fraxinus excelsior*)			
4.5	Grey willow – marsh bedstraw (*Salix cinerea – Galium palustre*)			
4.6	Purple moor-grass – tormentil (*Molinia caerulea – Potentilla erecta*) - Rare			
5	Low woodland/scrub	On base-rich (pH > 6.5), dry acidic, fertile, calcareous and limestone soils.	Tree and Understorey species: Hazel, hawthorn, blackthorn, birch, willow and ash.	Bramble, ivy, bracken, wild rose (*Rosa spp*.), ling heather, bell heather (*Erica cinerea*).
Sub-types				
5.1	Blackthorn (*Prunus spinosa*) scrub			
5.2	Hazel (*Corylus avellana*) scrub			
5.3	Juniper (*Juniperus communis*) scrub - Rare			

Semi-natural woodlands in Ireland need some sort of management which could involve removal of the invasive alien species, for eg – rhododendron (*Rhododendron ponticum* L.), cherry laurel (*Prunus laurocerasus* L.) etc and keeping sheep (*Ovis* sp) and deer (*Cervus* sp) away by fencing etc which will improve the natural regeneration of these areas. Replanting or using the stock grown from seeds that have been collected locally will help in safeguarding the genetic diversity of the semi-natural woodlands (Brian, 2020).

These woodlands are also important educationally, as they enable people to learn about Irish woodland diversity, flora and fauna. They also play an important role in the production of hardwoods. Many semi-natural woodlands are located near or inside National Parks and are managed by National Parks and Wildlife Service (NPWS) such as Glenveagh National Park in County Donegal and the Killarney National Park in County Kerry (Brian, 2020). They harbor a diverse amount of climax flora and fauna. So, it is crucial that studies are conducted on rewilding, regeneration, dynamics and diversity of tree and shrub species that make up these communities and furthering the spread of native species.

1.2 Regeneration

The development of new trees and shrubs from seeds dispersed naturally (by birds, wind, water etc) on the site is called natural regeneration (Department of Agriculture, Fisheries and Food, 2007). It is favourable over planting as it results in the preservation of genetic diversity and puts less pressure on the planting stock which is usually limited. But whether regeneration will take place on a particular site is not easy to predict (Forest Service, Department of Agriculture, Food and the Marine, 2015) as it may or may not replace the woodland community by the same or similar community (Ward and Parker, 1989). The main factors which result in natural regeneration are sufficient supply of seeds, ample sunlight, adequate grazing pressure on the ground layer as these increase the chances of seed germination (Cross and Collins, 2017).

Most Irish species excluding Holly (*Ilex aquifolium* L.) require a large amount of light for their development (Higgins, 2001). As a result, their regeneration occurs under gaps in high canopy and clearings. The light reaching the woodland ground depends on the tree canopy and field layer. Holly, hazel and yew are dense trees and cast a large amount of shade while trees like ash and birch cast a much lighter shade (Cross and Collins, 2017). If there is no regeneration in a woodland, it is implied that the amount of light reaching the ground is poor. In some woodlands, regeneration doesn't occur even if the level of sunlight is adequate. The reason could be over or under-grazing, high consumption of seeds by birds and animals or an increase in invasive species like cherry laurel (Cross and Collins, 2017). Invasive species such as cherry laurel and rhododendron grow quickly and outcompete the native species for nutrients, sunlight and space.

Ash produces a large number of seeds (17,500 seedlings/ 100 m^2 in one case) (Perrin *et al.* 2008), but very few of these seedlings turn into mature saplings. It is able to survive even in the shade and can grow very quickly under good sunlight to create dense stands. Birch and alder (*Alnus glutinosa*) seedlings rarely grow under dense canopies and they can be found in abundance in open land and clearings. Oak on the other hand can be found in large numbers under dense canopies as its seeds store a large amount of nutrition and enable it to survive in unfavourable conditions (Cross and Collins, 2017). The oak seedlings dont survive for long unless the canopy is cleared and increased bramble, bracken (*Pteridium aquilinum*) growth also negatively affects the development of its seedlings (Harmer and Morgan, 2007).

This calls for proper management of the tree canopy so that the tree seedlings are able to receive sunlight. A very small opening in the canopy may result in the eventual death of seedlings and if the opening is large, other species like bramble, rhododendron will increase in number which could also inhibit seedling growth (Cross and Collins, 2017). At sites where natural regeneration of Irish trees cannot be predicted, planting other native species can be undertaken. This will continue the process of regeneration and enable sufficient number of individuals to spread within a particular area (Cross and Collins, 2017).

1.3 Herbivory in Woodlands

Grazers are a common and natural part of semi-natural woodlands. Their activities such as browsing, grazing, wallowing, bark stripping, consumption of seeds and affecting their dispersal, can alter and affect the regeneration of trees and vegetation of woodlands (Putman, 1994). Such effects can be seen in woodlands where the number of grazers is very high and it often later results in a higher number of plants that are tolerant to herbivory (Gill, 1992a). The abundance of plants like bracken, woodrush (*Lazula* sp) and some grasses increased significantly in areas with high herbivory compared to ivy (*Hedera helix* L.), bramble etc which were absent because they were intolerant to herbivory (Putman, 1994; Perrin *et.al*., 2011).

Grazers do not prefer mosses, so woodlands that are grazed often provide excellent moss habitats. If the woodlands are not grazed, mosses may not be able to develop or survive because of high amounts of shade (Mitchell and Kirby,1990). Herbivory enables competitors to co-exist and increase biodiversity by controlling the aggressive species (Kelly, 2000). It also helps in promoting gaps and clearings which can increase the sunlight reaching the understory (Putman, 1994).

If the frequency of herbivory is very high, tree regeneration in semi-natural woodlands can be affected significantly. The continuous biting of seedlings can lead to low to no saplings at all in an area and woodlands like these also lack a fully developed shrub layer (Mitchell and Kirby, 1990). Deer may be very selective as to what species to browse and which to avoid and their grazing preferences can also be affected by the availability of food (Gill, 1992a). It was found by Gill (1992a) that roe deer (*Capreolus capreolus* L.) preferred eating silver birch (*Betula pendula*), but when rowan (*Sorbus aucuparia* L.) and ash were abundant, silver birch was avoided. Such selective grazing of one or more species over the other can affect the species which was preferred earlier (silver birch) and its sapling numbers in a woodland. The pattern of regeneration is also affected by herbivory as deer are not well protected in low cover areas. They favour higher altitudes and prefer not to take paths and tracks in woodlands (Perrin *et.al*., 2008) which could lead to confinement of tree saplings in such areas. Herbivory by hares was higher in gaps and clearings or low canopy areas compared to areas of dense canopy (Rackham, 1980).

The sapling response to herbivory usually varies with different species and how serious herbivory actually is. Saplings of ash were found to be highly tolerant of continuous herbivory and were able to replace shoot and leaf tissue approximately four times in one season as opposed to oak saplings which were intolerant and could not renew their shoot tissues once browsed (Mitchell *et al*., 1995). If herbivory is removed from a woodland, tree regeneration can be significantly affected. It leads to an initial increase in the growth of seedlings and saplings which were able to survive the first phase of herbivory and these can quickly reach tall heights (Peterken, 1996). But such increased growth of the ground flora can also be affected if grazers return (Pigott, 1983).

Regeneration is adversely affected due to overgrazing by deer and at times sheep. The semi-natural woodlands in Ireland are grazed and browsed by red (*Cervus elaphus* L.), sika (*Cervus nippon* L.) and fallow deer (*Dama dama* L.). The expansion of fallow deer is highly localized as compared to Red, sika and sika-red hybrid deer and this expansion is also associated with deer escaping from deer farms and their numbers have become high, near and within National Parks (Higgins, 2001). Rabbits (*Oryctolagus* sp), Irish hares (*Lepus timidus hibernicus*) also graze woodlands but not as severely as goats and deer while cattle, especially in lower altitudes (80m) are the most frequent grazers (Perrin *et.al*., 2008).

1.3.1 Controlling herbivory

One of the best ways to control herbivory is fencing. Alternatives like pocket exclosures, dead hedging which makes use of brash are also used to minimize herbivory and such methods can work if the area which has to be protected is small (Cross and Collins, 2017). Larger sites need active management to control herbivory. One of the main ways to control herbivores in the larger sites is culling which leads to healthy, well-regulated populations of deer that can co-exist with the semi-natural woodland flora and fauna. Culling should be conducted regularly to maintain deer populations. Their population has to be better understood for efficient culling so that the correct number and species of deer are removed (Cross and Collins, 2017).

1.4 Rewilding

Rewilding focuses on managing ecological succession, restoring ecosystem processes and reducing the human control of natural landscapes (Gillson *et a*l., 2011). It ensures that nature evolves naturally, as it would have without any human interference (Pereira and Navarro, 2015) and prioritizes on creating ecosystems that can sustain themselves (Cramer *et al*., 2008). The new ecosystems created as a result of rewilding could be similar to the older ecosystems, but they will most probably include some new biotic components which may have been introduced (Hobbs *et al.,* 2009).

There are plans by the NPWS to create a rewilding project in Nephin Beg mountains in County Mayo, Ireland. 4400 ha of commercial Coillte land will be used to rewild the Ballycroy National Park. This involves cutting conifers and replanting with rowan (*Sorbus* sp) and birch which are natives to increase biodiversity. The goal of the 15 year project is to naturalise native plantations and it will also restore bogs and create clearings to let more sunlight in for the plants growing in the field and ground layers (Filgueiras, 2018). Dunsany estate in County Meath is another example of a site in Ireland that has been rewilded (for nine years).

1.5 County Meath

County Meath is located in the eastern part of Ireland and has an elevation of 85 m above sea level. Dublin is located towards the eastern side of Meath while it is bounded on the south by County Kildare and Offaly. County Westmeath is located on its west and counties Cavan, Monaghan and Louth on the north (Meath County Council, 2015). The Boyne is the largest river in Meath and runs through areas that are designated as Special Protection Areas (SPA) and Special Areas of Conservation (SAC) as well as undesignated areas. The important lakes that occur in Meath are White Lough, Ben Loughs and Lough Doo and some bogs on its western side like the Moneybeg raised bog (Meath County Council, 2015). It has a low-lying topography and ranges from large pastures which are found in the Boyne and Blackwater river valleys and Drumlin hills located in the north. In the Southwest section of Meath, there are peatlands and areas of raised bogs and a 12 km coastline in the east (Meath County Council, 2020).

According to Koppen climate classification, County Meath experiences a marine west coast climate and comes under the Cfb subtype with cool winters and mild humid summers (Rafferty *et* *al*., 2018). 93% of the land surface in Meath is covered by mineral soils and the rest 7% is covered by peat soils which occur on thick peats (Meath County Council, 2015).

County Meath is the least forested county in Ireland, but before 3500 BC it was entirely covered with forests and mixed woodlands (Meath County Council, 2015). 3.22% (7521 ha) of Meath's area is covered by forests, large estates, modified and semi-natural woodlands compared to the national average of 11.01 % and the total woodland area of County Meath is 3850 ha (Perrin *et al*., 2008). The low woodland cover is because most of the land has been used for agriculture. The agricultural land use in Meath exceeded land use for forests and woodlands due to legal restrictions set up by wealthy landowners in the twentieth century to increase yields from tillage, cattle and crops. It has led to most of the woodlands occurring in small fragments on nutrient-deficient soil or places where agriculture is not possible, such as peatlands, steep slopes etc (Meath County Council, 2015).

Most of the woodland plant species in Meath are woodland specialists that are able to survive in low light and high humidity. The field layer of semi-natural woodlands is at times dominated by invasive and alien shrubs. Some of these invasive shrubs were originally planted in nearby gardens which later spread into the woodlands or directly planted into woodlands to provide game cover (Meath County Council, 2015). The common invasive non-native shrubs are cherry laurel and rhododendron which can easily cover large woodland areas and block all the sunlight reaching the ground layer, significantly inhibiting regeneration (Smith *et al*., 2011). Many woodlands in Ireland and Meath occur in fragments, as pockets of plantations or along demesne margins. A matrix of hedgerows can be found on the borders of these woodlands which at times act as important conduits, especially when woodlands are located close by (Perrin *et al*., 2008).

Perrin *et al*. (2008) have classified semi-natural woodlands based on a main group and vegetation types. Semi-natural woodlands with the following vegetation and stand types are found in County Meath:

Table 1.2: Semi-natural woodlands found in County Meath.
The woodlands differ on the basis of tree, field and ground layer species and the soil types that they are found on.

	Main Group	Vegetation Type	Occurrence	Tree Species	Field and Ground Layer Species
1	Birch *(Betula pubescens)* – Purple Moor Grass *(Molinia caerulea)*	European Blueberry *(Vaccinium myrtillus) – Wood rush (Luzula sylvatica)*	acidic soils with high organic content, peatlands.	*Birch, Sessile Oak* (*Quercus petraea*), Rowan *(Sorbus aucuparia) and* Holly (*Ilex aquifolium)*	European Blueberry Wood rush, Bramble, Tamarisk moss *(Thuidium tamariscinum)*
2	Ash *(Fraxinus excelsior)* – Ivy *(Hedera helix)*	Sycamore maple *(Acer pseudoplatanus)* – Hawthorn *(Crataegus monogyna)*	well-drained, deep, fertile and base-rich soils	Ash and Sycamore Maple	Ivy, Broad buckler fern *(Dryopteris dilatate)*, Soft shield fern (*Polystichum setiferum)*
3	*Ash (Fraxinus excelsior) – Ivy (Hedera helix)*	Beech *(Fagus sylvatica)* – Cherry laurel *(Prunus laurocerasus)*	well-drained, base-rich mineral soils	Beech, Ash, Pedunculate Oak *(Quercus robur)*	Ivy, bramble, Broad buckler fern, honeysuckle *(Lonicera periclymenum)*.
4	Ash *(Fraxinus excelsior)* – Ivy *(Hedera helix)*	Willow *(Salix triandra)* – Nettle *(Urtica dioica)*	River banks with gleyed & base-rich, highly fertile soils	Non-native Willows – Almond Willow *(Salix triandra),* Basket Willow *(S. viminalis),* White Willow *(S. Alba)* and Brittle Willow (*S. fragilis)*.	Nettle, Hedge bindeweed *(Calystegia sepium),* Red canary grass *(Phalaris arundinacea) etc.*

5	Alder *(Alnus glutinosa)* – Meadowseet *(Filipendula ulmaria)*	Ash *(Fraxinus excelsior)* – Sedge *(Carex remota)*	Waterlogged areas with base-rich, fertile & gleyed soils	Ash, Alder, Native Willow (*Salix cinereal)*	Bramble and Meadowsweet, Remote sedge, Lady fern *(Athyrium filix-femina),* Creeping buttercup*(Ranunculus repens)*
6	Alder *(Alnus glutinosa)* – Meadowsweet *(Filipendula ulmaria)*	Alder *(Alnus glutinosa)* – Bramble *(Rubus fruticosus)*	Waterlogged areas with base-rich, fertile gleys/ fen peats	Alder, Native Willow	Bramble, Ivy, *Agrostis stolonifera,* Meadowsweet

The site selected for this study was Dunsany estate in Co Meath because the landowner, Randal Plunkett asked us to get involved in order to set up baselines, study and survey the fragments of old woodlands and plantations that were probably not as disturbed as other semi-natural woodlands in the country. Studying these woodlands may provide an important insight into their flora and fauna.

1.6 Dunsany Estate

Dunsany estate has an area of 1600 acres. Dunsany Castle was built in 1180 by Hugh de Lacy who also commissioned the Killeen and Trim Castle (Dooley, 2001). The estate is currently home to the Plunketts, whose ancestors were the Cusack family (Ferres, 2018). Randall Plunkett's (current and 21st Lord of Dunsany) primary focus is on rewilding and out of the 1600 acres, 750 acres of land is now being rewilded (Rewilding Europe, 2020). He also plans to convert part of the estate into a wildlife reserve with limited intervention as this will allow flora and fauna to live for many years to come without any human intervention (Gabardi, 2019).

Another important reason as to why the site selected for study was Dunsany estate was because the effects of rewilding could be observed in greater detail here. It is also the only site in Ireland that is officially recognized by The European Rewilding Network (Rewilding Europe, 2020). There is no mass cutting at Dunsany and at times the weaker trees are pruned so that healthy trees can grow. The plantations and grasslands at the estate have been rewilded for eight and seven years respectively while the forests have been left undisturbed for a very long time. This has resulted in an increase in the number of hares (*Lepus timidus hibernicus*), pine martens (Martes martes), otters (*Lutra lutra*) and foxes (*Vulpes vulpes*) (Rewilding Europe, 2020). There are also plans to introduce red squirrels (*Sciurus vulgaris*).

Dunsany estate contains soils of Dunboyne, Ashbourne and Dunsany series (Finch *et al*., 1983). The Dunsany soil series is a poorly drained gley and its texture is characterized by a dark brown surface of clay and loam. Dunboyne soils are deep and well-drained and have medium to high base status. Their texture is loam to clay loam. Ashbourne soils are poorly drained with a clay loam to silt clay loam texture (Finch *et al*., 1983). The estate is now home to kestrels (*Falco tinnuculus*), buzzards (*Buteo buteo*), great spotted woodpecker (*Dendrocopos major*), wood pigeons (*Columba palumbus*), hooded crows (*Corvus cornix*), swallows (*Hirundo rustica*), Eurasian jays (*Garrulus glandarius*), while barn owls (*Tyto alba*) and jack snipe (*Lymnocryptes minimus*) have also returned (Rewilding Europe, 2020). Another reason for this increase in plants and animal species is the fact the there is hardly any pollution in the estate. Chemicals and fertilizers were previously used on the estate for farming but now, no chemicals or any pesticides are allowed to be used (Gabardi, 2019).

1.7 Aim, Objectives and Research Questions

The natural regeneration, seedling diversity, effects of herbivory and woodland structure and composition haven't been previously studied and evaluated at Dunsany estate. Therefore, this study investigated and developed a framework for subsequent analysis on the structure and composition, role of herbivory, regeneration of saplings and seedling diversity and number for a total of ten sites comprising seven semi-natural woodlands and three plantations at Dunsany estate in County Meath, Ireland.

1.7.1 Objectives

The objectives of this study were

1) To determine the woodland structure and composition by estimating ground flora and canopy cover, height and Diameter at Breast Height (DBH) of trees.

2) To estimate regeneration of saplings at the ten sites at Dunsany estate.

i) To study and estimate seedling diversity and number.

3) To study the herbivory regime at the chosen sites.

4) To compare the woodland diversity with plantations.

5) To determine the impacts of herbivory at the sites and recommend solutions for its management.

1.7.2 Research Questions

The following research questions were considered for this study

1) Does the woodland and plantation structure and composition affect the number and diversity of seedlings?

2) What is the floristic structure of the woodlands at Dunsany?

3) What are the factors affecting regeneration in the ten sites?

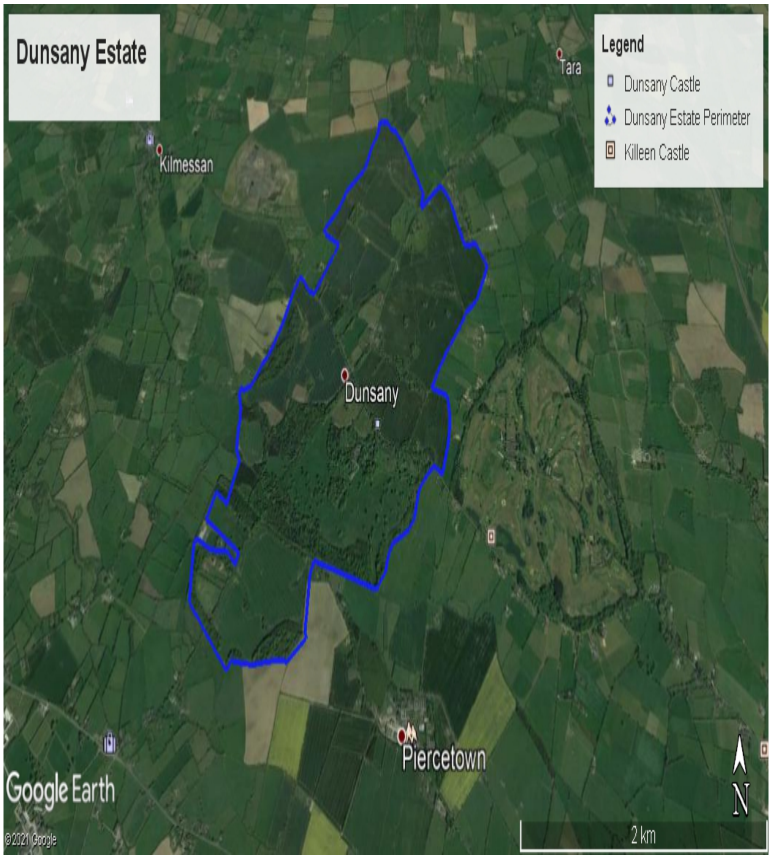
i) How does herbivory affect the regeneration and seedling number in the sites studied? Do herbivores prefer some plant species over others? Are there any other causes of damage to vegetation apart from grazing ie environmental or anthropogenic factors such as trampling, fires etc?

The aim, objectives and specific research questions were investigated by examining vegetation composition and regeneration in a set of plots covering a number of woodland and plantations at Dunsany. There have been very few studies of rewilded woodlands in Ireland. This project will provide a baseline from which future changes can be measured at Dunsany.

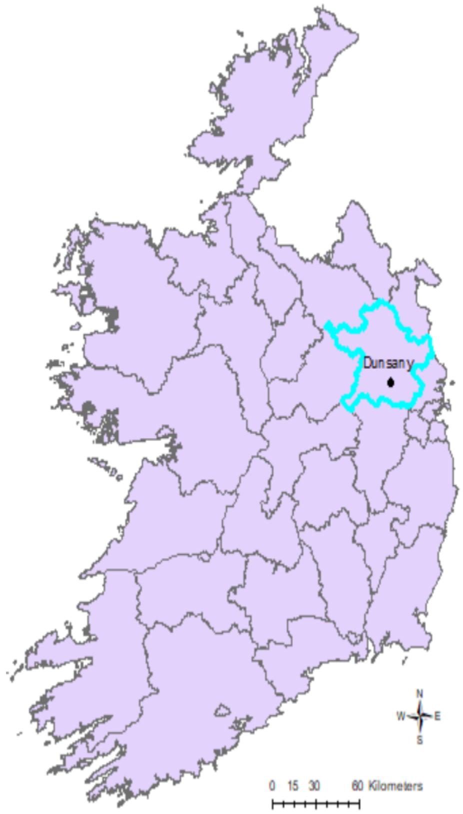
Chapter 2
Materials and Methods

The coordinates of Dunsany estate were 53.54 N, 6.62 W and its area was 1600 acres (Rewilding Europe, 2020).

Figure 2.1a and b: Dunsany estate (Google Earth, 2020) and Location of Dunsany estate in Co Meath, Ireland (ArcGIS, 2019)



2.1a



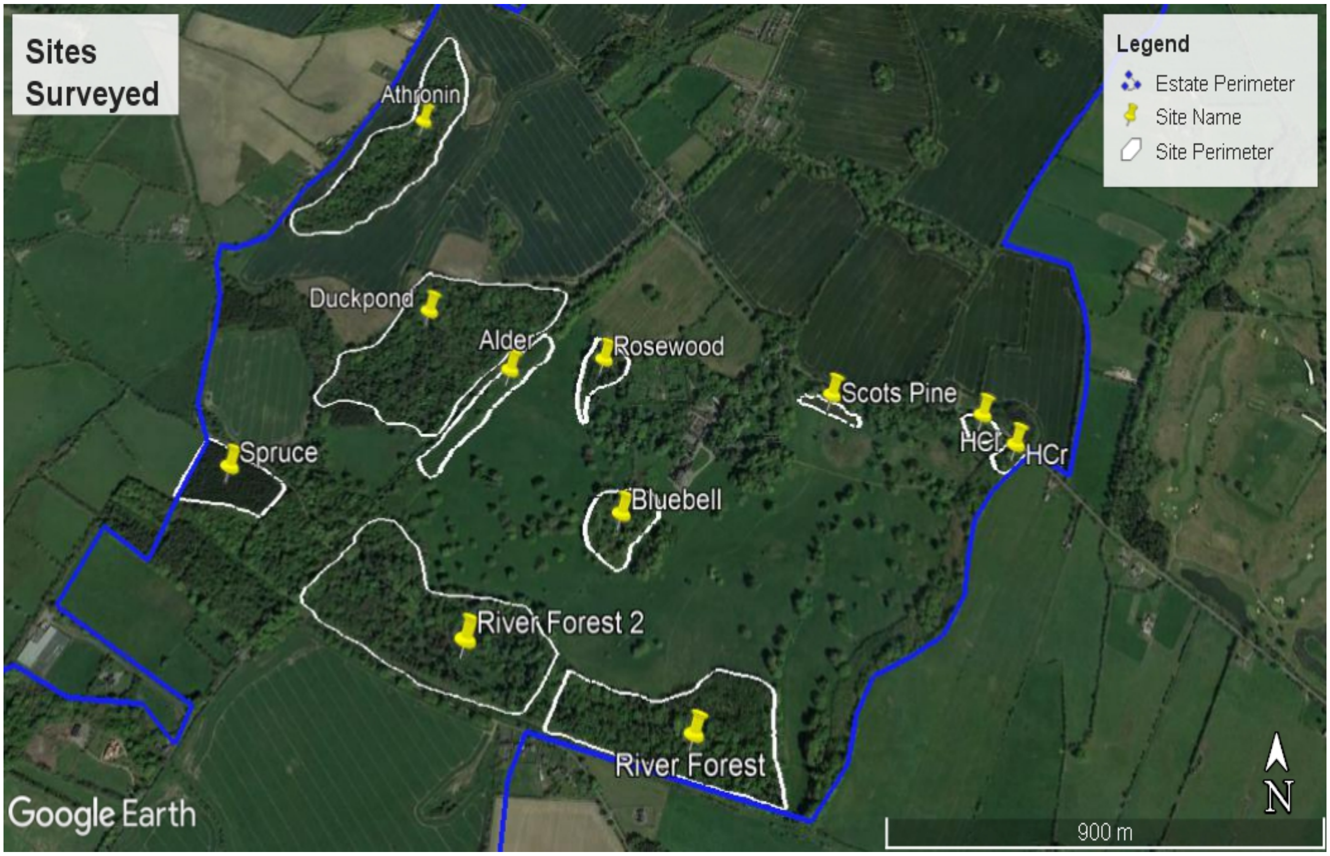
2.1b

The fieldwork was conducted between June and August 2020. Potential sites to survey in Dunsany estate were identified on Google Earth to facilitate location on the field. Locations of County Meath and Dunsany were mapped using ArcMap 10.7.1 program of ArcGIS. The initial site visit involved examining the habitat diversity of the estate and determining locations where the 10x10 m plots would be set up.

2.1 Field Survey Sites and Location of the Plots

From the initial site visit, ten sites (figure 2.2a) were selected for the study, including seven semi-natural woodlands and three plantations. The semi-natural woodlands surveyed during the study may have also been fragments of old woodlands or plantations. Recording plots of size 10x10 m were set up randomly within these sites; inside each 10x10m plot were positioned five 2x2 m quadrats (four in the corners and one in the center) for estimating seedling number and diversity which resulted in a total of 155 quadrats set at the 10 sites. The number of plots within each location depended on the area and diversity of the site; data were collected from a total of 31 plots (figure 2.2b). These plots were set up following the procedures of Higgins *et al*. (2004) and Perrin *et al*. (2008) and the number of plots in each of the sites were based on the diversity of vegetation and area. Fewer plots were set up at sites where vegetation was not diverse. Plots were not set up where cherry laurel was abundant as it is allelopathic, containing hydrocyanic (Prussic) acid and inhibits the growth of tree seedlings and ground flora species (Peterson and Talcott, 2013).

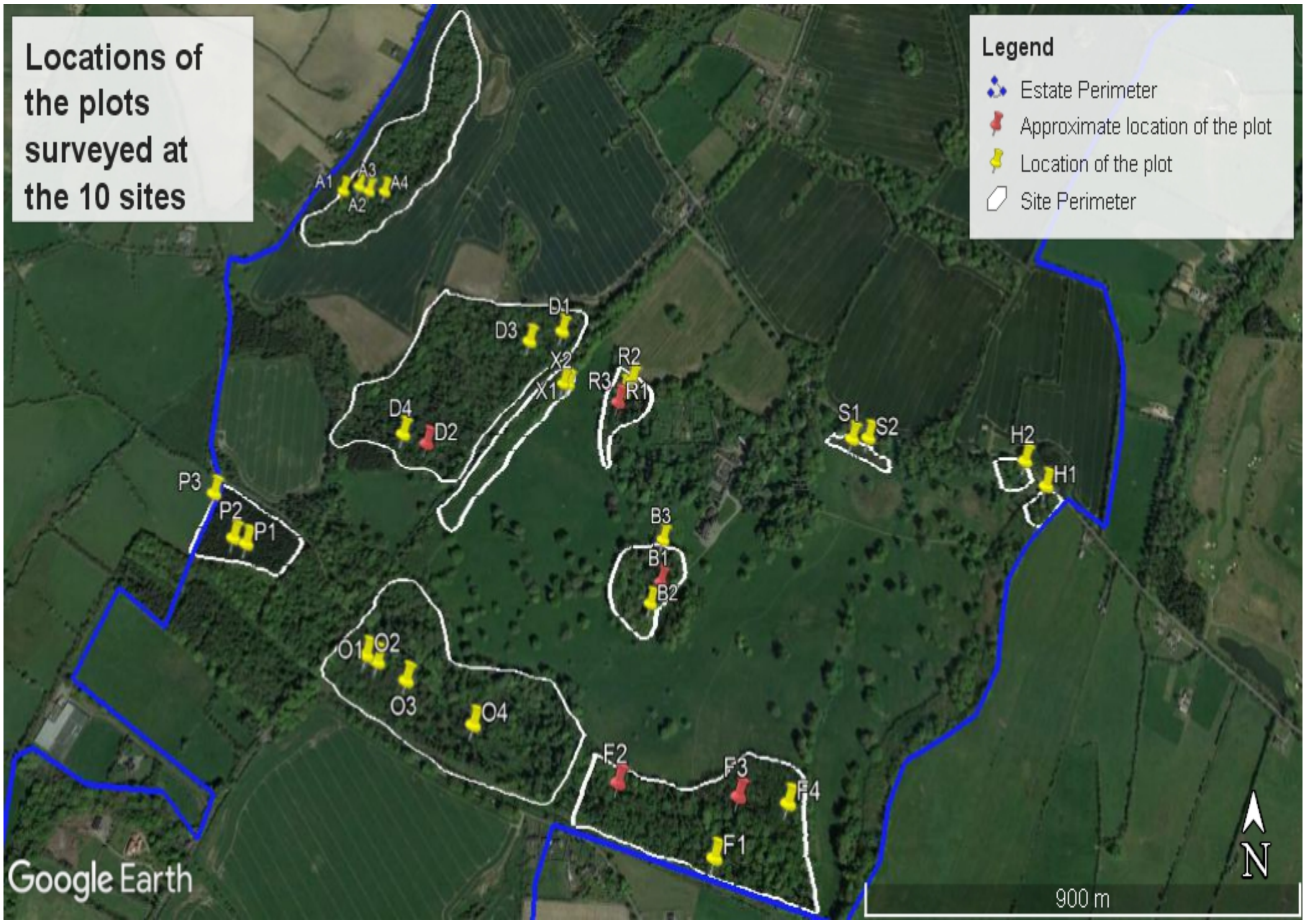
Figure 2.2a and b: Map showing the ten sites which were surveyed during the study (Google Earth, 2020) and Map showing the location of the 31 plots that were set up at the 10 sites (Google Earth, 2020)



2.2a

Abbreviations:

HCl and HCr: Left and right side of Horse Chestnut Woodland



2.2b

Abbreviations:

A1, 2, 3 and 4: Athronin Forest plots 1, 2, 3 and 4

B1, 2 and 3: Bluebell plots 1, 2 and 3

F1, 2, 3 and 4: River Forest plots 1, 2, 3 and 4

O1, 2, 3 and 4: River Forest 2 plots 1, 2, 3 and 4

S1 and 2: Scots pine plots 1 and 2

P1, 2 and 3: Sitka spruce plots 1, 2 and 3

R1, 2 and 3: Rosewood plots 1, 2 and 3

D1, 2, 3 and 4: Duckpond plots 1, 2, 3 and 4

H1 and 2: Horse Chestnut plots 1 and 2

X1 and 2: Alder plots 1 and 2

GPS coordinates were available for the plots marked with a yellow pin. As a GPS location could not be recorded (due to lack of an internet signal) in 5 plots (Rosewood Plot 1, Bluebell Plot 1, Duckpond Plot 2 and plots 2 and 3 of River Forest), approximate coordinates were estimated and marked with a red pin.

Table 2.1: Sites surveyed at Dunsany Estate

Sites Surveyed		
Semi-natural Woodlands	**Area (sq m)**	**Plots Set**
River Forest	76,710	4
River Forest 2	112,537	4
Duckpond	131,677	4
Athronin Forest	91,604	4
Horse Chestnut Woodland / HC (left and right side)	7999	2
Bluebell Wood	20,575	3
Rosewood	12,422	3
Plantations	**Area (sq m)**	**Plots Set**
Scots Pine and Oak	3888	2
Alder	20,377	2
Sitka Spruce	26,585	3

Table 2.2: GPS coordinates of the thirty-one plots surveyed at the ten sites

Semi-natural Woodlands	GPS Coordinates
Bluebell	
B1	53.5436, - 6.6226
B2	53.5340, -6.6230
B3	53.5351, -6.6225
Rosewood	
R1	53.5376, -6.6241
R2	53.5380, -6.6237
R3	53.5378, -6.6240
Horse Chestnut Woodland	

H1	53.5359, -6.6091
H2	53.5364, -6.6097
Duckpond	
D1	53.5420, -6.6263
D2	53.5689, -6.6313
D3	53.5388, -6.6275
D4	53.5370, -6.6319
Athronin Forest	
A1	53.5420, -6.6350
A2	53.5421, -6.6344
A3	53.5420, -6.6340
A4	53.5420, -6.6334
River Forest 2	
O1	53.5330, -6.6321
O2	53.5331, -6.6325
O3	53.5327, -6.6311
O4	53.5320, -6.6288
River Forest	
F1	53.5300, -6.6210
F2	53.5311, -6.6240
F3	53.5309, -6.6201
F4	53.5308, -6.6186
Plantations	
Scots pine	
S1	53.5368, -6.6158
S2	53.5369, -6.6152
Alder	
X1	53.5380, -6.6260
X2	53.5380, -6.6261
Sitka spruce	
P1	53.5350, -6.6370
P2	53.5350, -6.6374
P3	53.5359, -6.6368

2.2 Woodland Structure and Composition

Woodland structure and composition were determined by estimating canopy cover, height, DBH(Diameter at breast height) of trees and ground flora.

a) Tree canopy was estimated by observing the tree cover and amount of shading in each of the plots selected and trees with dominant canopy were recorded.

b) The tree height in each plot was measured by using a 15 cm scale and standing 10 meters away from the tree. With the scale in one arm stretched out, the height was estimated to the nearest meter.

c) DBH for trees was recorded by using a tape calibrated in DBH. The circumference of a tree is measured by wrapping the tape around its trunk, 1.3 m above the ground level and its diameter at breast height was then noted. All mature trees with DBH >7 cm were considered for determination of woodland structure and composition.

d) The different ground flora species (grass, woody species, forbs, herbs along with bare ground cover) were observed, identified (Parnell and Curtis, 2012) and recorded in % to give an indication of the type of vegetation in each plot.

2.3 Determining Regeneration

Regeneration was estimated by recording the number of saplings in different size classes in the chosen sites. In each 10x10 m plot, saplings with DBH <7 cm and height >25 cm were categorized into four height classes ie, 25-100 cm, 100-200 cm, 200-400 and >400 cm (Perrin *et al*., 2008). Young trees less than 25 cm tall were considered to be seedlings.

2.4 Seedling Number and Diversity

Seedling number was estimated by positioning a total of five 2x2 m quadrats in all 10 x10m plots (four quadrats in the corners and one in the centre). All tree seedlings, <25 cm tall in these five quadrats were counted by species.

2.5 Herbivory

The frequency of herbivory was determined by scoring signs of herbivory following methodology of Perrin *et al.,* (2008);

0 - No herbivory.
1 - Low herbivory: High regeneration, shrub layer is dense and no signs of browsing.

2 - Moderate herbivory: Saplings have been localized, shrub layer is patchy, field layer is more than 30cm tall.

3 - High herbivory: Significant damage to shrub layer, ground vegetation is less than 20cm tall, no to low tree regeneration.
4 - Severe herbivory: Tree regeneration and shrub layer absent. Extensive browsing and damage to ground flora visible. Severe herbivory was not observed in any of the plots.

2.6 Multivariate Analyses

The tree data (total number of trees of all species found in all plots at a site) along with *Rubus*, bare ground, herb, grass and canopy cover were used to examine variation in vegetation structure at the ten sites surveyed. Non-metric multidimensional scaling (NMS) was run on PC-ORD (version 5) using Sorenson's (Bray-Curtis) distance measure to determine differences in vegetation composition between sites. NMS was run in autopilot mode (default settings) after which the medium option was selected which extracted a maximum of four axis. The maximum number of iterations were 200. These data were also used for cluster analysis using PC-ORD. Lance and Williams flexible beta clustering (beta = -0.25) was used with Sorenson's (Bray Curtis) distance. Clusters were visualised in dendrograms and with clusters overlaid on NMS ordination plots.

2.7 Woodland, Plantation Sites Studied and their Floristic Structure

2.7.1 Bluebell Wood

Canopy species: *Fraxinus excelsior, Fagus sylvatica*; canopy height: 25 m.

Understory: *F. excelsior*, *Crataegus monogyna* Jacq., *Acer pseudoplatanus.*

Regeneration: Poor (3 saplings in 25-100 cm class).

Field and ground layer: *Climacium dendroides*, *Dryopteris filix-mas, Dryopteris affinis, Geranium robertianum, Prunella vulgaris, Rubus fruticosus, Rumex acetosella, Senecio jacobaea* with moderate leaf litter.

Figure 2.3a and b: plots 1 and 2 respectively.

2.3a 2.3b

2.7.2 Rosewood

Canopy species: *A. pseudoplatanus, Pinus sylvestris, Taxus baccata*; canopy height: 30-40 m.

Understory: *Acer pseudoplatanus, Crataegus monogyna, F. excelsior.*

Regeneration: Excellent (16 in 25-100 cm class, 19 in 100-200 cm, 11 in 200-400 cm and 10 in 400+ cm).

Field and ground layer: *C. dendroides, Agrostis stolonifera, G. robertianum, Hedera helix, Heracleum sphondylium, Poa* sp, *R. acetosella, R. fruticosus, Symphoricarpus albus, Urtica diocia* with little leaf litter.

Figure 2.4a and b: plots 1 and 2 respectively.

2.4a 2.4b

2.7.3 Duckpond

It was the largest site surveyed at the estate.

Canopy species: *A. pseudoplatanus, F. excelsior, P. sylvestris*; canopy height: 25-30 m.

Understory: *Corylus avellana, F. sylvatica, Illex aquifolium, Prunus laurocerasus.*

Regeneration: Moderate (145 in 25-100 cm class, 7 in 100-200 cm).

Field and ground layer: *Circaea lutetiana, G. robertianum, H. helix, Poa* sp*, R. fruticosus* with little to moderate leaf litter.

Figure 2.5a, b and c: plots 1, 3, 2 and 4 respectively.

2.5a

2.5b *Rhododenron ponticum* patch near plot 3

2.5c (plots 2 and 4 were set up near the old cricket field)

2.7.4 Athronin Forest

Canopy species: *C. avellana, F. excelsior, P. sylvestris, Ulmus glabra*; canopy height: 20-25 m.

Understory: *A. pseudoplatanus, F. excelsior, P. sylvestris.*

Regeneration: Good (19 in 25-100 cm class, 5 in 100-200 cm, 2 in 200-400 cm).

Field and ground layer: *C. dendroides, Chrysosplenium oppositifolium, G. robertianum, H. sphondylium, Poa* sp*, R. fruticosus, R. acetosella* with no leaf litter.

Figure 2.6a, b and c: plots 1, 3 and 4 respectively.

2.6a

2.6b

2.6c

2.7.5 Horse Chestnut Woodland:

Canopy species: *Aesculus hippocastanum, A. pseudoplatanus, C. avellana, P. sylvestris*; canopy height: 30-35 m.

Understory: *C. avellana, C. monogyna, F. excelsior.*

Regeneration: Moderate (26 in 25-100 cm class, 1 in 100-200 cm, 1 in 200-400 cm).

Field and ground layer: *H. helix, H. sphondylium, A. stolonifera, G. robertianum, Poa* sp*, R. fruticosus* with very little leaf litter.

Figure 2.7a and b: plots 1 and 2 respectively.

2.7a

2.7b

2.7.6 River Forest

Canopy species: *A. pseudoplatanus, F. sylvatica, P. sylvestris*; canopy height: 30 m.

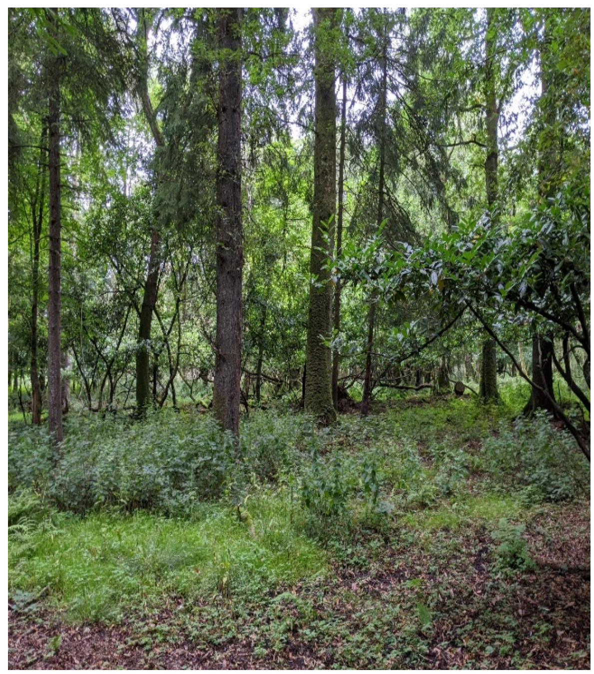
Understory: *C. monogyna, F. excelsior, F. sylvatica, I. aquifolium, P. laurocerasus.*

Regeneration: Good (265 in 25-100 cm class, 65 in 100-200 cm, 8 in 200-400 cm).

Field and ground layer: *Chrysosplenium oppositifolium, D. filix-mas, Agrostis stolonifera, G. robertianum, Oxalis acetosella, Poa* sp*, R. acetosella, R. fruticosus* with moderate leaf litter.

Figure 2.8a, b and c: plots 1, 2 and 3 respectively.

2.8a



2.8b

2.8c

2.7.7 River Forest 2:

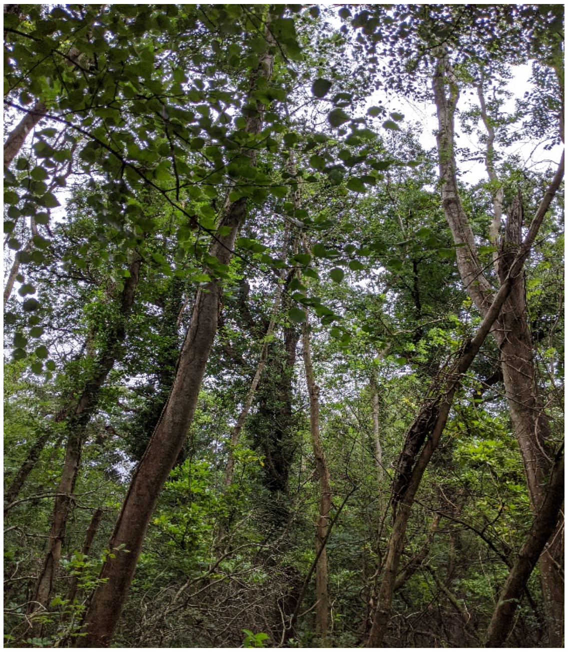
Canopy species: *A. pseudoplatanus, F. excelsior, P. laurocerasus, P. sylvestris, Quercus petraea*; canopy height: 30-40 m.

Understory: *A. pseudoplatanus, C. monogyna, F. excelsior, U. glabra.*

Regeneration: Excellent (93 in 25-100 cm class, 33 in 100-200 cm, 7 in 200-400 cm, 8 in 400+).

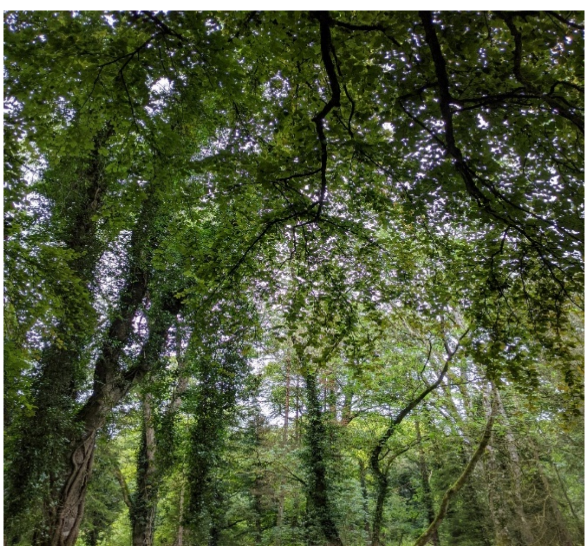
Field and ground layer: *C. lutetiana, H. helix, H. sphondylium, Poa* sp*, Phalaris arundinacea, R. frutiocsus, R. acetosella, Ribes nigrum, Solanum dulcamara* with little leaf litter.

Figure 2.9a, b and c: plots 1, 2 and 3 respectively.



2.9a

2.9b



2.9c

2.7.8 Sitka spruce plantation

Canopy species: *Picea sitchensis* (Bong.) Carr.; canopy height: 40-45 m.

Understory: *A. hippocastanum, A. pseudoplatanus, F. excelsior, F. sylvatica, Q. petraea.*

Regeneration: Excellent (46 in 25-100 cm class, 59 in 100-200 cm, 42 in 200-400 cm, 7 in 400+).

Field and ground layer: *C. dendroides, D. affinis, H. helix, G. robertianum, Polystichum setiferum, R. fruticosus* with a large amount of leaf litter.

Figure 2.10a and b: Plots 1 and 2 respectively.

2.10a 2.10b

2.7.9 Scots Pine and Oak plantation: It was the smallest site surveyed at the estate.

Canopy species: *P. sylvestris, Q. petraea;* canopy height: 20-25 m.

Understory: *A. pseudoplatanus, F. excelsior, Q. petraea.*

Regeneration: Poor (13 in 25-100 cm class).

Field and ground layer: *H. helix, G. robertianum, R. fruticosus* with a large amount of leaf litter.

Figure 2.11a, b and c: Plantation from 100m away and plots 1 and 2 respectively.

2.11a (Plantation from 100m away)

2.11b

2.11c

2.7.10 Alder Plantation:

Canopy species: *Alnus glutinosa, A. pseudoplatanus;* canopy height: 20-25m

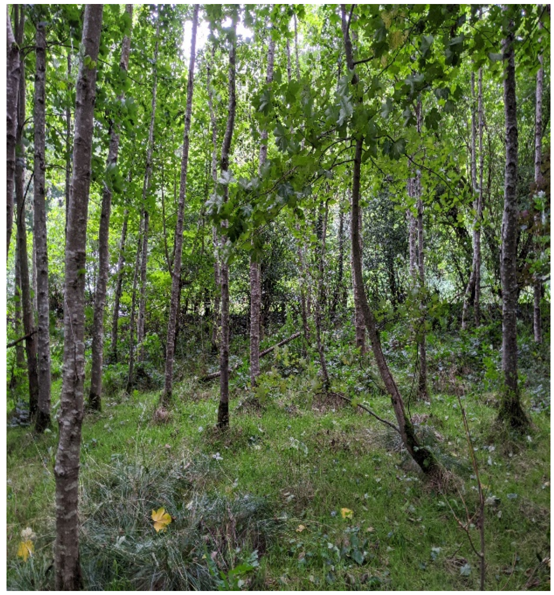
Understory: *A. pseudoplatanus, F. excelsior.*

Regeneration: Poor (1 in 25-100 cm class, 1 in 100-200 cm)

Field and ground layer: *Fillipendula ulmaria, P. arundinacea, A. stolonifera, R. acetosella, R. fruticosus, U. diocia, Poa* sp with a large amount of grass and no leaf litter.

Figure 2.12a, b and c: Plantation from 100m away and plots 1 and 2 respectively.

2.12a (Plantation from 100m away)



2.12b 2.12c

Chapter 3

Results

3 Data Analyses

3.1 Woodland Structure and Composition

NMS on PCORD 5 was run for the number of trees found in the thirty-one plots along with the five important variables determining tree structure and composition in each plot; they were Canopy, *Rubus*, grass, herb and bare ground cover. A 3-dimensional solution was recommended with a final stress value of 13.55.

Abbreviations used

Blu: Bluebell

HC: Horse Chestnut Woodland

Ros: Rosewood

Ath: Athronin Forest

Duc: Duckpond

RF: River Forest

ORF: River Forest 2

Spr: Sitka Spruce Plantation

Sco: Scots Pine Plantation

Ald: Alder Plantation

Table 3.1: R^2 values for axis 1, 2 and 3 obtained using Sorenson Bray-Curtis distance measure.

Axis	R^2 Values
Axis 1	0.203
Axis 2	0.309
Axis 3	0.175

Axis 2 had the highest R^2 value followed by axis1 and axis 3. 51.2 % variance was explained by axis 1 vs 2 plot and this plot had the highest orthogonality of 100, so it was the most important plot followed by 2 vs 3 plot (94.6 orthogonality) and 1 vs 3 plot (94 orthogonality).

3.2 Clusters in Ordination Space

A total of 6 groups were found to be suitable for representing the 31 plots. The 31 plots were grouped together based on similar stand structure and composition and were from different woodlands and plantations.

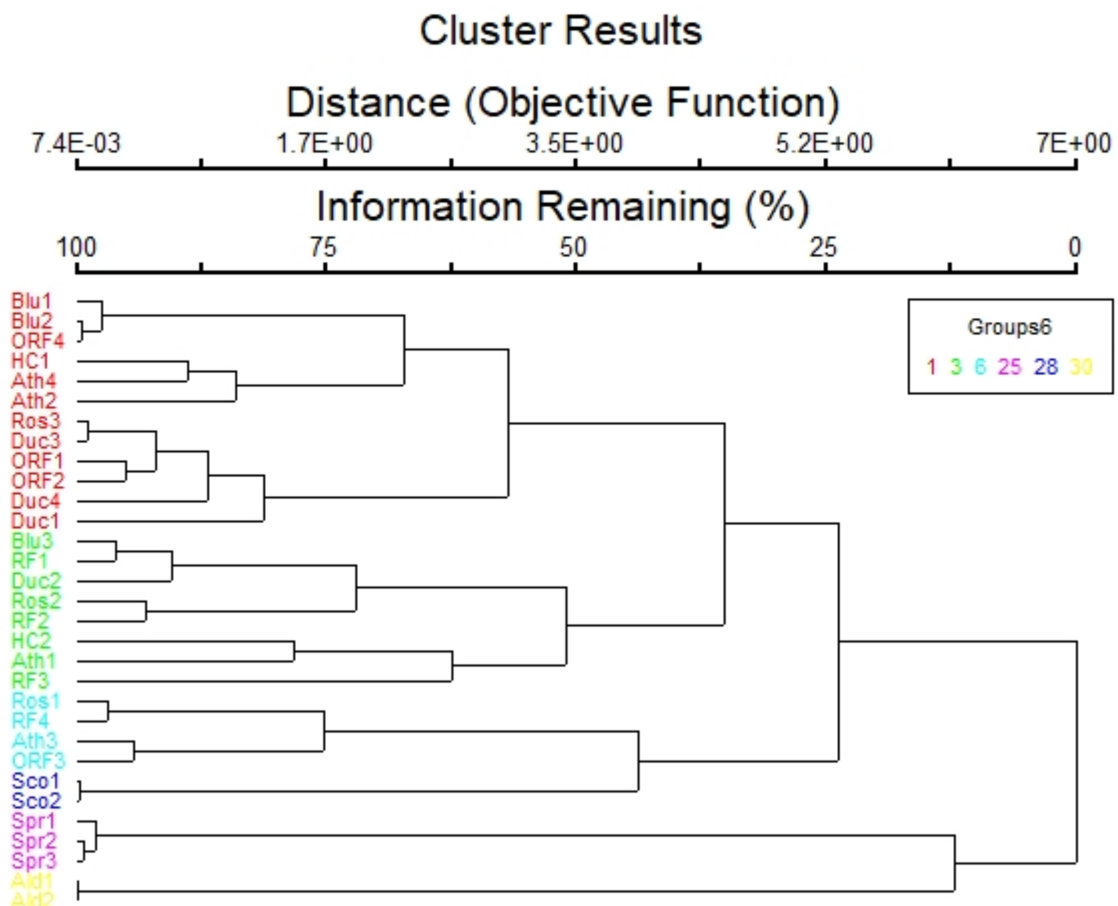


Figure 3.1: Dendrogram of all Dunsany plots clustered using Lance & William's flexible beta clustering (beta = -0.025) on a Bray-Curtis distance matrix. The six cluster solution is highlighted in different colours.

Table 3.2: Description of groups

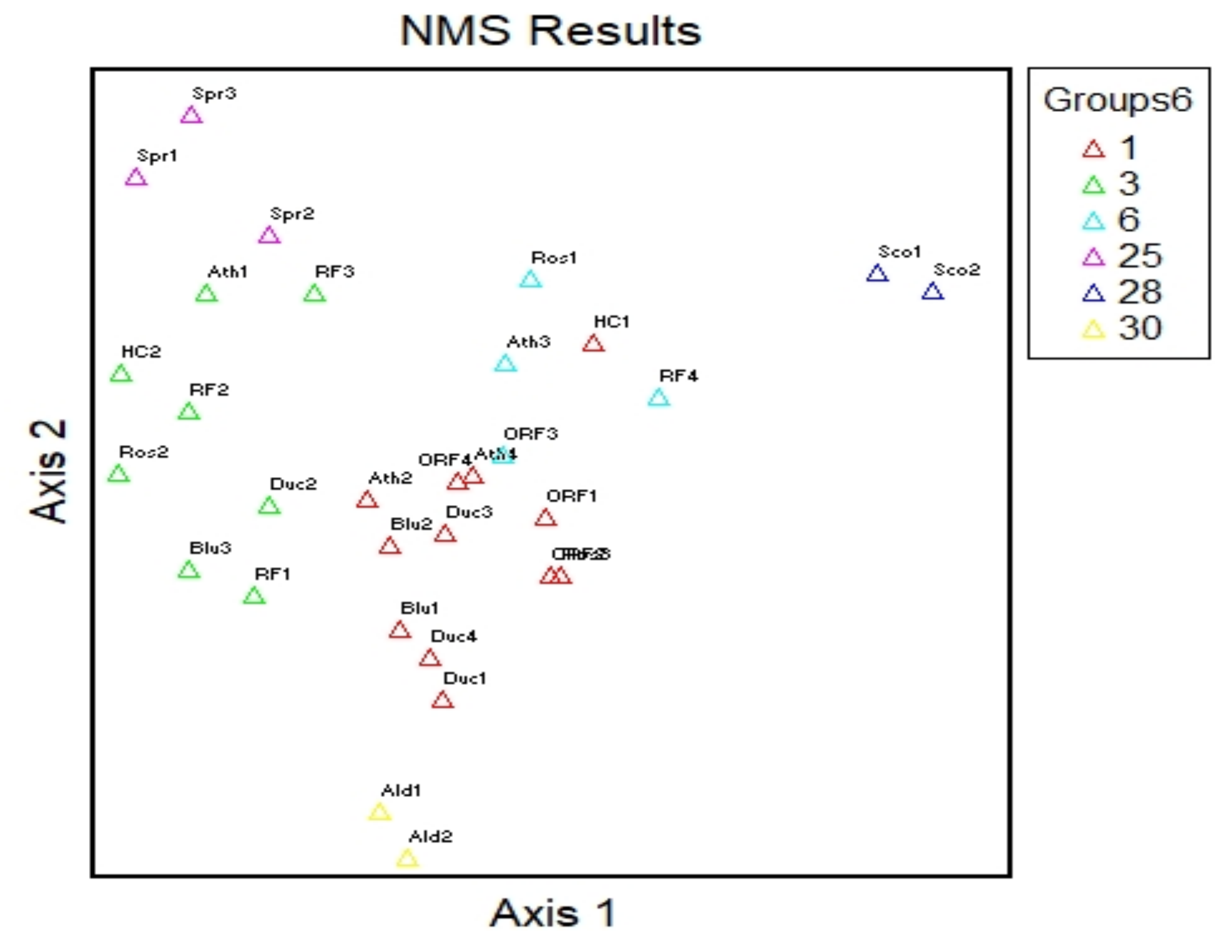
Groups 1, 3 and 6 comprised of plots from woodland sites while groups 25, 28 and 30 comprised of plantation plots.

Group	Plots within the Group
1	Blu 1, Blu 2, ORF1, ORF2, ORF4, Duc1, Duc3, Duc4, HC1, Ath2, Ath4, Ros3
3	Blu3, RF1, RF2, RF3, HC2, Ros2, Ath1, Duc2
6	Ros1, RF4, Ath3, ORF3
28	Sco1, Sco2

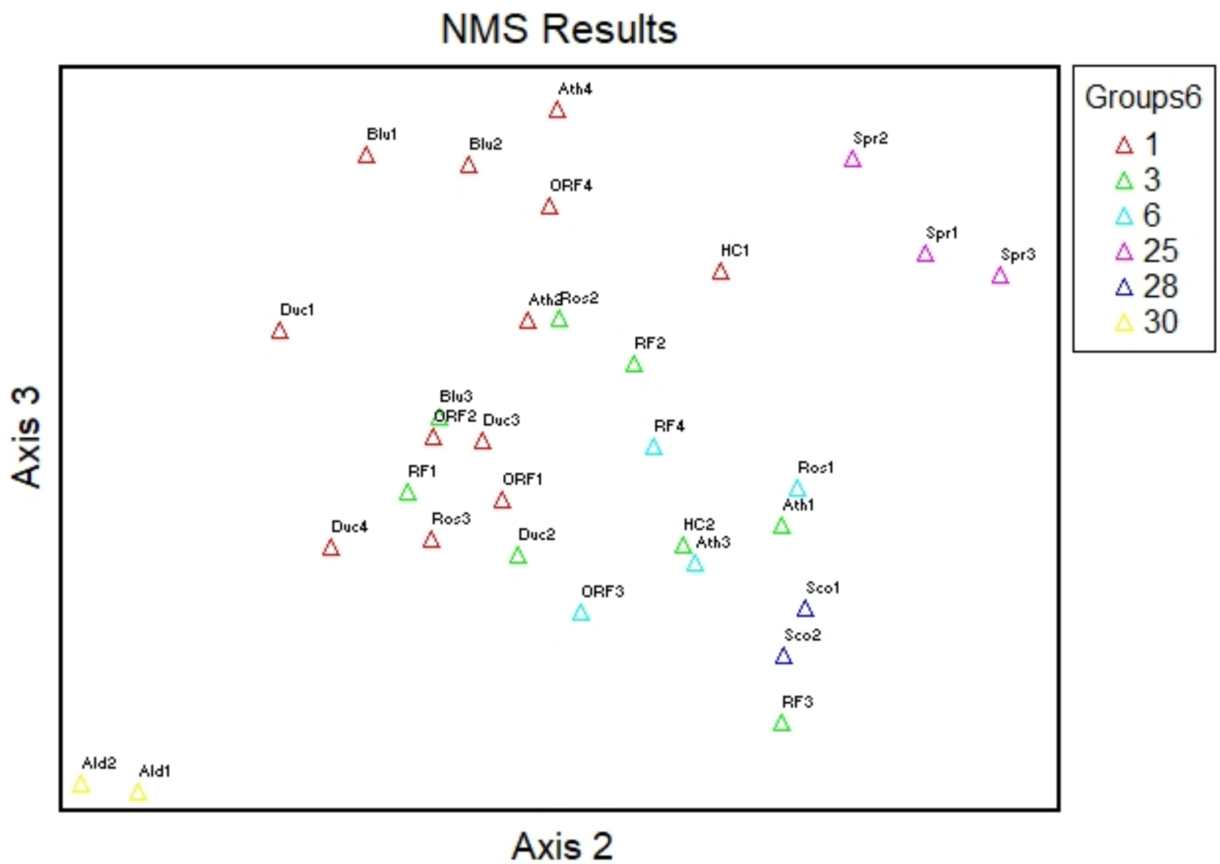
25	Spr1, Spr2, Spr 3
30	Ald1, Ald 2

Figure 3.2: NMS ordination of Dunsany woodland plots using Bray-Curtis distance; a: axis 1 vs 2, b: axis 2 vs 3 and c: axis 1 vs 3

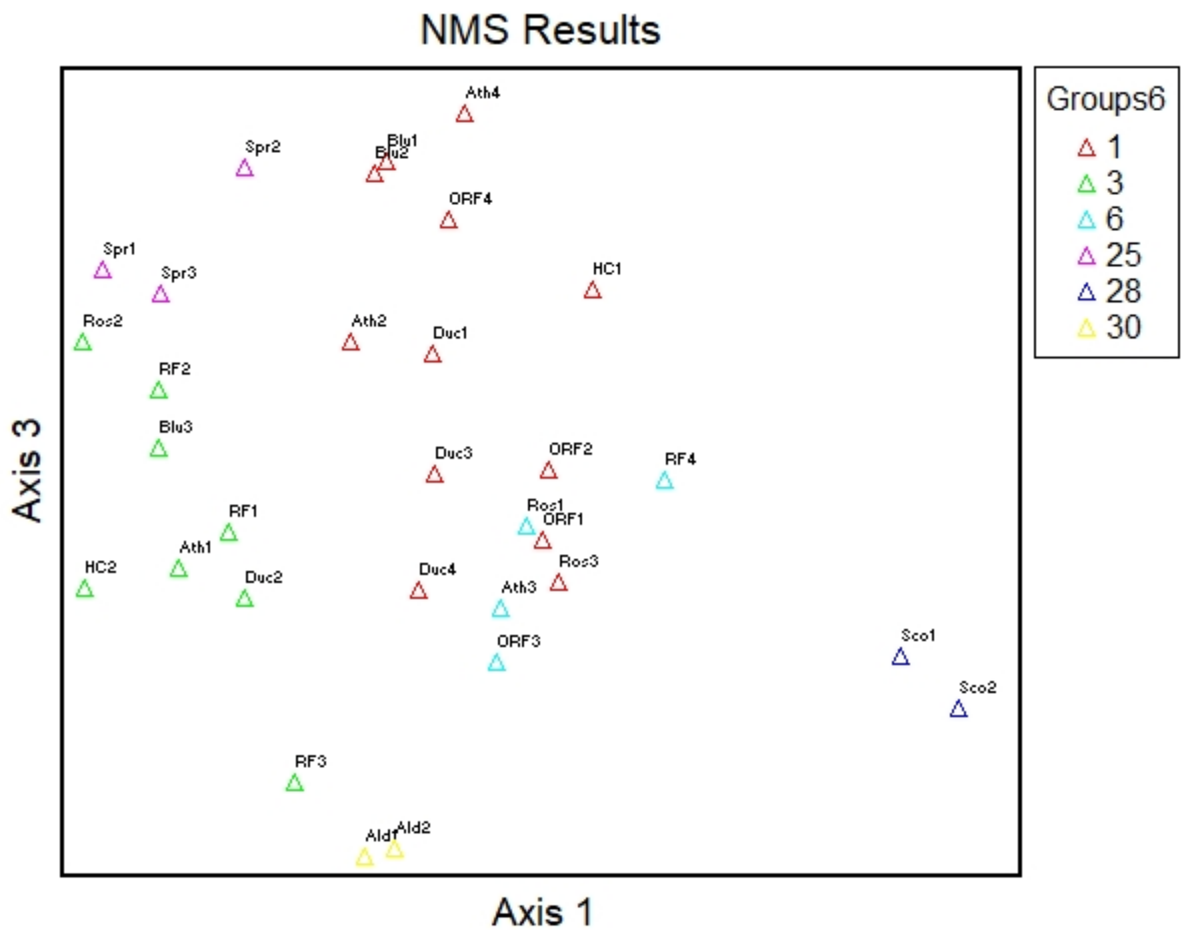
3.2a



3.2b


NMS Results
Axis 3
Axis 2
Groups6
1
3
6
25
28
30
Ath4
Blu1
Blu2
ORF4
Spr2
Spr1
Spr3
HC1
Duc1
Ath2
Ros2
RF2
Blu3
ORF2
Duc3
RF4
Ros1
RF1
ORF1
Ath1
Duc4
Ros3
Duc2
HC2
Ath3
ORF3
Sco1
Sco2
RF3
Ald2
Ald1

3.2c



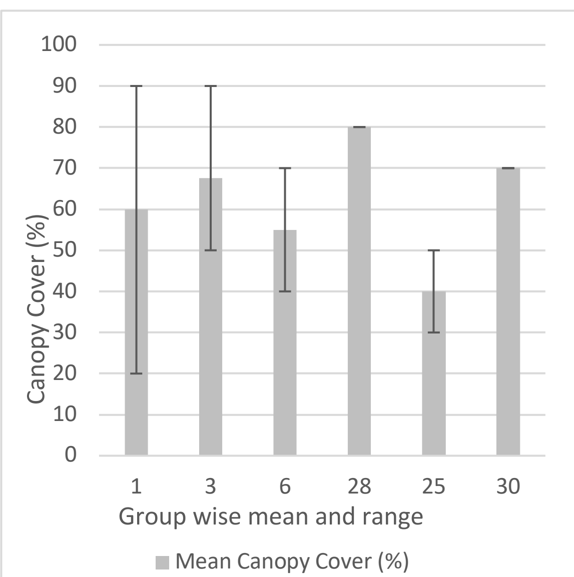
All groups were fairly well separated in the axis 1 vs 2 and 1 vs 3 ordination plots (figures 3.2a and 3.2c). The 2 vs 3 plot only separated groups 25 and 30 or Alder and Spruce plantation plots. All these groups were grouped on the basis of plots with similar bare ground cover, canopy cover, herb cover, grass cover, *Rubus* cover and common tree species. In both 1 vs 2 and 1 vs 3 ordination plots, it could be observed that some plots within each group were not close to the rest, due to differing canopy, bare ground, grass, herb and *Rubus* cover as well as tree numbers and species growing in them.

In figure 3.1, groups 25 and 30 were separated by long branches reflecting very different species composition, though plots within each of these two groups were very similar to each other (joined by a short branch) as plots in group 30 had *A. glutinosa* and *A. pseudoplatanus* in common while plots in group 25 had *P. sitchensis* in common. Group 28 and 6 were also separated by a fairly long branch which was again due to different tree species in their plots with group 28 having a very high number of *Q. petraea*. Plots in group 28 were very similar to each other with *Q. petraea* and *P. sylvestris,* canopy, bare ground and herb cover in common (please refer to tree table 3.4). Groups 1 and 3 were the largest groups with 12 and 8 plots respectively, and there was some sub-structuring within them, with plots being similar based on tree species and numbers as well as *Rubus* cover, bare ground cover etc. For example, Ros3 and Duc3 in group 1 were joined by a very short branch. Both had *P. sylvestris, F. excelsior* and *A. pseudoplatanus* in common.

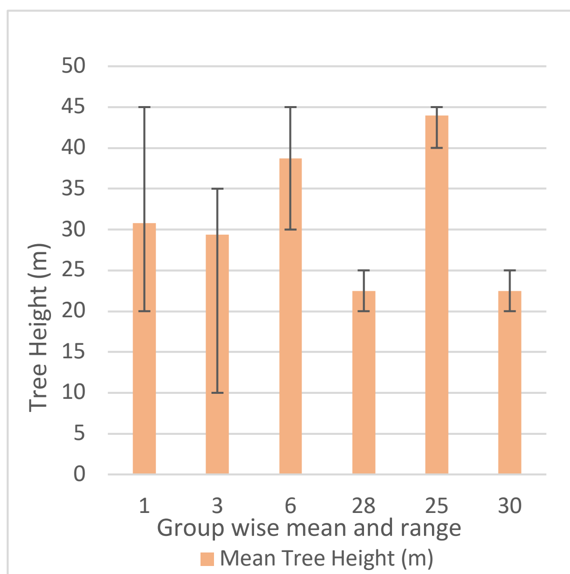
3.3 Variables Recorded

For each group, variables such as *Rubus*, herb, canopy, bare ground and grass cover along with tree height were recorded. In general, a greater range for these six variables were found in woodlands (group 1, 3 and 6) compared to plantations (group 25, 28 and 30). This was probably because of a constant cover or absence (for some groups) in plantations compared to varying cover in woodlands. Figure 3.3 illustrates the mean and range (in whiskers) of canopy, *Rubus*, bare ground, herb, grass cover and tree height for each group.

Figure 3.3: Mean and Range of a: Canopy cover, b: tree height, c: *Rubus* cover, d: Bare ground cover, e: Herb cover and f: Grass ocver for each group



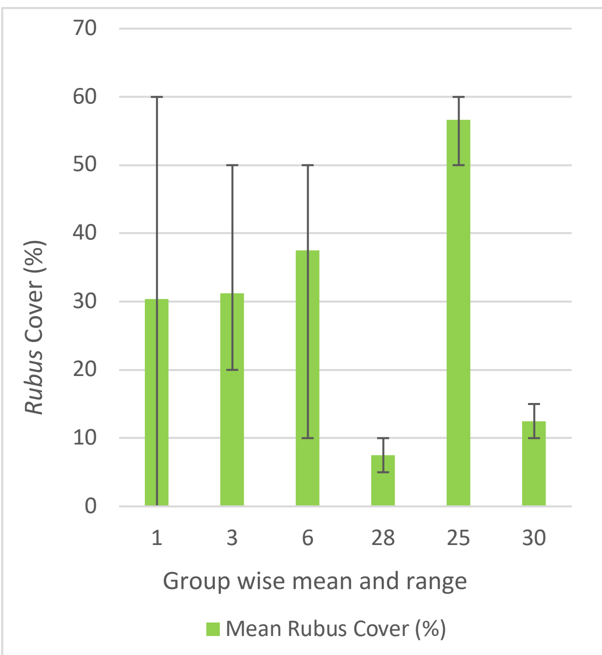
3.3a



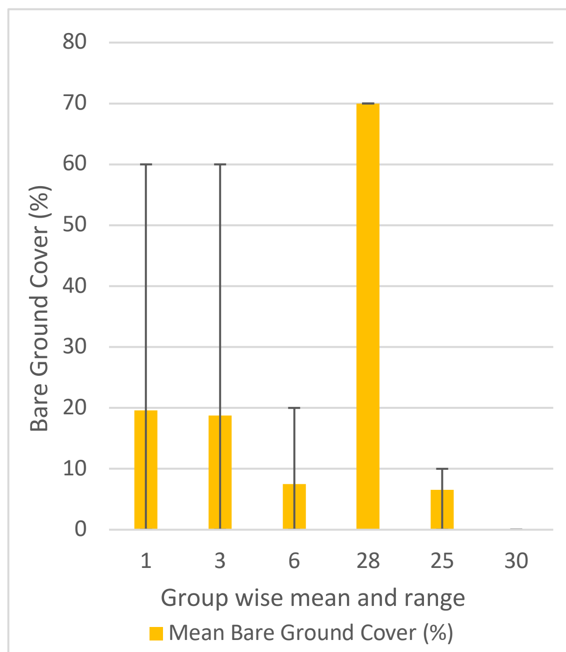
3.3b

Groups 1, 3 and 6 had a moderate mean canopy cover (~60%) as the trees were well-spaced and the tree species were also different and of varying ages. Group 28 and 30 had high mean canopy cover (70 and 80% respectively) as a large number of trees were growing very close to each other in a much smaller area. Group 28 and 30 both consisted of two plots each, having 80 and 70% mean canopy cover respectively resulting in a range of 0. A 0 range could be seen for some groups in the bare ground, grass and herb cover graphs as well.

The greatest tree height range was observed in groups 1 and 3 at 25 m and lowest in groups 25, 28 and 30. Tree height range was the same at 5 m for the latter three groups as they were of similar heights, most likely because these were plantations of similar aged individuals. The greater diversity of species and heights in groups 1, 3 and 6 suggested a range of age classes and some natural regeneration and recruitment. Lowest mean tree height was recorded in group 28 and 30 at 22.5 m and highest in group 25 at 44 m.



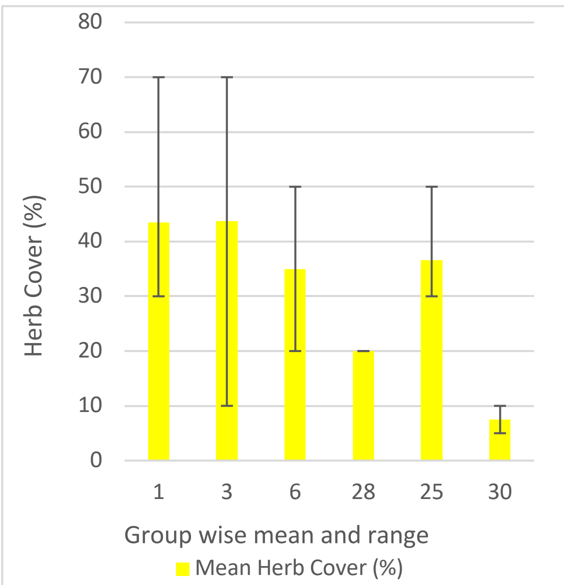
3.3c

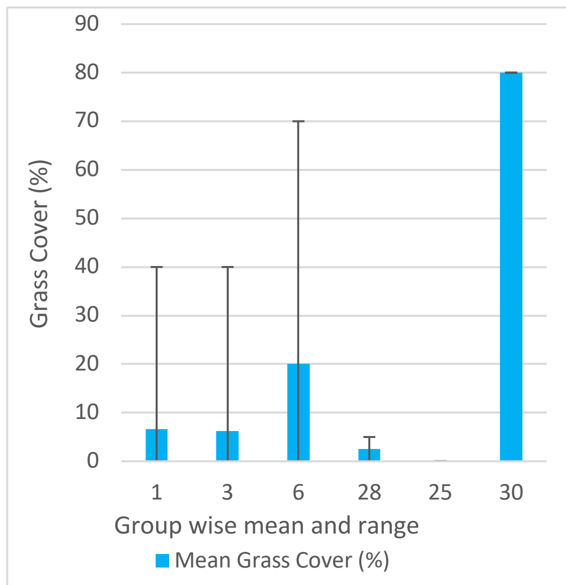


3.3d

Rubus cover didn't vary greatly in the woodlands surveyed and its mean remained between 30-37% for groups 1, 3 and 6. A greater range was observed within group 1 which was probably due to it having the highest number of plots. Groups 28 and 30 had very low *Rubus* cover which may have been due to a very dense canopy cover (*Rubus* is a light demanding species, Balandier *et al.,* 2012). Group 25 had the highest *Rubus* cover as it probably had a very light canopy cover.

The mean bare ground cover was low in the groups 1, 3 and 6 (7-19%) because there was an abundance of *Rubus*, herb and other ground flora in the understory. Bare ground cover was very low for groups 25 and 30 as well. *Rubus* dominated the understory in group 25, while group 30 had an abundance of grass. In group 28, the mean bare ground cover was the highest at 80% as it included leaf litter (from *P. sylvestris*), which probably didn't allow any vegetation to grow in the understory.





3.3e 3.3f

The mean herb cover was higher in groups 1, 3 and 6 (36-44%) because of ample light reaching the understory and lower leaf litter. It was low in groups 28 and 30 or Scots pine (20%) and alder plantations (7%) due to high amount of leaf litter and grass respectively. It was much higher in group 25 as the canopy cover was lighter. The mean grass cover was low (6-20%) in groups 1, 3, 6, 25 and 28 except 30. The low grass cover in the five groups was probably due to grazing by red deer that were spotted at many sites in the estate. Group 30 had an 80% grass cover maybe because it was fenced.

3.4 Tree DBH

Table 3.3: Species wise total diameter at breast height (cm) of mature trees (more than 400 cm in height and DBH > 7cm) for each group

Abbreviations:

Acer: Acer pseudoplatanus

Alnu: Alnus glutinosa

Cory: Corylus avellana

Crat: Crataegus monogyna

Fagu: Fagus sylvatica

Ilex: Illex aquifolium

Pice: Picea sitchensis

Pinu: Pinus sylvestris

Prun: Prunus laurocerasus

Quer: Quercus petraea

Ulmu: Ulmus glabra

n: No of plots in each group

Group	*Acer*	*Alnu*	*Cory*	*Crat*	*Fagu*	*Frax*	*Illex*	*Pice*	*Pinu*	*Prun*	*Quer*	*Ulmu*	*n*
1	489.1	0	238.6	38.3	91.8	868.6	48.6	0	610.2	58.2	124.4	35.6	12
3	239.9	0	0	34	470.3	0	71	0	0	33.6	107.6	51.3	8
6	58	0	0	16.6	18.3	48	0	0	415.3	0	263.6	148.9	4
28	0	0	0	0	0	0	0	0	147.6	0	770.6	0	2
25	0	0	0	0	0	5	0	1023.2	0	0	0	0	3
30	131.9	709.3	0	0	0	0	0	0	0	0	0	0	2

Trees with highest DBH in woodland groups 1, 3 and 6 were *F. excelsior, F. sylvatica* and *P. sylvestris* respectively*. F .excelsior* trees were of varying ages and height, but were the most abundant tree species at the estate resulting in a very high DBH (group 1). All *P. sylvestris* trees recorded in groups 1 and 6 and *F. sylvatica* in group 3 were tall and mature. In plantations, the highest DBH was recorded for *P. sitchensis,* seen only in spruce plantation followed by *Q. petraea* and *A. glutinosa. P. sitchensis* numbers were also lower than the other two species but the trees were mature (40-50 yrs old) and much larger in size. On the other hand *Q. petraea* and *A. glutinosa* were numerous and recorded in Scots pine and alder plantations. These two species were not mature (about 20 yrs old) and were found to be growing very close to each other.

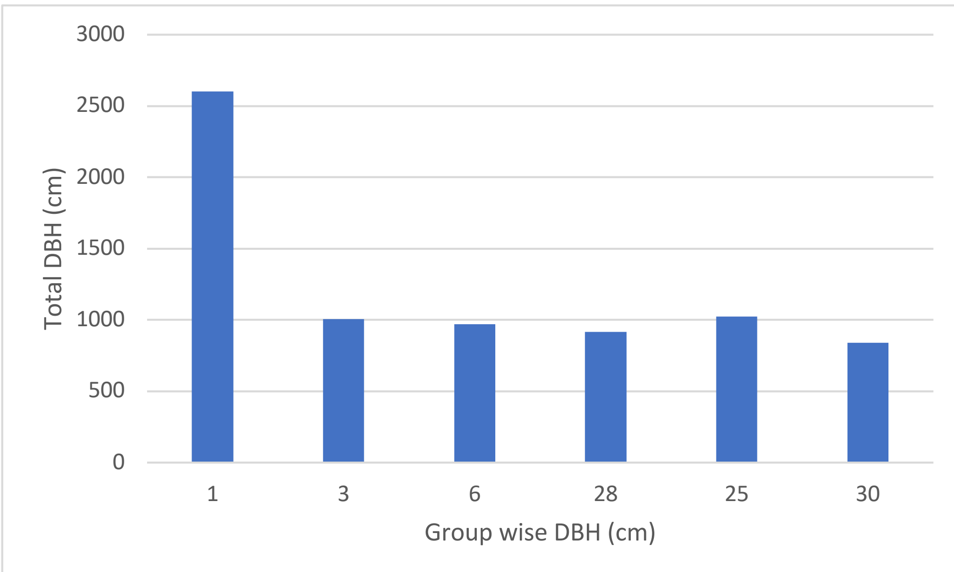


Figure 3.4: Total tree DBH (cm) for all species by group

The total tree DBH in a site gives an estimate of total tree density which relate to the amount of shading in each plot. The highest total DBH was seen in Group 1 (2603.4 cm) and total number of trees recorded in this group were 121 (highest of any group) which resulted in the highest total DBH. A possible reason for this high DBH could be the fact that group 1 had the highest number of plots at 12. Even though the number of trees in groups 28 and 30 were 61 and 55 respectively, they were immature and of similar heights, resulting in the lowest total DBH of all groups (918.2 and 841.2 cm respectively).

Table 3.4: Comparison of groups on the basis of total number of trees (more than 400 cm in height and DBH >7cm) of each species recorded in them.

For abbreviations please refer to table 3.3.

Group	*Acer*	*Alnu*	*Cory*	*Crat*	*Fagu*	*Frax*	*Ilex*	*Pice*	*Pinu*	*Prun*	*Quer*	*Ulmu*	*n*
1	29	0	12	4	9	41	4	0	11	6	2	3	12
3	5	0	0	3	8	0	2	0	0	4	1	2	8
6	3	0	0	2	2	1	0	0	13	0	3	7	4
28	0	0	0	0	0	0	0	0	8	0	53	0	2
25	0	0	0	0	0	1	0	27	0	0	0	0	3
30	8	47	0	0	0	0	0	0	0	0	0	0	2

In general plantations were smaller in area and had more trees per plot compared to the woodlands. Woodlands had a higher diversity of trees growing over a large area with fewer trees per plot. A very high number of *Acer pseudoplatanus* (29)*, Corylus avellana* (12)*, Fraxinus excelsior* (41) separated group 1 from the rest and *C. avellana* was also only found in group 1. Group 3 was separated from others because *F. excelsior* and *P. sylvestris* were not recorded in it and these two species were common in groups 1 and 6. Group 6 was separated due to high number *of P. sylvestris* and *U. glabra. Ilex aquifolium* and *Prunus laurocerasus* were two species which were not recorded in group 6 but were common in groups 1 and 3 (separating them from group 6). Groups 25, 28 and 30 were separated from the other groups because a high number of trees belonging to only two species were recorded in them and also the tree species were very different in each of these groups. For example, *Picea sitchensis* and *Alnus glutinosa* were recorded in groups 25 and 30, but were absent in all other groups. Even though *Pinus sylvestris* and *Quercus petraea* were recorded in other groups, their numbers were not as high as they were in group 28, which separated it from the rest.

Table 3.4 was used to characterize the following type of semi-natural woodlands and plantations types*:

Group 1: *Fraxinus-Acer-Pinus* woodland

Group 3: *Fagus-Acer-Quercus* woodland

Group 6: *Pinus-Quercus-Ulmus* woodland

Group 28: *Quercus-Pinus* plantation

Group 25: *Picea* plantation

Group 30: *Alnus- Acer* plantation

*For full description of woodlands and plantation types based on structure, composition, herbivory, regeneration and seedling diversity, please refer to tables 3.12 and 3.13.

3.5 Regeneration of Saplings

The number of regenerating saplings in each of the six groups were separated into four categories based on their heights. All saplings recorded in these height classes had a DBH of less than 7 cm and were more than 25 cm in height. All individuals under 25 cm were called seedlings.

The four height classes were:

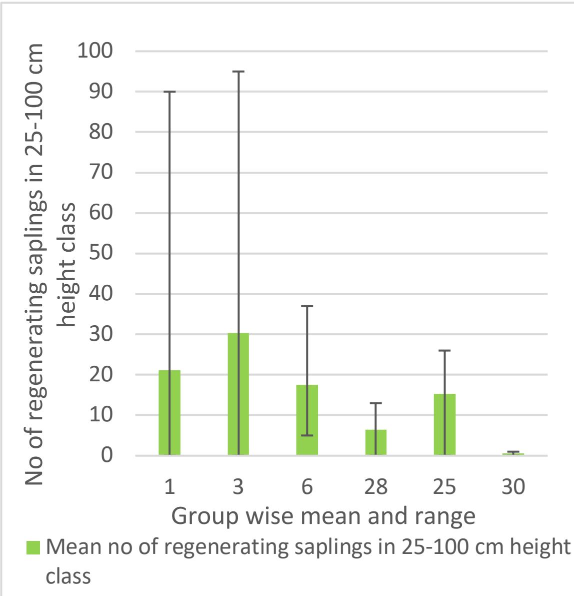
a) 25-100 cm

b) 100-200 cm

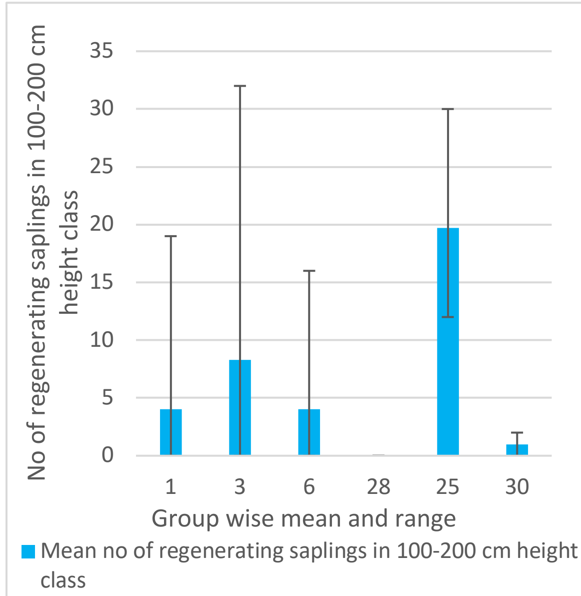
c) 200-400 cm

d) 400+ cm

Figure 3.5: Mean and range of regenerating saplings in size classes; a: 25-100 cm, b: 100-200 cm, c: 200-400 cm and d: 400+ cm.



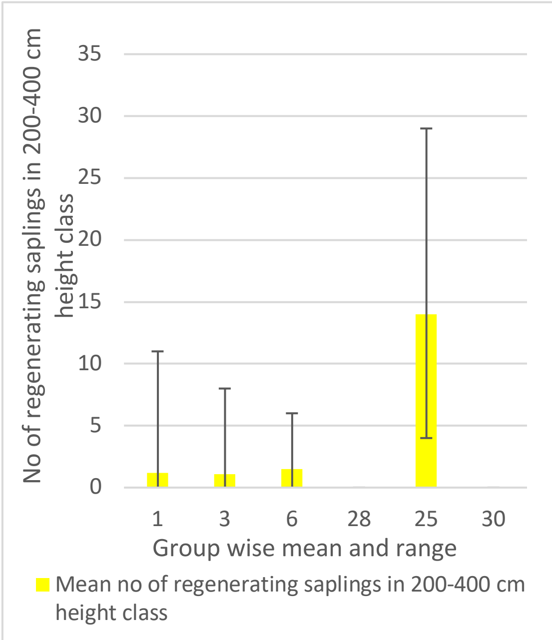
3.5a



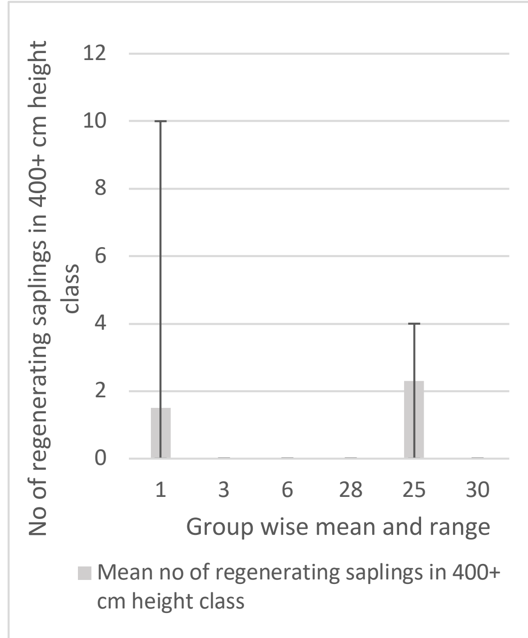
3.5b

The mean and range of saplings growing in the 25-100 cm height class in groups 1 and 3 were the highest recorded at the estate at 21.2 and 30.4 respectively. A moderate number of saplings were found regenerating in groups 6 and 25 while groups 28 and 30 exhibited low to little mean regeneration (6.5 and 0.5) and range probably due to very high canopy, grass cover and leaf litter. Groups 1, 3, 6 and 25 had a low to moderate canopy cover which may have resulted in a higher regeneration in this size class.

For groups 1, 3 and 6, in the 100-200 cm height class, a low to moderate mean number of saplings (4, 8.3 and 4 respectively), but with a greater range were found to be regenerating. Group 25 exhibited the highest mean regeneration (19.7) with a moderate range, maybe because it had the lowest canopy cover which allowed ample amount of light to reach the understory. Little or no regeneration was observed in groups 28 and 30.



3.5c



3.5d

The mean number of regenerating saplings in 200-400 cm class in groups 1, 3 and 6 was very low (1.1 to 1.5). The best mean sapling regeneration (14) in this class with the greatest range was recorded in group 25. No regeneration was recorded in groups 28 and 30. Regeneration of saplings in the 400+ cm class was observed only in groups 1 and 25. Even with just 3 plots, group 25 had a higher mean regeneration (2.3) than group 1 (1.5), group 3 (0) and group 6 (0) that had 12, 8 and 4 plots respectively. Group 25 had the highest mean number of regenerating saplings as well (~50) and the most even size class spread followed by groups 3 and 1. Group 30 exhibited the worst mean regeneration (~2 saplings). The saplings growing in the 25-100 cm class were also found in every group.

A downward trend in sapling regeneration was observed with an increase in size classes that is, the highest number of saplings were recorded in 25-100 cm class and lowest in 400+ cm class, as seen in table 3.5. The most abundant sapling found to be regenerating across all size classes was *A. pseudoplatanus* followed by *F. excelsior*. These two species grow exceptionally well in both light and dense canopies and resist grazing to an extent which may have explained their high numbers in all size classes.

Table 3.5: Regeneration in 25-100, 100-200, 200-400 and 400+ cm class by group

	25-100 cm	100-200 cm	200-400 cm	400+ cm
Total saplings	627	191	71	25
Groups (G) with best regeneration (Plot name with highest number of saplings in paranthesis)	G1 & G3; 79.2% of all saplings G1 (Duc3 – 90) & G3 (RF2 – 95)	G3 & G25; 65.4% of all saplings G3 (RF2- 32) &G25 (Spr3 – 30)	G1 & G25; 78.8% of all saplings G1 (Ros3 – 11) & G25 (Spr2- 29)	G1 & G25; 100% saplings G1 (Ros3 – 10 saplings) G25 (Spr3- 4)
Worst regeneration	G28 & G30.	G28 & G30.	G28 & G30	G3,6,28 & 30
Most abundant sapling species in group with best regeneration (number in parenthesis)	G1: *F. excelsior* (144) & *A. pseudoplatanus* (46) G3: *F. excelsior* (104) & *F. sylvatica* (71)	G3: *C. monogyna* (20) & *F. excelsior* (15) G25: *A. pseudoplatanus* (23) and *F. excelsior* (19)	G25: *A. pseudoplatanus* (20) & *F. excelsior* (13) G1: *A. pseudoplatanus* (10), *F. excelsior* (2)	G1: *A. pseudoplatanus* (9) and *C. monogyna* (4) G25: *A. pseudoplatanus* (3) and *F. excelsior* (2).

Table 3.6: Mean number of each species regenerating in each height class per plot by group, with number of plots (n) in which the species occurred, in parentheses

Group wise Species	**Regeneration (in cm)** : **Mean number of saplings per plot in each height class (and number of plots/n, in which the species occurred in)**			
	25-100 cm	**100-200 cm**	**200-400 cm**	**>400 cm**
Group 1 (n = 12)				
Acer pseudoplatanus	3.8 (5)	1.8 (2)	0.8 (1)	0.75 (1)
Alnus glutinosa	0	0	0.08 (1)	0.16 (2)
Aesculus hippocastanum	0.6 (1)	0	0	0
Corylus avellana	2.5 (2)	0.16 (1)	0	0
Fagus sylvatica	0.08 (1)	0	0.08 (1)	0
Fraxinus excelsior	12 (6)	0.5 (3)	0.16 (1)	0.08 (1)
Crataegus monogyna	0	0.16 (1)	0	0.33 (2)
Ilex aquifolium	2.08 (1)	0.25 (1)	0	0
Prunus laurocerasus	0	0	0	0.16 (1)
Unknown	0	1.08 (1)	0	0
Group 3 (n = 8)				
Acer pseudoplatanus	4.9 (4)	1 (1)	0	0

Crataegus monogyna	2.9 (2)	2.5 (3)	0.125 (1)	0
Fagus sylvatica	8.9 (4)	1.75 (2)	0	0
Fraxinus excelsior	13 (3)	1.9 (2)	0.5 (1)	0
Buxus sempervirens	0.4 (1)	0.25 (2)	0	0
Prunus laurocerasus	0.4 (1)	0	0.5 (1)	0
Ilex aquifolium	0	0.9 (1)	0	0
Group 6 (n = 4)				
Acer pseudoplatanus	1.25 (1)	1 (1)	0	0
Fraxinus excelsior	11.5 (3)	0	0	0
Crataegus monogyna	0.5 (1)	1.25 (1)	1 (1)	0
Ulmus glabra	4.25 (2)	1.75 (1)	0	0
Fagus sylvatica	0	0	0.5 (1)	0
Group 28 (n = 2)				
Acer pseudoplatanus	4.5 (1)	0	0	0
Fraxinus excelsior	2 (1)	0	0	0
Group 25 (n = 3)				
Acer pseudoplatanus	2 (1)	7.7 (3)	6.7 (3)	0.7 (2)
Fraxinus excelsior	6 (2)	6.3 (3)	4.4 (3)	1 (2)

Aesculus hippocastanum	1.3 (1)	0	0	0.3 (1)
Quercus petraea	2.7 (1)	1.3 (1)	2.3 (1)	0
Ilex aquifolium	2 (2)	2 (1)	0	0
Fagus sylvatica	0.7 (1)	1.7 (1)	0.7 (1)	0.3 (1)
Corylus avellana	0	0.7 (1)	0	0
Group 30 (n = 2)				
Acer pseudoplatanus	0	0.5 (1)	0	0
Fraxinus excelsior	0.5 (1)	0.5 (1)	0	0

F. excelsior showed the best regeneration in the 25-100 cm class across all groups except group 28 where *A. pseudoplatanus* had better regeneration. The best overall regeneration in the 100-200, 200-400 and 400+ cm classes across all groups was seen for *A. pseudoplatanus. Crataegus monogyna* was not as common as *F. excelsior* and *A. pseudoplatanus* but was found regenerating in all height classes and in a number of plots indicating good regeneration.

Alnus glutinosa, Buxus sempivirens and *Ulmus glabra* saplings were each found in one group; group 1, 3 and 6 respectively, indicating poor regeneration. Groups 1 and 25 had a moderate diversity of sapling species (10 and 7 species respectively) across a range of size classes while groups 28 and 30 had very low sapling diversity (2 species) mostly restricted to small size classes.

3.6 Herbivory Regime

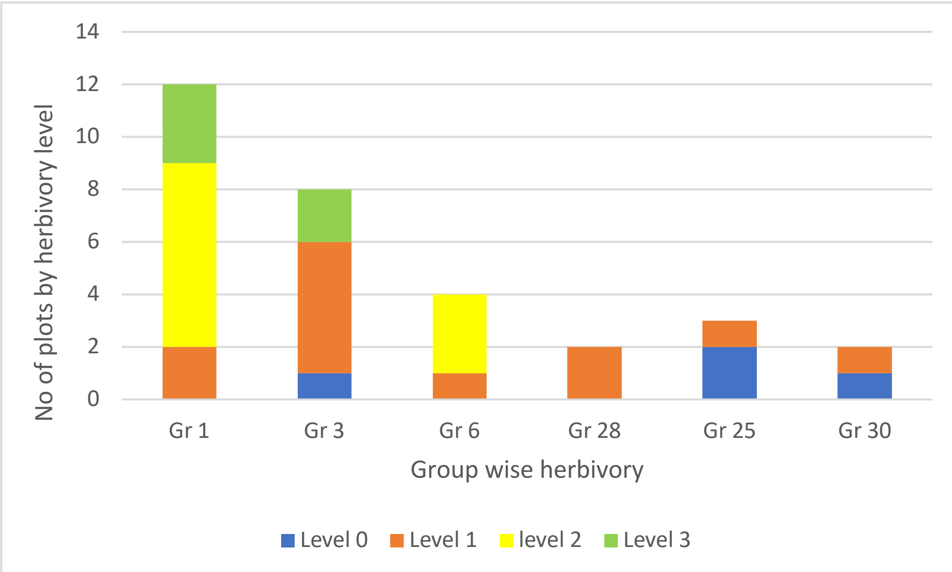


Figure 3.6: Plot wise herbivory regime for each group.

Among groups 1 and 3, herbivory was spread across a number of levels (level 1, 2, 3 in group 1 and 0, 1, 3 in group 3 respectively) which was probably due to the fact that they had very high number of plots (12 and 8 respectively) from multiple sites exhibiting a wide range of herbivory. These groups included plots from River Forest 2, Duckpond and Athronin (sites with level 3 herbivory) where red deer and its trails were abundant. Groups 6, 25 and 30 exhibited herbivory over two levels ie (level 1, 2 in group 6 and 0, 1 each in groups 25 and 30 respectively), while group 28 only exhibited level 1 herbivory. Groups 25 and 28 had an excess of leaf litter while group 30 was fenced which may have resulted in low herbivory. The most common herbivory was level 1 as it was observed in all groups.

3.7 Factors Affecting the Regeneration of Saplings

Three major factors were found to be affecting the regeneration of saplings at Dunsany estate:

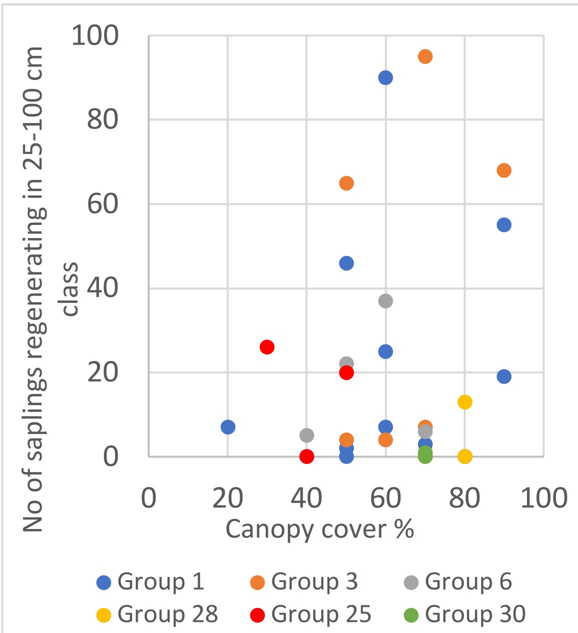
1) Canopy Cover

2) *Rubus* Cover

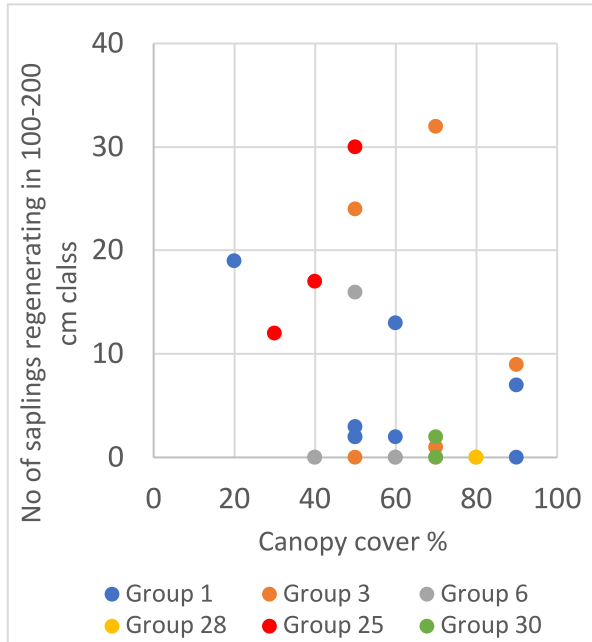
3) Herbivory

For the 25-100 cm size class, a high number of saplings (vs canopy, *Rubus* cover and herbivory) were recorded in groups 1 and 3, 100-200 cm size class in group 25 and 3, 200-400 cm size class in group 25 and 400+ cm size class in group 1. The following scatter plots (Fig. 3.7) illustrate the relationship of these three factors with regeneration of saplings in the four size classes.

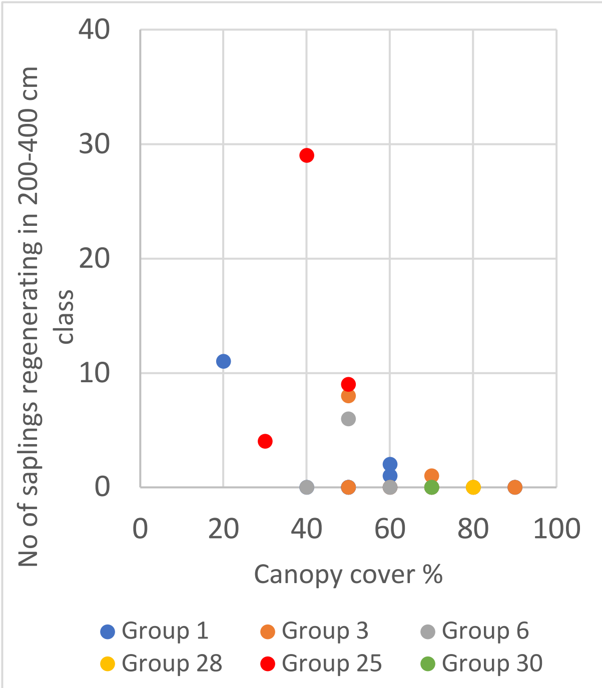
Figure 3.7: Relationship between canopy cover (%) with the number of saplings regenerating in the size classes; a: 25-100 cm, b: 100-200 cm, c: 200-400 cm and d: 400+ cm respectively

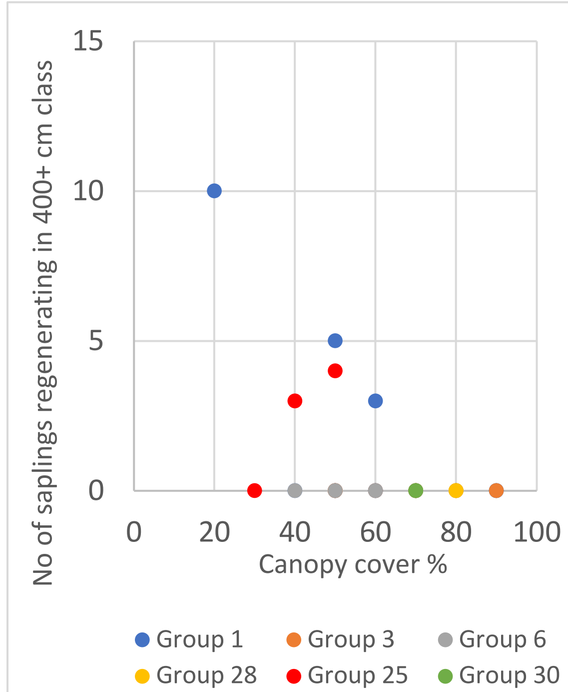


3.7a



3.7b





3.7c 3.7d

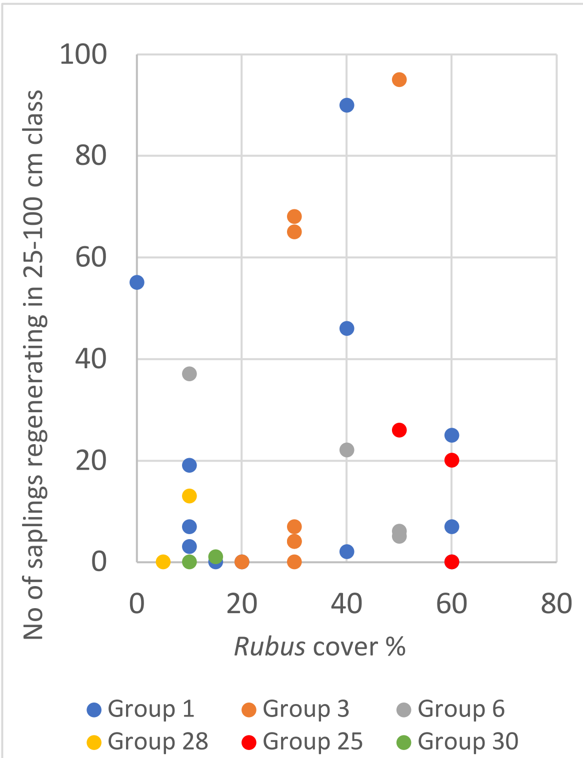
The plantations had a higher canopy cover than woodlands. An overall increase in number of saplings in the 25-100 cm class was observed with increasing canopy which meant that smaller saplings were able to grow well in dense canopies. While sapling numbers in the larger classes especially 200-400 and 400+ cm decreased with increasing cover. The best regeneration with canopy cover across all size classes was recorded in group 25 (lowest cover: 44%) followed by group 1 (60% cover).

Table 3.7: Relationship between sapling abundance and canopy cover for the four size classes.

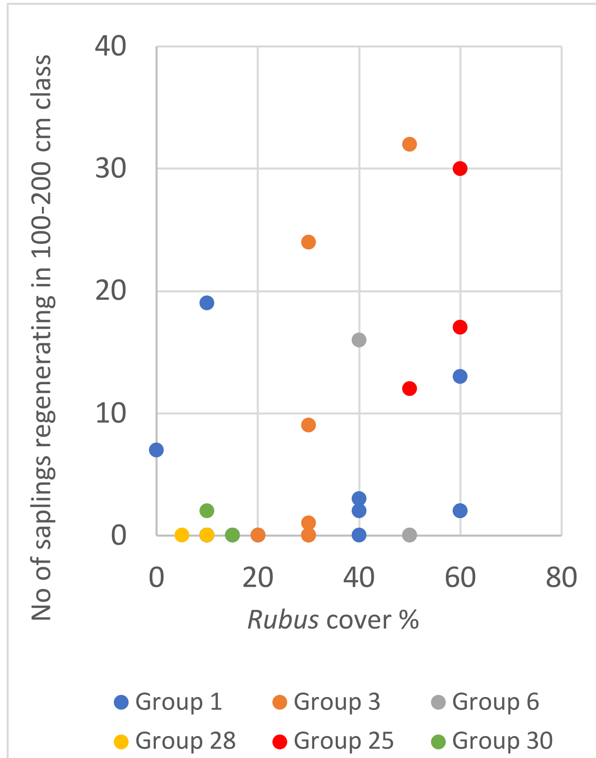
	25-100 cm	100-200 cm	200-400 cm	400+ cm
Canopy cover range at which most saplings were found to be regenerating	50-90%; 589 or 94% of all saplings.	20-60%; 140 or 73.3% of all saplings.	20-50%; 61 or 86% of all saplings.	20-60%; 25 or 100% saplings.

A higher number of small saplings (25-100 cm) were recorded in high canopy cover, while the larger size class saplings were restricted to lower canopy cover.

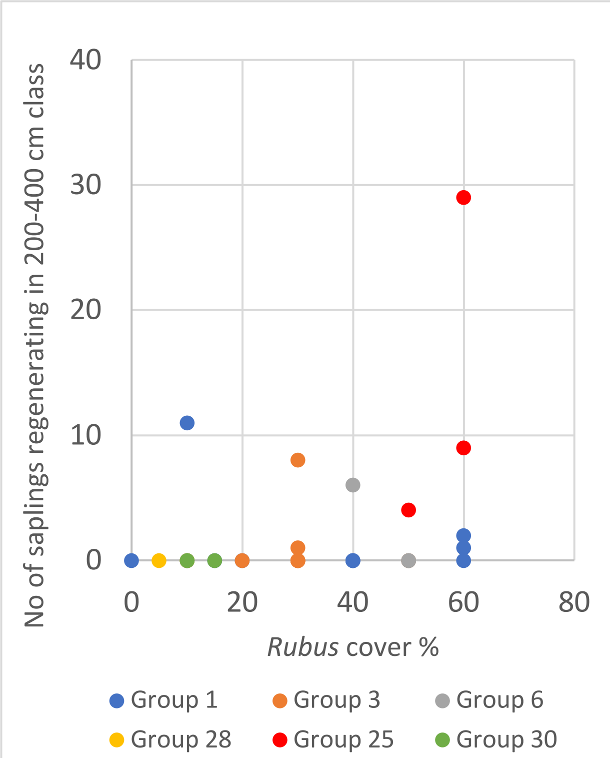
Figure 3.8: Relationship between *Rubus* cover (%) with the number of saplings regenerating in the four size classes; a: 25-100 cm, b: 100-200 cm, c: 200-400 cm and d: 400+ cm respectively

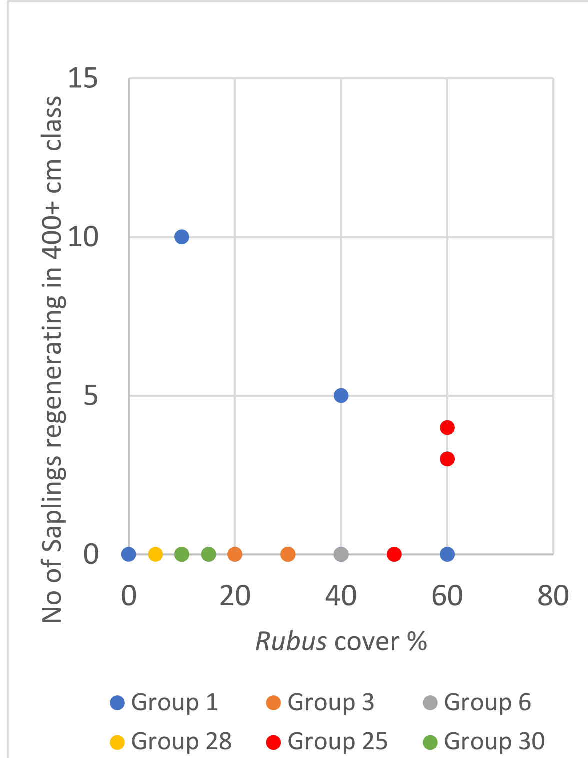


3.8a



3.8b





3.8c 3.8d

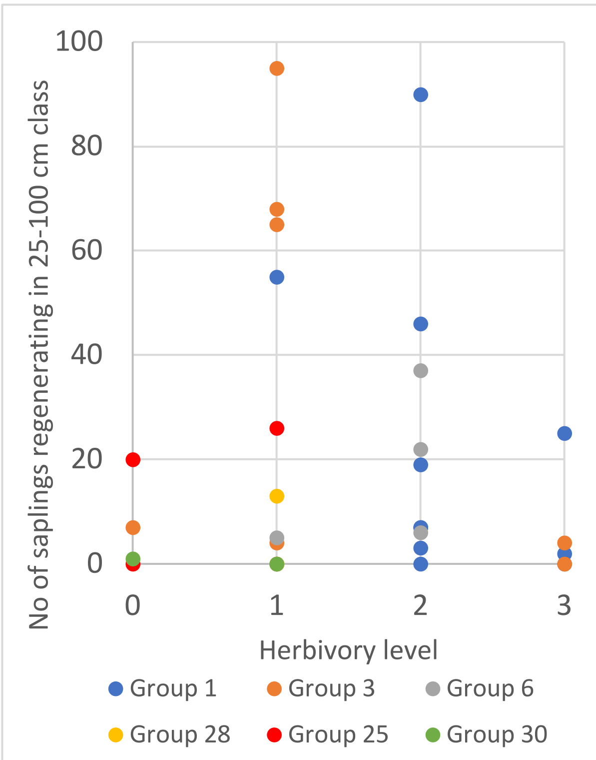
With the exception of group 25, woodlands had a higher *Rubus* cover than plantations. The number of saplings in 100-200 cm class increased with increasing *Rubus* cover. The weak negative relationship of *Rubus* cover with saplings in the 400+ cm size class could not be justified as majority of plots had zero saplings (in the 400+ cm size class) irrespective of *Rubus* cover. The best overall regeneration across all size classes with *Rubus* cover was seen in Group 25 (highest *Rubus* cover: 56.6%) followed by group 1 (30.4%) and group 3 (31.25%). No clear trend was recorded in 25-100 cm and 200-400 cm classes.

Table 3.8: Relationship between *Rubus* cover and sapling abundance for the four size classes

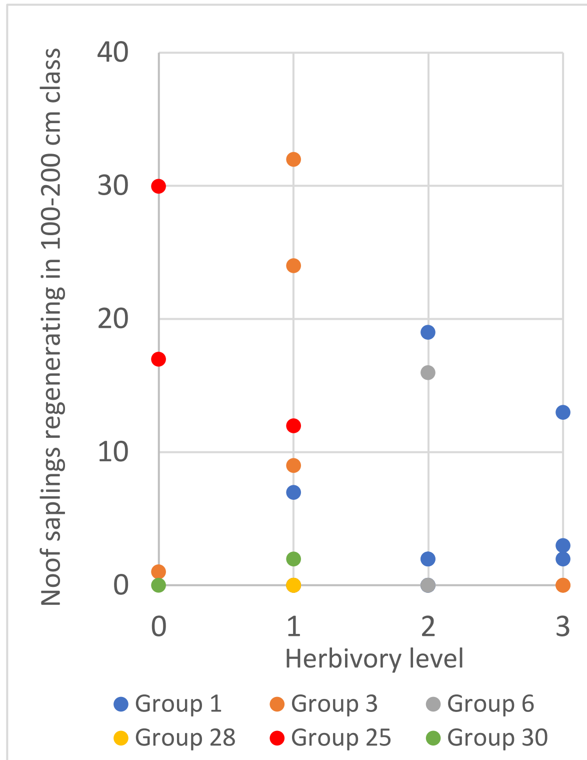
	25-100 cm	100-200 cm	200-400 cm	400+ cm
Rubus cover range at which most saplings were found to be regenerating	0-40%; 442 or 70.5% of all saplings	20-60%; 163 or 85.3% saplings	20-60%; 60 or 84.5% saplings	40-60%; 15(very few) or 60% of saplings

Majority of saplings in the smaller size class (25-100 cm) were restricted to lower *Rubus* cover while saplings in the larger size classes were regenerating in moderate *Rubus* cover.

Figure 3.9: Relationship between Herbivory and number of saplings regenerating in the four size classes; a: 25-100 cm, b: 100-200 cm, c: 200-400 cm and d: 400+ cm respectively



3.9a



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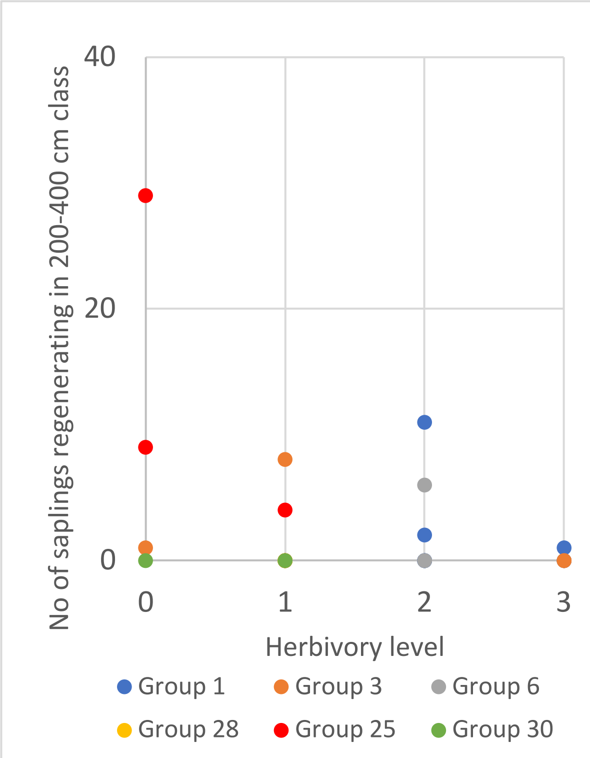
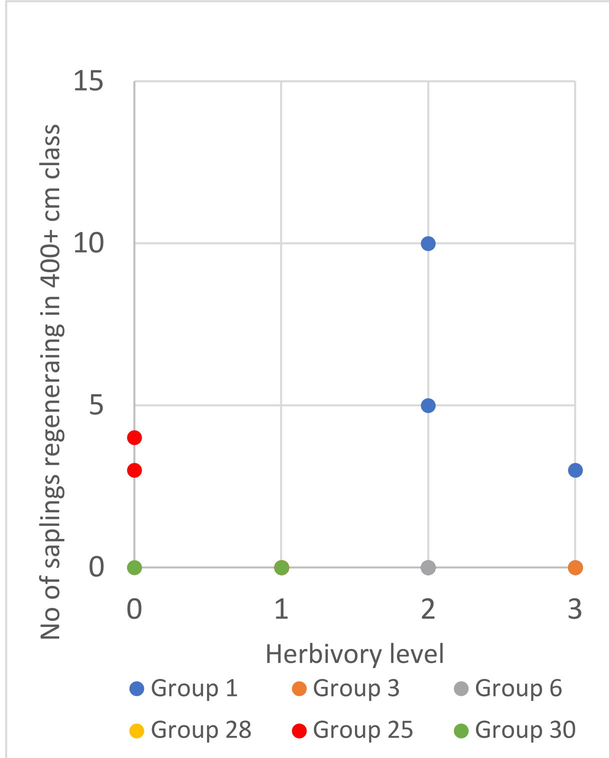


3.9c



3.9d

The herbivory levels in woodlands were higher than plantations. No clear trend was observed in the 25-100 cm and 400+ class while sapling numbers decreased with increasing herbivory in 100-200 cm and 200-400 cm classes. Lowest number of saplings in all size classes were recorded at level 3 and highest at level 1 (25-100 and 100-200 cm class), level 0 (200-400 cm) and level 2 (400+ cm). The best regeneration across all size classes with herbivory was observed in group 25 (lowest herbivory).

Table 3.9: Relationship between herbivory and sapling abundance for the four size classes

	25-100cm	100-200 cm	200-400 cm	400+ cm
Herbivory level at which most saplings were found to be regenerating	Level 1; 331 or 52.8 % of all saplings	Level 1; 86 or 45% of saplings	Level 0; 39 or 55% of saplings	Level 2; 15 or 60% of saplings.

Almost half of the saplings in the smaller and moderate size classes (25-100 and 100-200 cm) were regenerating at level 1 herbivory while larger size class saplings were restricted to level 0 and 2 (very few in 400+ cm class) herbivory respectively.

Table 3.10: Mean number of seedlings (0-25 cm in height) per plot for each species by group

Abbreviations:
Abie: Abies alba
Aesc: Aesculus hippocastanum
Taxu: Taxus baccata

For rest of the abbreviations please refer to table 3.3.

	Mean Number of Seedling species per plot by group												
Group	*Frax*	*Acer*	*Fagu*	*Quer*	*Cory*	*Ilex*	*Crat*	*Ulmu*	*Alnu*	*Taxu*	*Abie*	*Aesc*	*Prun*
1	83.9	23.2	8.1	1.8	4	2.3	4.8	5.8	0.1	0.8	0.4	1.3	1.7
3	80.3	45.5	38.5	1.1	1	0.1	13	4.6	0	0.6	0.3	0.1	0.1
6	46	10	1.3	2.5	0	0	8	8	0	0	0.3	0	0
28	63.5	21.5	7.5	2	0	1	2.5	1	0	0	0	0	0
25	38	3	0.3	4.3	2.7	3.3	0	0	0	0	0	0	0
30	3.5	3.5	0	1	0	0	0	0	2.5	0	0	0	0

The three most abundant seedling species at the estate were *F. excelsior* (total 2081), *A. pseudoplatanus* (741) and *F. sylvatica* (426) and were found in all the groups (except *F. sylvatica*; found in 5 groups). The least abundant were *A. glutinosa* (6), *A. alba* (8) and *T. baccata* (15). The highest total number of seedlings at 1657 were recorded in group 1 out of which 1007 and 278 belonged to *F. excelsior* and *A. pseudoplatanus* respectively, followed by group 3 in which a total of 1482 seedlings were recorded out of which 642 belonged to *F. excelsior*, 364 to *A. pseudoplatanus* and 308 to *F. sylvatica* respectively.

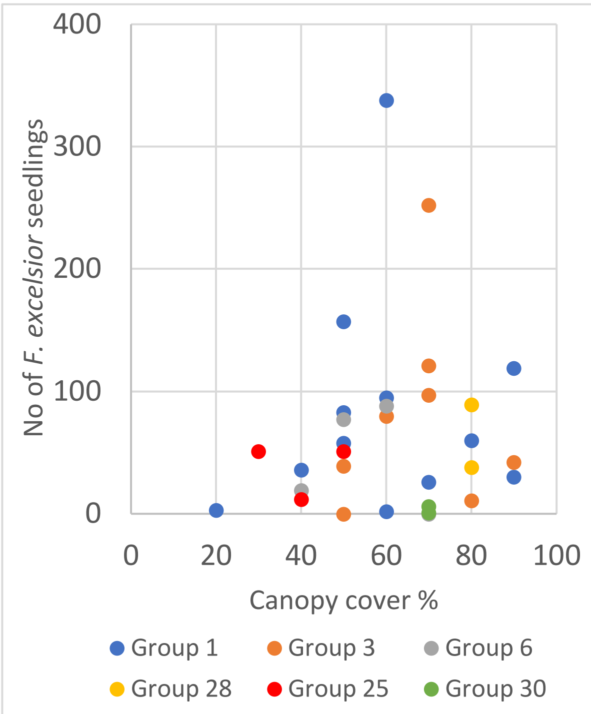
3.8 Factors Affecting the Number of Seedlings

The number of seedlings were also affected by canopy, *Rubus* cover as well as herbivory and scatter plots were created for *F. excelsior, A. pseudoplatanus* and *F. sylvatica* seedling numbers and the total number of seedlings.

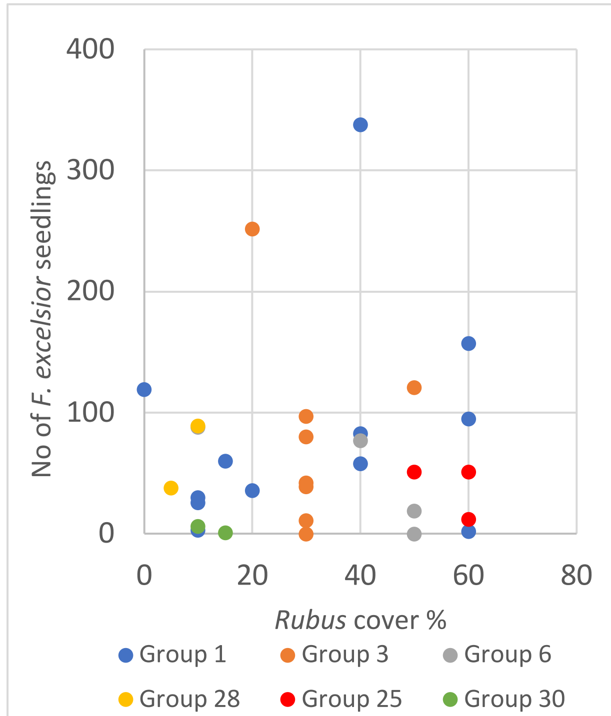
Table 3.11: *F. excelsior, A. pseudoplatanus* and *F. sylvatica* seedling numbers by group

	F. excelsior	*A. pseudoplatanus*	*F. sylvatica*
Total seedlings	2081	741	426
Group (G) with highest numbers (Plot name with highest number of seedlings in paranthesis)	G1: 1007; 48.4% of all seedlings (Duc3: 338)	G3: 364; 49.1% of all seedlings (Ath1: 172)	G3: 308; 72.3% of all seedlings (RF2: 171)
Group with lowest number	G30 (7)	G30 (7)	G30 (0)

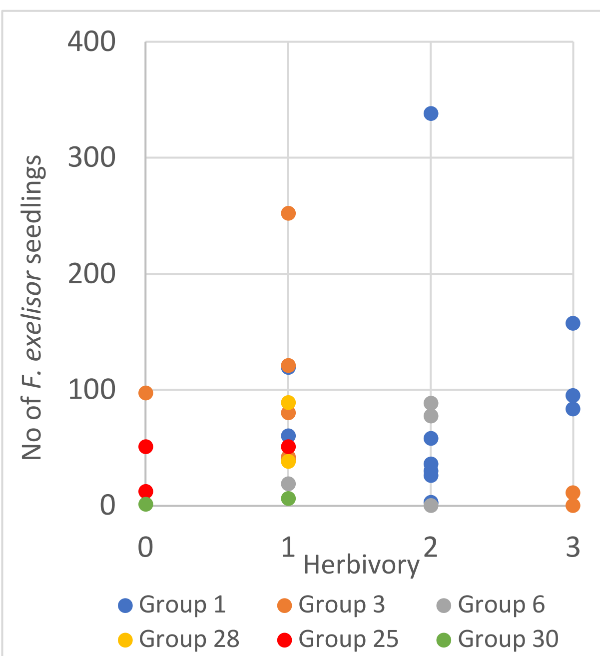
Figure 3.10: Relationship between the number of *F. excelsior* seedlings and a: Canopy, b: *Rubus* Cover and c: Herbivory.



3.10a



3.10b



3.10c

The number of *F. excelsior* seedlings in the woodlands were higher compared to plantations.

Canopy cover

A weak positive relationship was observed with canopy cover. The overall numbers increased with increasing cover until 70% and then dropped at 80-90%. A moderate number was recorded in group 25(~45% cover) and group 28 (80% cover) and very few in group 30 (70% cover). The highest seedling number across all groups was recorded at 40-70% cover; 1683 or 80.8% of all seedlings.

***Rubus* Cover**

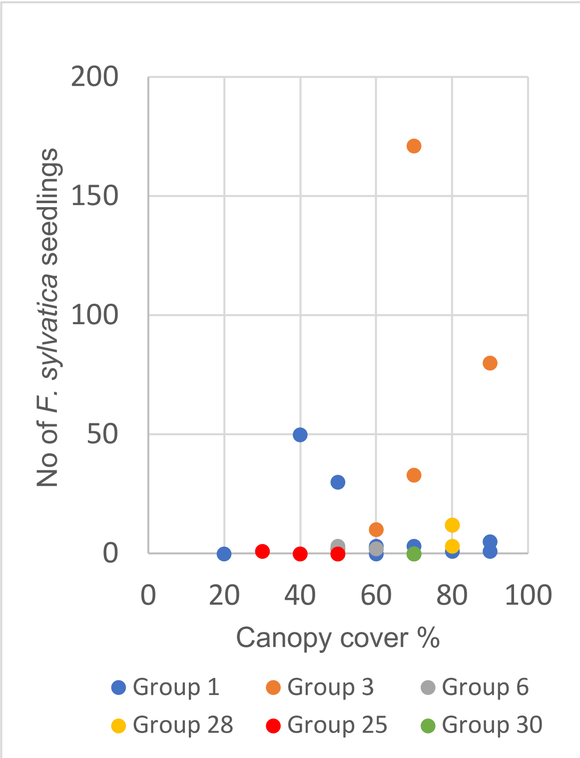
No clear trend was observed with *Rubus* cover. The highest number of seedlings were recorded at 30-60% cover; 1333 or 64% of all seedlings.

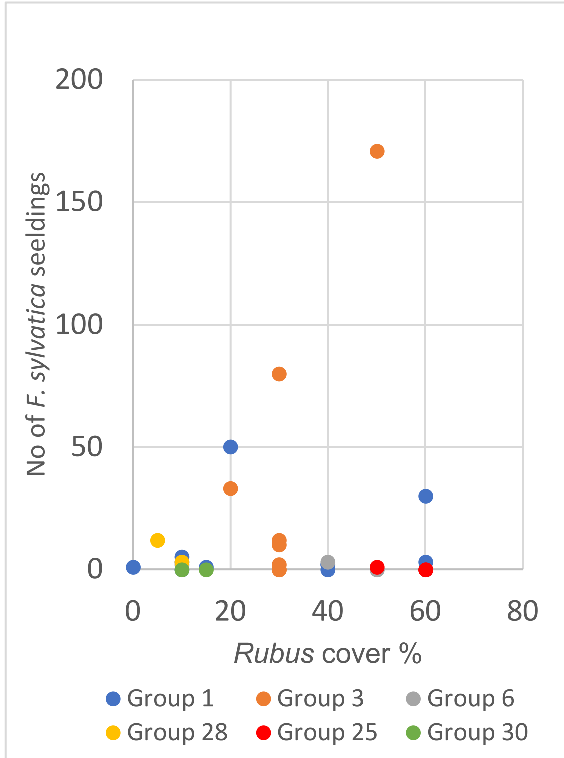
Herbivory

A weak positive trend was observed with herbivory, with numbers increasing from level 0-2 for groups 1, 3, and 6. Seedling numbers were constant for group 25, 30 at level 0-1. The highest numbers were recorded at level 1; 916 or 44% of all seedlings.

No clear trends for *A. pseudoplatanus* seedlings with canopy, *Rubus* cover and herbivory were observed.

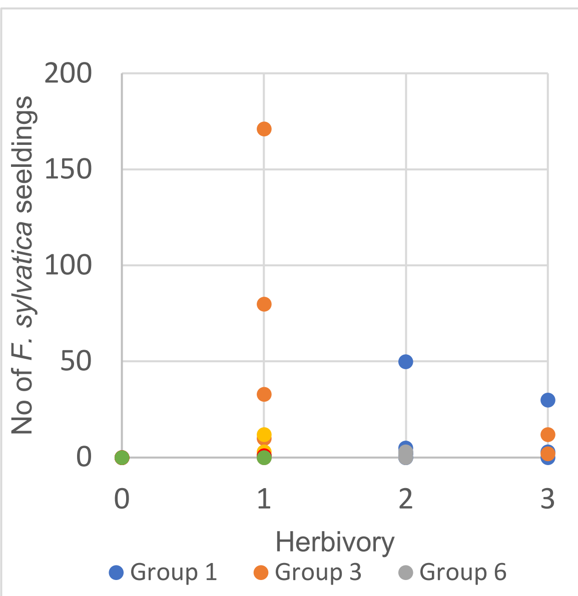
Figure 3.11: Relationship between the number of *F. sylvatica* seedlings and a: Canopy, b: *Rubus* Cover and c: Herbivory.





3.11a

3.11b



3.11c

The number of *F. sylvatica* seedlings were higher in woodlands as compared to the plantations (especially in groups 1 and 3 and low in groups 6 and 28).

Canopy Cover

No clear trend was observed with increasing canopy cover. The highest numbers were recorded between 60-80% cover; 277 or 65% of all saplings

***Rubus* cover**

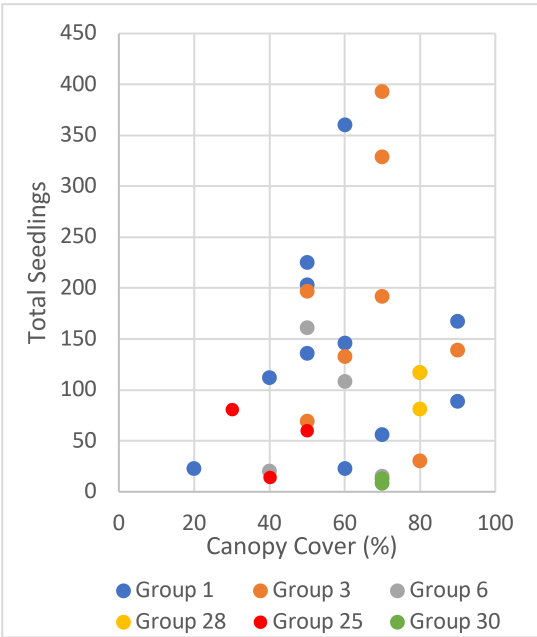
A weak negative relationship was observed with *Rubus* cover. The highest number of seedlings were recorded at 20-40% cover; 194 or 45.5% of all seedlings.

Herbivory

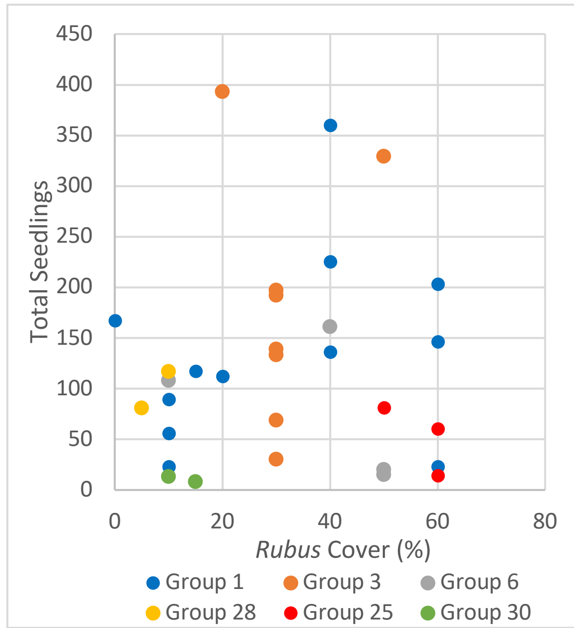
A weak negative relationship was observed with increasing herbivory. The highest numbers were recorded at level 1 herbivory: 312 or 73.2% of all seedlings.

Total Seedling Analysis (seedling numbers of all species recorded in a plot of a group)

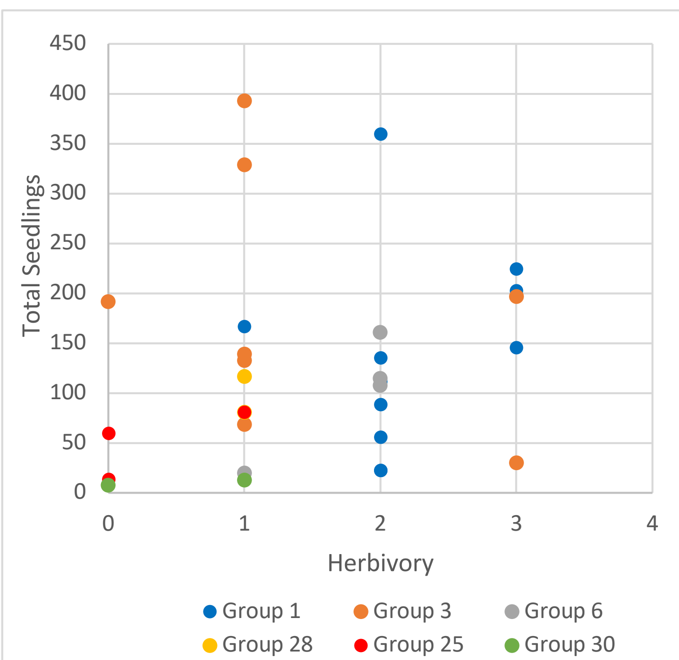
Figure 3.12: Relationship between the total number of seedlings with a: Canopy, b: *Rubus* Cover and c: Herbivory.



3.12a



3.12b



3.12c

The total number seedlings recorded at the estate were more in woodlands as compared to plantations.

Canopy Cover

An overall increase in total number of seedlings across groups was observed with increasing canopy. The highest numbers were recorded at 50-70% canopy: 2827 or 74% seedlings.

***Rubus* Cover**

An unclear trend for total seedlings was observed with increasing *Rubus* cover. The highest seedling numbers were recorded at 0-30% cover: 2044 or 53.5% seedlings.

Herbivory

No clear trend was observed with herbivory. The highest numbers were recorded at level 1: 1659 or 44% seedlings.

3.9 Description of the Six Groups on the basis of Woodland Structure, Regeneration and Herbivory Regime.

Table 3.12: Description of woodland and plantation groups based on structure and composition

Abbreviations:

DBH: Diameter at breast height

n: number of plots

Sp: Species

Group	Canopy Cover	Tree Height	*Rubus* Cover	Bare Ground Cover	Herb Cover	Grass Cover	Tree Diversity	DBH	n
1	Moderate & variable	Moderate & variable	variable	variable	Well developed	little	Highest (10 sp)	Highest	12
3	Moderate to High	variable	moderate	variable	Well developed	little	High (7 sp)	low	8

6	Moderate & variable	High	Well developed & variable	little	Moderate & variable	Moderate &variable	High (7 sp)	High	4
28	Highest	Shortest	low	Highest	Moderate	little	Low (2 sp)	Very low	2
25	Lowest	Highest	Best developed	low	Moderate	N/A	Low (2 sp)	High	3
30	High	Shortest	Low	-	Low	Highest	Low (2 sp)	Lowest	2

Table 3.13: Description of woodlands and plantation groups based on regeneration, herbivory regime and seedling number and diversity.

Abbreviations: 25-100, 100-200, 200-400 and 400+ cm: Regeneration of saplings in the 25-100, 100-200, 200-400 and 400+ cm height classes respectively.

Group	**25-100 cm**	**100-200 cm**	**200-400 cm**	**400+ cm**	**Herbivory Regime**	**Seedling Diversity**
1	High & variable	Moderate	Low and variable	High	Highly Variable	Highest (13 sp)
3	Highest & variable	High	Low	-	Highly variable	High (12 sp)
6	Moderate	Moderate	Low	-	Variable	Moderate (7 sp)
28	Low	-	-	-	Not variable	Moderate (7 sp)
25	Moderate	Highest	Highest	Highest	variable	Low (6 sp)
30	Little	Little	-	-	variable	Very low (4 sp)

Chapter 4
Discussion

This vegetation survey was the first of its kind conducted at Dunsany estate in County Meath and provided a baseline for future analysis and surveys. A total of 31 plots were set up at 7 semi-natural woodlands and 3 plantation sites. The semi-natural woodlands surveyed may have also been very old plantations or fragments of woodlands. Seedling numbers and diversity, sapling regeneration, structure and composition along with the herbivory levels at these sites were recorded.

4.1 Canopy Cover

The canopy cover varied among the sites surveyed. The highest mean cover at 77.5% and 80% respectively, was recorded for woodlands and plantations in Duckpond (group 1) and Scots pine-oak plantation (group 28). The plantations had an overall higher and almost constant cover compared to woodlands, as a large number of trees were growing very close to each other. An exception was the Sitka spruce plantation (group 25) where cover ranged from 30 to 50%. At this plantation, fewer trees were growing further away from each other, which may have resulted in the low cover.

The regeneration across all size classes was found to be higher in groups with a lighter canopy such as groups 1 and 25 compared to those with denser canopies (group 28, 30). In groups 28 and 30, the most abundant trees were oak and alder. Oak (Higgins, 2001) and alder (Deal and Harrington, 2006) when growing in dense stands cast a very dense shade. The most abundant trees in woodlands were ash and sycamore and these have a light (Wardle, 1961) and moderate (Ambrazevičius, 2016) canopy.

4.1.1 Relationship of number of ash, sycamore, beech seedlings and the total number of seedlings with canopy cover

The number of ash seedlings increased with increasing canopy cover. Ash is a species that can tolerate dense canopies and can grow well under it for up to 28 years (Gardner, 1976). This may explain its high numbers under dense canopies. No clear trends were seen for beech and sycamore seedlings with canopy cover.

A total of 3817 seedlings were recorded at the estate out of which the most abundant (3248 or 85.1%) were ash, sycamore and beech. These three species along with oak (Higgins, 2001), elm (Thomas *et al.,* 2018), yew (Perrin, 2002), holly (Scottish Forestry, 2019) can grow well in shade and probably resulted in an overall positive relationship of total seedlings with canopy cover. According to Watt (1947), ash and sycamore are the first seedlings to grow in large numbers in English woodlands. Both species can tolerate a variety of soils (moist, dry, basic, well-drained) and are shade-tolerant, which allows them to remain dormant and grow under the canopy for years. They exhibit increased growth in presence of light in gaps and clearings (Rusanen and Myking, 2003).

4.1.2 Relationship of canopy cover with the number of saplings regenerating in the four size classes

A positive relationship was observed between saplings in 25-100 cm class and canopy cover. This meant that smaller saplings, 67.2% of which were ash and sycamore, were able to survive and persist in shady areas. The best overall regeneration was recorded in group 25 (Sitka spruce plantation) that also had the lowest canopy cover. But the saplings in the 100-200 cm, 200-400 cm and 400+ cm classes showed a negative trend.

A well-known mechanism of regeneration in semi-natural woodlands is the Watts Gap Phase model (Peterken, 1996). According to Watt (1924) semi-natural woodlands pass through various stages of development and the regeneration of tree species is mainly restricted to the canopy gaps because regeneration is inhibited in areas with a denser shade. He also proposed that the ability of individuals to regenerate well in shady conditions can only be achieved by tolerant species like beech and ash, but these species also need canopy gaps to reach maturity (Ellenberg, 1988).

4.2 Vegetation Diversity

A total of 18 tree species as seedlings, 16 as mature trees and 33 species of ground flora were recorded in the semi-natural woodlands; this compares with, 9 species as seedlings, 6 as mature trees and a ground flora of 19 species in the plantations, making woodlands more diverse than the plantations. It should also be noted that more plots were set up in the semi-natural woodlands compared to plantations. The most common ground flora species in the six groups was bramble (*Rubus fruticosus*), found in twenty-two woodland and all seven plantation plots studied. *Rubus* is very common in woodlands and exhibits a high growth rate in light as opposed to shady areas, tolerates a variety of soils types and outcompetes other species for space, sunlight and nutrients (Harmer, 2007).

4.2.1 Factors affecting the diversity of vegetation

Fewer species were recorded in plantations as compared to the semi-natural woodlands. This may have been due to a denser canopy, high amount of leaf litter and regular management before the estate was rewilded. The dense canopy and tree stands of one or two species may have also physically or biotically limited seed dispersal, affecting the overall vegetation diversity in plantations. The woodlands surveyed had never been used for agriculture, so the time since rewilding was ambiguous. They were much larger in area compared to the plantations, had a lighter canopy and little leaf litter. This could have resulted in higher seedling/tree diversity and numbers.

Except for ash and sycamore, a higher number and diversity of seedlings were found in sites where canopy cover was lower. No Scots pine and Sitka spruce seedlings were recorded at the estate while yew and Silver fir seedlings were uncommon but found at multiple sites such as River forest, Rosewood, Duckpond and River Forest 2. Even though wych elm is an uncommon species in Meath (Perrin *et al.*, 2008), a moderate number of its seedlings and saplings were recorded in groups 1 and 2 (in River forest and River Forest 2 sites). It is a very shade-tolerant species (Grime *et al*., 2007) and shows increased growth in presence of light (Säumel and Kowarik, 2013). The tree abundance was highest for ash followed by sycamore and Scots pine in woodlands and oak followed by alder in plantations.

The highest seedling, tree and ground flora diversity were recorded in groups 1 and 2 respectively, especially in River Forest 2 (13 seedling and 10 tree species) and Duckpond (13 seedling and 8 tree species) sites. In River Forest 2, the average canopy cover was only 50% which may help to explain the high seedling diversity and numbers. In other sites like Bluebell, Horse chestnut woodland, the canopy cover was higher, while in Athronin forest, the herbivory levels were very high, probably limiting the number of species growing there.

4.2.2 Findings from other studies

Fahy and Gormally (1998) in County Galway studied and compared a semi-natural oak woodland, a clear-fell site where Sitka spruce was harvested and a Sitka spruce plantation. They recorded 41 plant species in the oak woodland, 38 in the clear-felled site and only 19 in the Sitka spruce plantation, concluding that semi-natural woodlands had a greater range of species compared to plantations. These results were very similar to the present study conducted at Dunsany.

Coote *et al.* (2012), studied 55 plantations and 20 semi-natural woodlands across Ireland. They found that plantations and woodlands differed on the basis of an understory and concluded that plantations mostly lacked an understory and had a poor shrub cover. Oliver and Larson (1996) described that plantations resembled the ‘stem exclusion stage’ of forests which occurs when all growing space is occupied and the new plants are unable to regenerate. Plantations are frequently clear-felled before reaching the stem exclusion phase. As a result, they never develop a vertical layer that is essential for birds and other animals for food and shelter.

4.3 Herbivory

An important natural phenomenon in semi-natural woodlands is herbivory. High levels of herbivory can affect the growth of plant and tree species, while no herbivory at a site can have a negative effect too, as plants like *Rubus, H. helix* can easily dominate the ground layer inhibiting the growth of other tree seedlings and plants (Perrin *et al.,* 2008).

4.3.1 Effect of herbivory on vegetation

The main herbivore at the estate was the native red deer. Herds of red deer and many deer trails were seen in Athronin, Duckpond and River Forest 2 sites. Irish hares are also responsible for consuming seedlings (Edlin, 1965; Rodwell, 1991), and a few were seen during the study period. The herbivory levels were much lower in plantations (levels 0 and 1) compared to the woodlands (levels 0-3 recorded). In the woodlands, level 3 or high herbivory was recorded in groups 1 and 2 at sites like Athronin, Duckpond and River Forest 2.

The high canopy cover, poorly developed shrub and field layer and large amounts of leaf litter may have limited the use of plantations by herbivores. Sites with high herbivory such as Duckpond had low regeneration, while sites with lower herbivory like Sitka spruce plantation, Rosewood, River forest had high regeneration in most classes. In the Alder plantation, both plots had a very high grass cover (80%) but low herbivory. The low herbivory in alder plantation may be due to it being located right next to the main road, which limited the number of deer and other herbivores and it was also fenced unlike the Scots pine and Sitka spruce plantations.

4.3.2 Plant species consumed most frequently

The most frequently consumed species at the estate were hogweed, ash and *Rubus*. At many sites, hogweed was trampled severely and bark stripping on ash trees was seen in Bluebell and Athronin forest. Hogweed flower buds and stalks and ash and *Rubus* leaves and branches were found to be bitten off. No other signs of damage to plants apart from herbivory were recorded during the study period.

Figure 4.1: Evidence of herbivory at the estate; a: Trampled hogweed, b: Hogweed flower buds bitten off, c: *Rubus* leaves and stem bitten off, d: Bark stripping by red deer on an ash tree.

4.1a

4.1b

4.1c

4.1d

Deer eat hogweed stem and leaves while birds are known to consume its seeds (Johnson *et al.,* 1995). But hogweed can withstand herbivory, as it stores a large amount of food reserves in its roots (Tannas, 2004), which may explain it growing in large numbers in sites with high herbivory. Red deer may also be targeting its flowers and buds (tops of flowering stems at Dunsany were often bitten off). This could potentially promote vegetative growth as the large leaves did not appear to be specifically targeted. Red deer prefer broadleaved trees over conifers (Nelson and Leege, 1982). Leaves of ash, rowan (*Sorbus sp*), goat willow (*Salix caprea* L.) and aspen (*Populus tremula* L.), are some of the important sources of food to them (Čermák and Grundmann, 2006). They typically consume plants and trees that lack spines, have larger leaves and longer shoots as it allows them to eat more in one bite (Shipley *et al.,* 1998). Ash produces a large number of leaves that are nutritious and have no spines making it an ideal diet for herbivores (Weber-Blasckhe *et al.,* 2008). Red and fallow deer prefer eating leaves of trees and shrubs that lack spines but have also been known to consume *Rubus* leaves, while birds eat its fruits and seeds (Johnson *et al.,* 1995). Its numbers have been declining in the British broadleaved woodlands where the deer populations are high (Kirby, 2001).

4.3.3 Relationship of herbivory with ash, sycamore, beech seedlings and the total number of seedlings

Ash seedling numbers increased with increasing herbivory. It has been known to resist herbivory to an extent (Hester *et al.,*1996), replace grazed shoot and leaf tissue (Mitchell *et al.,* 1995) and the highest number of ash seedlings were found to be growing at level 1-2 herbivory, which may describe its high growth rate in areas with moderate to high herbivory. In temperate forests and woodlands, moderate levels of herbivory by red deer, hares etc helps in dispersing seeds (via droppings), increasing light and nitrogen levels and opening up regeneration niches which are beneficial to forest species (Picard and Baltzinger, 2012) and may have also led to an increase in the number of ash seedlings at Dunsany. Heavy herbivory could potentially remove seedlings, saplings and result in an increase of unpalatable species or species that are resistant to herbivory (Augustine and McNaughton, 1998) such as *Oxalis acetosella* (Perrin *et al.,* 2011) while an absence of herbivory may probably result in an increase in scrub and ground vegetation which could prevent seedling establishment.

Beech seedling numbers decreased with increasing herbivory. Even though beech seeds are toxic and leaves unpalatable (Cooper and Johnson, 1984), they are consumed by hares, birds, mice, voles and grey squirrels (Harmer, 1994). This may have resulted in the negative trend with increasing herbivory. No clear trends were observed for sycamore seedlings and the total number of seedlings.

4.3.4 Relationship of herbivory with number of saplings regenerating in the four size classes

Saplings numbers in 100-200 cm and 200-400 cm classes were found to decrease with increasing herbivory. This was seen in groups 1, 3 and 25. Herbivory usually has a negative effect on regeneration as deer, sheep and hares affect plant diversity and numbers and cause damage to herb, woody and shrub layers (Boulanger *et al*., 2017)**.** Herbivores in large numbers trample and consume the woodland vegetation, resulting in an increased growth of weeds and unwanted species that can colonize open lands quickly (Kirby and Thomas, 2000). No clear trends were observed for regeneration in 25-100 and 400+ cm classes.

4.3.5 Controlling Herbivory

At Dunsany, herbivory was very low in plantations and moderate in the woodlands surveyed. It is recommended that temporary fences and exclosures be set up at the woodland sites where high levels of herbivory were recorded. Mitchel and Kirby (1990) suggest that the fences may be removed once the saplings exceed the maximum browse height of red deer, which is 1.8m as found by Mayle (1999). Long term fencing of woodlands is not advisable as it increases *Rubus* and *H. helix* numbers, which inhibit herb and ground flora diversity (Perrin *et al.,* 2006) while permanent fencing increases herbivory in the surrounding areas (Perrin *et al.,* 2011). Perrin *et al*. (2006) while studying the woodlands of the Muckross Peninsula in Killarney National Park, southwest Ireland, found that sapling regeneration rate varied greatly between woodlands and also stands within the same woodland, which made it hard to recommend the correct herbivory measures and guidelines. Monitoring regeneration and ground flora regularly within woodlands that are fenced for management is necessary. This ensures that sites are fenced only for a specific time and not for long periods (Perrin *et al.,* 2006). These measures are recommended in Athronin, Duckpond and River forest 2 sites at Dunsany where level 3 herbivory was recorded.

4.4 Defoliation by Ash sawfly larvae (*Tomostethus nigritus*)

Leaves of ash trees at the canopy level were found to be defoliated. Ash sawfly larvae in large numbers were found to be consuming the leaves of ash trees in South Belfast, N. Ireland (AFBI, 2016) and is believed that the same ash sawfly larvae were responsible for defoliating the ash tree leaves at Dunsany estate too.

Figure 4.2 Ash tree leaves defoliated by ash sawfly larvae; a: At canopy level, b: Leaves on entire tree defoliated

4.2a

4.2b

4.5 *Rubus* and its Effect

Rubus is one of the most common shrubs in Irish and English woodlands and is essential to a number of insect, bird and animal species because they feed on its fruits and leaves (Harmer and Willoughby, 2007). But *Rubus* in high numbers can have a negative effect on biodiversity. *Rubus* cover didn't vary greatly in the woodlands surveyed and ranged from 30-37%. Scots pine and alder plantations had the lowest *Rubus* cover which may have been due to a very dense canopy cover, as *Rubus* is a light-demanding species (Balandier *et al.,* 2012).

4.5.1 Relationship of ash, sycamore and beech seedling numbers and the total number of seedlings with *Rubus* cover

Beech seedling numbers decreased with increasing *Rubus* cover. It is a slow-growing species while *Rubus* grows very quickly. It is very likely that *Rubus* may have easily outcompeted it for sunlight and space (Harmer *et al.,* 2010). No clear trends were observed with the number of ash and sycamore seedlings and the total number of seedlings.

4.5.2 Relationship of *Rubus* with the number of saplings regenerating in the four size classes

Rubus is considered to be a species that competes with others for space, nutrition, light etc. But some studies have found that regenerating trees and saplings can be seen growing next to it in semi-natural woodlands. This may imply that it could play a role in the protection of these species from herbivores such as deer (Kelly, 2002). Harmer *et al.* (2010) in their study of a beech woodland in central southern England found that *Rubus* could play a role in the protection of species that grow quickly such are silver birch, ash, willow, sycamore, that is at the same rate as *Rubus*, while oak and beech will not be able to regenerate due to their slow growth. The *Rubus* will rapidly grow large and take up all the light and space required for their growth (Harmer and Morgan, 2007).

The number of saplings in 100-200 cm class increased with increasing *Rubus* cover, possibly because they were the same size as a mature *Rubus* shrub, that could offer them some protection from herbivores. The best overall regeneration was recorded in Sitka spruce plantation which had the highest mean *Rubus* cover (56.6%) and lowest herbivory.

Sapling numbers in 400+ cm class showed a weak negative trend with *Rubus* cover that could not be justified as majority (87%) of the plots surveyed had zero saplings in this size class. The lowest number of saplings (25) were also recorded in the 400+ cm class and only in four plots of the thirty-one surveyed. A possible explanation for the low regeneration could be that *Rubus* in high numbers can act as a weed and negatively affect the growth and regeneration of saplings species that are light demanding (Harmer, 2004). It also competes with other seedlings for sunlight, nutrition, colonizes new areas quickly and provides shelter to rabbits and voles which cause considerable damage to seedlings and saplings (Harmer and Willoughby, 2007). More extensive studies may be needed to prove whether there is a definite decrease in regeneration in the larger size classes with increasing *Rubus* cover. No clear trends were observed for saplings regenerating in 25-100 cm and 200-400 cm classes.

4.6 Regeneration

The regeneration of saplings also varied from one site to the other. Woodland groups had an overall better regeneration compared to the plantations. However, the best regeneration was recorded in group 25 or Sitka spruce plantation (saplings in high number in the larger height classes were found here). The worst regeneration was recorded in alder plantation and a major reason for this was probably the dense canopy cover. Another possible reason for poor regeneration in dense plantations may have been the greater restriction on seed inputs from external sources. This would likely limit seed dispersal and negatively affect the establishment of seedlings and saplings. The downward trend in sapling numbers with increasing size classes recorded in Dunsany could have been due to competition with plants like *Rubus* and other weeds for light and nutrients, herbivory, disease, weather and other environmental conditions, changing soil pH and high canopy cover. One more reason for this downward trend could be the time factor. It would take a much longer time for the saplings to grow 400 cm or more in height especially those that are shade-suppressed. This might be related to changes in past management, and the smaller sapling classes will in time survive and grow and increase numbers in this taller size class.

4.6.1 Regeneration in Sitka spruce plantation (Group 25)

The possible reasons for high regeneration in this plantation could be very low herbivory and canopy cover. But a large amount of leaf litter (made up of the spruce needles) - about 10 cm thick was also found here. This could mean that any tree seeds falling on this leaf litter may have had very little chance of germination, hence the low seedling number and sapling count in the smallest class, 25-100 cm. The saplings recorded in the larger classes must have germinated when the estate was actively managed. At that time there may have been no to low leaf litter and herbivory. Three and two saplings of ash were recorded in the 200-400 cm and 400+ cm size classes respectively. These saplings might have been much older than their size class indicated.

4.6.2 Species exhibiting the best regeneration

Ash was the most abundant species at all sites in the 25-100 cm class followed by sycamore. Ash is able to form a ‘seedling bank’ in which small plants and saplings, which may be fairly old and supressed by the canopy are able to exploit canopy gaps (Wardle, 1961). Another reason for high numbers may have been the proximity of seed sources as there was an abundance of ash trees at the estate. Once they grow larger than the herb layer, saplings regenerate rapidly and have a head start on species that need to germinate from seed (Higgins, 2001).

However, sycamore was more abundant in the 100-200, 200-400 and 400+ cm classes followed by ash. One of the main reasons for high sycamore regeneration apart from the proximal seed source may be a phenomenon called ‘alteration of regeneration’, where it replaces ash as the dominant species (Higgins, 2001). This phenomenon results in an increased regeneration of a species growing under the canopy of an alternate species and vice versa (Waters and Savill, 1992). This in turn leads to a cycle of woodland regeneration (Watt, 1947). It has also been noted for ash, beech and oak where ash (Rackham, 1980) and beech (Peterken, 1996) replace oak as dominant species. The lower regeneration of ash in the larger size classes may also be due to damping off and ash dieback fungus (*Hymenoscyphus fraxineus*) that increase the mortality rate of seedlings and saplings (Wardle, 1959). A few ash saplings were found to be completely wilted due to ash dieback at Dunsany estate.

4.6.3 Findings from other studies

Perrin *et al*. (2008) found that ash was the most abundant species in the <25 cm class and accounted for 69% of all regeneration in their study after which its numbers dropped, while Higgins *et al.* (2004) concluded that ash accounted for 43% of all regenerating species.
Linhart and Whelan (1980) in their survey of two sites in Coed Gorswen National Nature Reserve in the Conway Valley in North Wales also found ash to be most abundant and exhibiting the highest regeneration followed by sycamore and oak.

4.6.4 Moderate regeneration was observed for Hawthorn (*C. monogyna*)

A total of sixty-one hawthorn saplings, regenerating in all size classes in multiple woodlands (25 in 25-100, 27 in 100-200, 5 in 200-400 and 4 in 400+ cm class) were recorded in this study. It is a light-demanding (Scottish Forestry, 2019), common native understory tree (10-15m in height) which grows quickly in the first 15 years and has a dense canopy. The thorns on its branches make it unfavourable for herbivores (Jones, 2015).

Hawthorn fruits in July and August and birds play an important role in dispersing its seeds. It can grow on a wide range of soils and is able to tolerate unfavourable conditions (Jones, 2015). Hawthorn was the third most frequently recorded species in Dunsany, found in four of the seven semi-natural woodland sites surveyed. Perrin *et al.* (2008) in their survey of 1320 woodland sites across all 26 counties of Ireland found that hawthorn was the most frequently recorded tree species, recorded in 92.3% of the sites surveyed followed by ash (recorded in 90.2% sites). Higgins *et al*. (2004) in their survey of 204 semi-natural woodland sites across five counties of Ireland found that hawthorn was the third most frequently recorded species, recorded in 48% of the sites surveyed.

4.6.5 Regeneration of Wych Elm (*U. glabra*) and Yew (*T. baccata*)

Wych elm and yew are both uncommon in County Meath (Perrin *et al.,* 2008). They were not common at the estate either, but yew seedlings and elm saplings and seedlings were recorded a few times during the study.

Figure 4.3a and b: Wych elm sapling recorded in River Forest 2 and Yew seedling in Duckpond sites respectively.

4.3a

4.3b

4.6.5.1 Factors that may have affected their regeneration

Despite tolerating moderate shade, yew cannot regenerate in dense canopies of conifers or broadleaves like oak, beech etc (Perrin and Mitchell, 2013) and there was an abundance of broadleaved trees at Dunsany estate. Even though yew is toxic to herbivores, it is heavily browsed by red deer, goats, hares and rabbits (Rodwell, 1991), which is one of the main factors responsible for its poor regeneration in Ireland (Perrin, 2002). The seventeen elm saplings in the 25-100 cm size class and a further seven in the 100-200 cm class were all recorded at the River Forest 2 site. Wych elm seeds are consumed by birds, woodmouse (*Apodemus sylvaticus*), grey squirrels etc and deer typically consume its leaves and shoots (Hulme and Hunt, 1999). The Dutch Elm disease caused by the fungus *Ophiostoma novo-ulmi* and transmitted by elm bark beetles

(*Scolytus* spp.) has also been responsible for destroying a large number of elm trees and all over Europe (Navroodi, 2015).

4.6.6 Seedlings and saplings for the following species were not recorded at Dunsany estate

4.6.6.1 Scots pine (*P. sylvestris*)

Scots pine is mostly introduced in Ireland but is native in the Burren in County Clare (McGeever and Mitchell, 2016). It is a light-demanding pioneer species that can regenerate well in canopy gaps and open areas. It grows well on well-drained, non-calcareous soils and is often found in association with trees like rowan (*Sorbus* sp), juniper (*Juniperus sp*) and birch (*Betula* spp.) (Smith, 2020).

4.6.6.2 Factors that may have affected its regeneration

The seeds are wind-pollinated. Before dispersal, they are consumed by birds like common crossbill (*Loxia curvirostra*), Coal tit (*Parus ater*) and siskin (*Carduelis spinus*) (Castro *et al*.,1999). These birds feed on open cones by removing the seeds and the seedwing which falls on the ground (Lescourret and Genard, 1986). Post-dispersal, the seeds are consumed by pine marten (*Martes martes*), red and grey squirrels (*Sciurus vulgaris*) and woodmouse (Castro *et al*., 1999).

No Scots pine seedlings were seen in the Scots pine plantation. This may be due to poor dispersal, fewer clear or open gaps, and that it does not regenerate well under its own canopy (Smith, 2020). Lots of grey squirrels were also observed at the estate which may have consumed its seeds. The soil was also not ideal for its growth as two of the three types of soils at Dunsany are poorly drained and it is known to grow best on well-drained soils (Smith, 2020).

4.6.6.3 Sitka spruce (*P. sitchensis*)

This is a non-native, pioneer that is well-adapted to the Irish soil and climate and grows in areas with high rainfall (>1000mm/yr) (Bianchi *et al.,* 2019). It is shade-tolerant and produces a large number of seeds, allowing it to regenerate naturally (Peterson *et al.,* 1997). Sitka spruce starts producing seeds at an age of 25-35 and seed production increases when it reaches 40 yrs. The seeds are dispersed by wind and germinate easily on low fertility soils, which are moist without much leaf litter (Nixon and Worrell, 1999). The mortality rate of seedlings is also high but since many are produced, a few eventually turn into saplings and trees.

4.6.6.4 Factors that may have affected its regeneration

Pre-dispersal: Birds such as Siskins and Coal Tits consume its seeds when they are in the cone (Mckenzie *et al.,* 2007). Post dispersal, deer, rabbits and hares eat its leaves and seeds. A poor source of seeds and seedling bank, large amount of leaf litter (as recorded in Dunsany), can also significantly affect its regeneration because seeds falling on the ground will not be able to germinate (Nixon and Wordell, 1999).

4.6.7 Improving the regeneration in plantations

The trees in plantations were approximately of the same age and were densely planted. Pruning or thinning the trees in plantations from time to time and creating small gaps within them could lower the canopy cover and allow more light to enter the understory, which may improve seed germination and regeneration of native species (French *et al.,* 2008). Periodic light thinning of the Sitka spruce and Scots pine trees may favour ash and oak regeneration and in time, the plantations could be shifted to a mixed ash or an Ash-Oak woodland. This would also give better age structure variation and probably support more biodiversity. Another way of improving regeneration and biodiversity could be an availability of a seed source and converting conifer plantations into a mix of native or non-native trees. Such mix of forests are also important for carabid beetles as a varying amount of sunlight at the ground level is beneficial to them (Humphrey *et al.,* 2002b). A project on carabids (at Dunsany estate) was being conducted at the same time as this woodland and plantation survey. The project investigated carabid diversity and it was found that a mix of forests had different mixes of carabids in them. Lurz *et al.* (2003) found that conifers in Britain provide habitat to the native red squirrel which is otherwise out competed by the non-native grey squirrel in broadleaved woodlands. Native broadleaved tree species like oak, birch, elm that are able to grow on different types of soil can be planted in the plantations to improve the overall regeneration (Coote *et al.,* 2012). This will also improve the seed source in the plantations. Management of herbivory in plantations is also important because over or under grazing can affect the ground flora negatively (Mitchell and Kirby, 1990; Perrin *et al.*, 2006; Perrin *et al*., 2011).

Chapter 5

Conclusion

The ten sites surveyed in this study were different from each other in terms of vegetation structure, composition, herbivory levels, regeneration and seedling diversity and numbers. The semi-natural woodlands were found to be more diverse than the plantations on the basis of seedling, tree, sapling species and floristic structure. This was probably due to lighter canopy cover, proximal seed source, better seed dispersal, larger area and that they had remained undisturbed for a longer period of time. Similar results have also been found by Fahy and Gormally (1998) and Coote *et al*. (2012).

Scots pine and alder plantations had poor regeneration due to high leaf litter, dense planting and canopy cover which could have limited opportunities for seed dispersal as well as germination and establishment of native species. The three major factors affecting regeneration and seedling numbers were *Rubus*, canopy cover and herbivory. Ash and sycamore were the most abundant seedling and sapling species at the estate and also exhibited the best regeneration in all size classes. They can tolerate different types of soils, grow well in shade for years and resist herbivory to an extent. This might have explained the positive relationship of ash seedlings with increasing canopy and herbivory. Both these species are able to create seedling banks, which gives them a head start over other species (Higgins, 2001). Another determinant of high seedling numbers was the proximity of seed sources and efficient seed dispersal, which may have been due to an abundance of ash and sycamore trees at the estate. The negative relationship of beech seedlings with *Rubus* cover and herbivory was probably due to it being a slow-growing species and its leaves and seeds being consumed by birds, deer, hares etc.

The positive relationship of sapling regeneration in the smaller size classes with canopy and *Rubus* cover seemed to indicate that sapling species (out of which 67% were ash and sycamore) grow well under shade and that *Rubus* is able to protect them from some environmental factors. Similar results have also been found by Harmer *et al*. (2010). But very high canopy and *Rubus* cover can negatively affect regeneration as found by Watt (1924) and Harmer (2004) respectively. According to them, shade-tolerant species need light and gaps to reach maturity, and *Rubus* in high numbers can easily outcompete them for space, nutrients etc. It was also concluded that rewilding most likely had an overall positive effect on the vegetation at Dunsany as no pesticide use and tree cutting over nine years may have improved the flora as a number of different plants including the uncommon wych elm and yew were recorded.

5.1 Recommendations for improving the diversity of vegetation at Dunsany estate

An efficient way of increasing sapling regeneration, seedling and ground flora diversity and numbers at the estate could be the gradual thinning of trees in sites such as Bluebell wood, Duckpond, and the plantations as this will allow more light to reach the understory. The regeneration of Sitka spruce and Scots pine may improve by carefully managing the amount of leaf litter on the ground and by the removal of some Sitka spruce and Scots pine trees from their plantations. The thinning of alder, Sitka spruce and Scots pine trees in their respective plantations may also allow other native species (ash, birch, oak, elm etc) to regenerate and improve the overall structure and composition, seed source and dispersal. This mix of conifer and broadleaved trees at the estate could result in an increase in carabid diversity and the number of red squirrels that are uncommon in Ireland. Installing bird feed boxes, fake predators (hawk, owls etc) etc around the estate could help control and manage the rate of seed and seedling consumption by birds. Creating temporary fences along with proper monitoring of the sites with high herbivory such as Athronin, Duckpond and River Forest 2 may lead to better regeneration of saplings and seedlings, especially those of the uncommon yew (Perrin, 2002) and elm (Navroodi, 2015). The rangers in Killarney National Park (in County Kerry) have set up exclosure fences (of wire stock netting with barbed wire) about 2 m in height in the park. These fences have not allowed any deer or other herbivores to enter and hence resulted in an increase in the regeneration of yew (Perrin, 2002). Similar fences could also be installed in sites like River Forest 2, Duckpond, Rosewood, Athronin forest where yew seedlings were recorded. The thinning and trimming of cherry laurel which is an invasive and allelopathic species, at the Duckpond site could result in an increased regeneration of other native tree species. No studies in Ireland have been conducted on the role of *Rubus* in aiding the regeneration of fast-growing species. So, further research which could be at the estate or around different counties in Ireland will be required to support the results of this study.

The results of this preliminary study will provide a framework for future studies that are conducted at Dunsany. Further and more extensive work which may include future resurvey of the estate over a five-year time frame and study on similar or different types of woodlands and plantations will be needed to support these results.

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