An Assessment of Ground beetle (Carabidae) communities in the Re-wilding project at Dunsany Castle Estate, County Meath.

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Abstract

Dunsany Estate in County Meath has recently been converted into a rewilding project, by removal of all agricultural practices. The estate is now a matrix of tall grass meadows and woodland, surrounded by organic arable crop. There is a need for systematic surveys of the biodiversity at the site to facilitate research and conservation management in the future.

This project has aimed to provide the initial baseline data of Ground Beetle (Carabidae) communities. Carabid beetles are often surveyed as biodiversity and environmental indicators, therefore this initial assessment of carabid populations was carried out to provide insights into the ecological processes and invertebrate communities present at the reserve.

Carabid beetles were sampled by pitfall trapping over a 6 week period throughout a broad range of grassland and forest habitats in the rewilding region of Dunsany. Pitfall trap sites differed slightly in their environmental characteristics. Community analysis was done to investigate whether there was distinct carabid communities in each location that would indicate habitat differentiation. This was done using NMS ordination and cluster analysis.

The grassland carabid communities were all similarly grouped in cluster analysis, excluding one, and this was distinct from the forest communities. The forests were further sorted into 3 different groups that differed by their dominant species. The ecology and habitat associations of species were then discussed with regard to whether the habitat has reached the successional stage of semi-natural habitat, or is in an intermediate restoration stage. In the grasslands, there was a mix of both agriculture-associated species and those associated with a semi-natural habitat, whereas in the forests, mostly generalists and open habitat species were found.

These findings can inspire many future research questions on the patch size, connectivity and population changes of Carabid beetles over time. It has also identified different locations that can be used as reliable replicates in future hypothesis testing, by their comparable species composition of carabid beetles.

Key words

Carabidae, Ordination, Forest, Grassland, Rewilding, Bioindicator

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1 Introduction

1.1 Dunsany Estate

Dunsany Castle Estate is a large, privately owned estate in County Meath, spanning roughly 650 hectares (*Fig. 1)*. Approximately 520 hectares of this land has undergone a recent shift in land use towards a re-wilding project that aims to restore the area into a nature reserve. This is the first rewilding site in Ireland to be officially recognised by the European Rewilding Network (Rewilding Europe, 2020). The scale, management and history of the estate makes it an interesting site for conservation research.

In the past, the 300 hectares of grassland at Dunsany estate was used for agriculture and consisted of livestock grazing pastures and arable land. The 220 hectares of forest were used for recreational purposes such as hunting. These forests constitute mix of native and non-native species and have patches of coniferous plantations, deciduous woodland and cultivars which were planted for decorative purposes along the now derelict pathways roughly 100 years ago (Rewilding Europe, 2020; Donohoe, 2019; Spagnoli Garbardi, 2019).

The plans to convert the estate into a nature reserve began in 2014 (Rewilding Europe, 2020). This has involved the removal of all agricultural practices, cessation of pesticide and fertiliser input, prevention of any hunting on the land and felling cycles in plantations. The drainage at the site is no longer routinely cleared, and therefore encourages wetland mires to re-establish. This has facilitated natural succession, resulting in a forest-grassland mosaic of tall grass meadows with young tree saplings scattered throughout, as well as patches of wet mires, and forests that are patchy in their vegetation composition and structure. There are large amounts of potential habitats for wildlife, which is made evident by the presence of top predators such as Buzzards (*Buteo buteo* Linnaeus 1758) nesting onsite (*Appendix 4*). In addition to this, rescued foxes and badgers are reintroduced into Dunsany and there is a small population of Red deer (*Cervus elaphus* Linnaeus, 1758), which is the only large herbivore present (*see Appendix 4 and 5)* (Rewilding Europe, 2020; Spagnoli Garbardi, 2019; Donohoe, 2019).

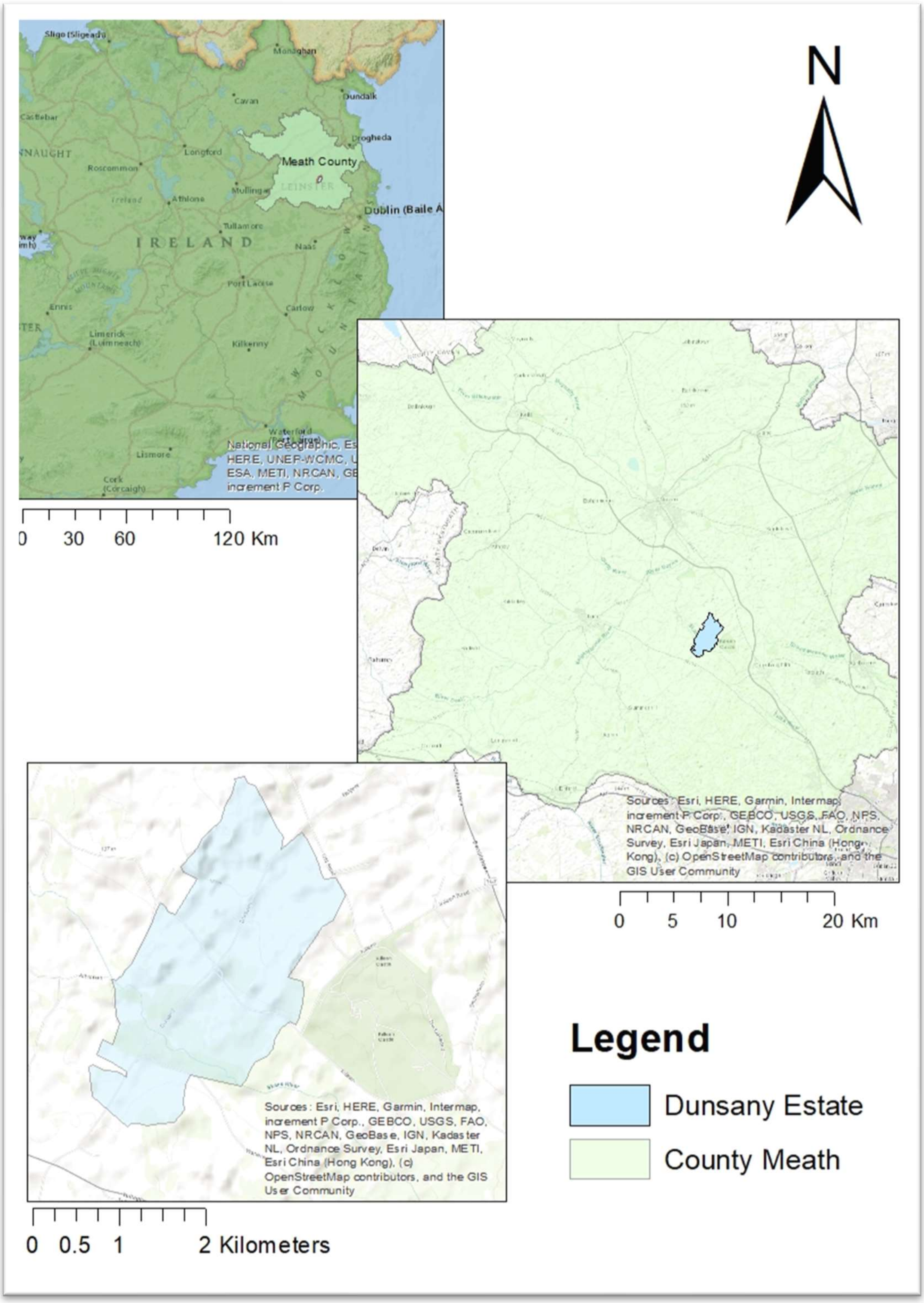

Figure 1: Map of Dunsany Estate perimeter, showing its location in County Meath and the Republic of Ireland. Map was made with ArcGIS Desktop software by ESRI

The level of anthropogenic disturbance to these habitats is now very low. As this is a private land with little public access, it is unique compared to many other nature reserves in Ireland. Most footfall is restricted to the main grounds surrounding the castle and other areas have been left undisturbed for several years.

There has not yet been any systematic surveys of the habitats or biodiversity at the Dunsany Estate. A biodiversity assessment is therefore required in order to evaluate the current habitat and establish a monitoring programme and conservation plan for the future management of the site.

This project has investigated the species composition of Ground beetles (Carabidae Latreille, 1802) in the different grassland and forested regions throughout the Dunsany Nature Reserve as part of the initial baseline biodiversity data that can be used for future research at the site.

1.2 Carabidae - Ground Beetles

Carabidae (Latreille, 1802) are a diverse group of ground beetles found widespread throughout Europe (*Fig. 2*). There are roughly 211 known species in Ireland, some of which are endemic to the island (Anderson, 2000). These beetles are found in a range of different habitats, however certain species groups are associated with different habitat types (Anderson, 2000; Lövei and Sunderland, 1996). For this reason, they are commonly used as a key bioindicator of biodiversity and environmental characteristics such as habitat type, quality and succession stage (Johan Kotze et al., 2011; Cameron and Leather, 2012; Koivula, 2011). As they are relatively well-studied, easy to sample in a repeatable manner and have species communities that are associated with different ecological processes, carabids are good model organism for biodiversity and environmental research (Koivula, 2011; Ferris, 1999).

Figure 2: Carabus granulatus (Linnaeus 1758). *An example of a beetle from the Carabidae family.*

1.3 Carabid ecology and biodiversity bioindication

As the majority of carabid beetles are carnivorous, they provide ecological information about other invertebrate communities that they prey on. This gives a broad representation of the overall invertebrate biodiversity at the ground level within a habitat (Ferris, 1999; Cameron and Leather, 2012; Lövei and Sunderland, 1996). Many species of carabids prey on aphids or are phytophagous of the seeds of crop weeds, thus are considered useful biological pest control for agricultural crops (Trichard et al., 2013). The Carabidae beetles have a wide range of physiological traits, such as diet specialisation and dispersal ability, and therefore the presence or composition of different ecological groups can represent a range of ecological processes (Lövei and Sunderland, 1996; Anderson, 2000; Koivula, 2011; Cole et al., 2002).

Additionally, Carabidae and other beetles are common prey for ground nesting birds and bat species (Vaughan, 1997; Vickery et al., 2009). The decline in ground nesting birds has been associated with the reduction of large carabid beetles (Blake et al., 1994; Boatman et al., 2004; Vickery et al., 2009). In particular, increased agricultural intensity and pesticide use has indirectly affected populations of Skylark (*Alauda arvensis* Linnaeus, 1758), Lapwing (*Vanellus vanellus* Linnaeus, 1758), Yellowhammer (*Emberiza citrinella* Linnaeus, 1758) and game birds due to the reduction in environmentally sensitive large predatory carabids, such as the *Carabus* (Linnaeus, 1758) genus, leading to a less optimal foraging strategy for these birds (Blake et al., 1994; Cole et al., 2002; Boatman et al., 2004; Vickery et al., 2009).

Despite the high diversity and abundance of invertebrates in an ecosystem, they can often be overlooked in conservation policies and research, where most of the focus is on birds and mammals (Cardoso et al., 2011). Many invertebrate groups have a important role in ecological processes, for example nutrient cycling and pollination, therefore the assessment and monitoring of indicator groups would be highly beneficial for a rewilding project (Bengtsson et al., 1996; Sommaggio, 1999). This is especially significant when reintroducing insectivorous birds that rely on a diverse invertebrate community (Vickery et al., 2009; Boatman et al., 2004).

1.4 Carabids and Environmental indicators of habitat type

The diversity and species composition of carabid beetles communities can differ dependent on habitat type and quality, as many species are particular to specific environmental conditions (Thiele, 1977; Lövei and Sunderland, 1996; Johan Kotze et al., 2011). This is generally due to sensitivity of microclimate conditions such as soil moisture, light and disturbance (Thiele, 1977; Lövei and Sunderland, 1996; Johan Kotze et al., 2010). Therefore, the land use, management intensity and habitat type may strongly affect which carabid species are present in an environment.

In Northern Ireland, Carabids are surveyed in the monitoring of Environmentally Sensitive Areas as an indicator for habitat quality (Anderson, 2000; Anderson, 1997). Carabid communities were shown by Blake at al., (2003) to have distinct association with 15 different habitat types, this correlates with the National Vegetation Classifications (NVC) and therefore compliments vegetation surveys in biodiversity assessment. Alternatively, there are other studies that have found carabid communities did not associate with plant composition, but are, however, associated with other characteristics such as vegetation structure, for example. (Ní Bhriain et al., 2002; Ings and Hartley, 1999; Brose, 2003). Barsoum et al., (2014) also found that the carabid communities in different forest types were more influenced by the historical land uses and adjacent habitat than the tree species present. This is particularly significant in woodland-agricultural landscape matrices, where the diversity and presence of some species is more closely associated with the past landscape composition before conversion to agriculture, and can give an insight into the functional connectivity and biodiversity value of fragmented wildlife refuges throughout these regions (Neumann et al., 2017). Consequently, the systematic survey of Carabidae is useful to include in monitoring programmes as they can provide information of other trophic levels, successive stage, vegetation structure and diversity in areas of bare ground (Blake et al., 2003).

When monitoring environmental change in a habitat, the resulting change in carabid communities can be observed more rapidly compared to vegetation (Perner and Malt, 2003). They act as good short term indicators of environmental change from agricultural pasture to semi-natural grasslands, where plant communities are often a long term indicator due to their longevity and seed banks (Perner and Malt, 2003; Blake et al., 2003). Moreover, carabids have trait-specific species responses to habitat fragmentation, urbanisation, environmental management and changes, which can be observed in the in species composition present (Gaublomme et al., 2008; Neumann et al., 2016; Wamser et al., 2012; Blake et al., 1994; Toïgo et al., 2013).

1.5 Carabid communities in grassland and agricultural land

The species richness of carabid communities was inversely related the degree of management from arable crops to grassland in a study by Perner and Malt (2003). This study indicated that the processes of grassland succession that occurs when agricultural practices are reduced or removed will affect the populations of carabid species present. Many studies have compared carabid communities in varying levels of agricultural practices and intensity. This helps give an insight into the carabid population changes that may occur in a rewilded grassland from agricultural pastures, where conventional agricultural practices are stopped completely (Clark et al., 1993; Baguette and Hance, 1997; Andersen, 1999; Eyre et al., 2013; O'Sullivan and Gormally, 2002; Cole et al., 2002).

It is known that fertiliser and pesticides can lead to a reduced species richness in carabid populations (Lee et al., 2001). When comparing organic and conventional potato crops, the higher abundance of carabids in the organic crop was an indirect result of more weed cover (O'Sullivan and Gormally, 2002). Similarly, the species richness when comparing different amounts of tillage was highest in fields with reduced or no tillage, due to the increased weed cover (Andersen, 1999). There are some species that are associated with the productivity, disturbance and bare ground that generally occurs in tillage crop fields and therefore are less abundant once tillage is stopped, due to the change in microclimate. In contrast, others only persist in fields of low disturbance and agricultural management. These species rely on features such as unmanaged grassy areas, hedgerows and woodland patches as temporary refuge sites (Lee et al., 2001; Fournier and Loreau, 2001; Wamser et al., 2012; Schneider et al., 2016). Grazing regimes were also shown to not only have an effect on carabid communities, but fields grazed by cattle have different carabid species than sheep grazed fields (Lyons et al., 2017). The change from grazing to tall un-grazed grass in Dunsany may therefore also have an effect on the species composition. In the past, some fields in Dunsany were cattle grazed, and others were sheep grazed, however, as both have been un-grazed for over 6 years, it is likely that the differences can no longer been observed by carabid communities, however may still be apparent in plant diversity (Lyons et al., 2017; Perner and Malt, 2003).

Agricultural intensity has varying effects on carabid species dependent on their ecology. For example, Cole et al. (2002) characterised carabids into ecological groups and studied their occurrence on a range of agricultural and semi-natural grasslands and found that some groups, particularly the large predatory carabids, only inhabit semi-natural grasslands. Others were found at a higher density in intensive agricultural land. This was likely due to trait specific characteristics in diet and body size (Cole et al., 2002; Blake et al., 1994; Wamser et al., 2012; Neumann et al., 2016). The large group of *Carabus* species that predate leafhoppers (Cicadellidae Latreille, 1802) are more abundant in unfertilised ground and have large larvae that cannot inhabit the compact ground in agricultural land. The small diurnal *Collembola* (Lubbock, 1871) feeders have the opposite response because their *Collembola* prey benefit from high fertiliser input (Cole et al., 2002). With this in mind, the dominant carabid species with known ecological requirements can indicate whether the invertebrate community is more associated with its previous agricultural pasture or a successional stage to semi-natural grassland (Blake et al., 2003; Koivula, 2011).

The homogenisation of landscape from agricultural practices has led to habitat loss for many invertebrate species throughout Europe (Desender and Turin, 1989; Ekroos et al., 2010). Wildlife refuges, such as hedgerows and field margins are important buffer sites for carabids and other invertebrate species (Pywell et al., 2005; Lee et al., 2001). Some of the regions of Dunsany could act as an important overwintering refuge for common crop species that act as biological pest control and provide more suitable habitats for poor disperser species associated with unmanaged, stable environments (Pywell et al., 2005; Neumann et al., 2016; Fournier and Loreau, 2001).

1.6 Carabid diversity in Forests

In general, the carabid species associated with forests are thought to differ from those in grasslands (Thiele, 1977; Lövei and Sunderland, 1996; Johan Kotze et al., 2011; Koivula, 2011). However, this is dependent on many factors such as regional location and habitat quality(Blake et al., 2003; Day et al., 1993; Eyre and Luff, 1994). The forest associated species are influenced by forest management, as shown by studies that compare carabid communities of semi-natural deciduous forests with those of plantation cycles(Day et al., 1993; Fahy and Gormally, 1998; Magura et al., 2003; Fuller et al., 2008; Butterfield et al., 1995). Leaf litter layer, soil moisture and canopy cover are the key determining factors of carabid species groups in different forest types (Day et al., 1993; Fahy and Gormally, 1998; Magura et al., 2003; Fuller et al., 2008; Butterfield et al., 1995). Similarly to grassland habitat, the degree of forest management will affect the carabid species richness and diversity dependent on the level of disturbance, amount of open areas and regeneration within a forest (Toïgo et al., 2013; Ings and Hartley, 1999).

1.6.1 Plantations and Semi-natural woodland

The abundance of beetles is generally higher in deciduous semi-natural woodlands compared to plantations (Fuller et al., 2008; Fahy and Gormally, 1998). This does not necessarily indicate that the species diversity is higher, however, in the majority of comparisons made, the composition of species has differed (Fahy and Gormally, 1998; Fuller et al., 2008; Butterfield et al., 1995). More of the rare specialist woodland-associated species tend to inhabit semi-natural woodland compared to the intensely managed plantation forest (Butterfield et al., 1995). Moreover, the clear-fell regions of plantations are more similar in species composition to the plantation forests than other semi-natural glades and open habitats (Butterfield et al., 1995; Fahy and Gormally, 1998). Plantations have much drier soil, higher disturbance, differing canopy cover and leaf litter layer, which provide poor quality habitat for woodland invertebrate communities(Fahy and Gormally, 1998; Butterfield et al., 1995; Fuller et al., 2008). Consequently, the specialised forest species are usually lacking in coniferous plantations(Fahy and Gormally, 1998; Butterfield et al., 1995; Fuller et al., 2008). Carabid diversity in the rewilded, unmanaged coniferous plantations in Dunsany may differ from a typical plantation due to its lack of management or felling, however their age and stand type may also result in different species composition to the deciduous forests.

1.6.2 Regeneration

There has been some evidence that carabid species composition can differ dependent on regeneration in forested areas (Ings and Hartley, 1999; Poole et al., 2003). Poole et al., (2003) found greater species richness in mature forest compared to regenerating forest. Similarly, Ings and Hartley (1999) found that there was more diversity in the unfenced forest regions compared to the fenced, which suggests that the lack of regeneration and resulting vegetation structure due to deer browsing had an effect on invertebrate species composition (Melis et al., 2006). Deer are present in Dunsany, and their effect on vegetation structure and regeneration is currently unknown. In order to monitor the indirect effect of deer browsing on invertebrate communities in Dunsany over time, initial baseline data is required of the current carabid communities present along with a vegetation and regeneration analysis in each area.

1.6.3 Forest management

Research in abandonment of forest management systems has suggested that a reduction is beneficial for the forest specialists and woodland-associated invertebrates (Toïgo et al., 2013). Similar to grassland, each ecological group of carabids is affected by the removal of forest management in different ways. For example, humus activity and basal layer, representative of canopy cover and food supply in a study by Toigo et al (2013), was positively associated with forest carnivore species, whereas an increase of pH positively influences omnivores. This was thought to be due to its effect on the flora diversity, therefore enhancing the plant-based food sources.

The forests in Dunsany have a mix of plantations and deciduous woodland and are surrounded by mostly agricultural land and rewilded grassland sites. Moreover, these forests are extremely patchy in their vegetation composition and structure, and often patches of coniferous plantation can be found on the outskirts of a large deciduous woodland area, therefore the carabid diversities are difficult to predict with regard to forest type.

1.7 Biodiversity at Dunsany

Patchy habitat with both forested and open grasslands interspersed together is generally helpful to promote biodiversity, by providing a wider range of microclimates and resources for invertebrate species(Ings and Hartley, 1999; Neumann et al., 2016).

There was some suggestion that in the UK and Ireland, forests are too small and fragmented to have the distinct forest communities as seen in other parts of Europe (Barsoum et al., 2014; Gaublomme et al., 2008; Eyre and Luff, 1994). Instead, these forests have a similar composition to the adjacent grassland communities and inhabit mostly open habitat species and generalists(Barsoum et al., 2014; Fournier and Loreau, 2001; Eyre and Luff, 1994).

Dunsany is a recent rewilded area, where most of the open habitat regions are around 6-10 years old. There are variations in the time since rewilding and previous land use in different areas as well. By providing initial baseline data, this study gives an opportunity to explore the invertebrate community change throughout the rewilding process. It aims to investigate what the carabid species composition is in each region as a first indication as to what ecological processes may be occurring at present.

1.8 Research Questions

In order to gain the first insight to carabid communities at the Dunsany Estate, this study has investigated the species composition in a wide range of habitat patches throughout the main rewilding region. Carabid diversity was sampled by pitfall trapping across a range of contrasting habitats throughout the Dunsany rewilding area. This was done to establish baseline data that can be used to guide further research and monitoring programmes. This inductive approach used the following research questions:

- What is the Carabid diversity at Dunsany?

- Are there distinct carabid species compositions that represent habitat differentiation across Dunsany?
- Does the carabid community of grassland habitats differ from the adjacent forest patches, or are they grouped by regionality?

Dunsany regions that differ in the dominant species and abundance of ground beetles is discussed with regard to their ecological requirements and habitat association. This study has coincided with vegetation analysis of the grasslands and forests of Dunsany as parallel research to this study to give more general biodiversity assessment of the Estate.

2 Methods

2.1 Site selection

The initial investigation was done by remote sensing using Google Earth to define broad habitat types, such as grassland and woodland. Each defined region could be viewed from 2009 to 2019, to give a rough outline of some of the management changes that have occurred at the estate within this time period. These locations were then investigated further upon visiting Dunsany Nature Reserve, where a qualitative assessment was made in each area to give a more detailed outline of the habitat patches.

Seventeen pitfall trap sites were designated across the reserve, eight of these were open grassland habitat and nine were closed forested habitat (*Fig 3 and 4)*. To give as broad a scope of the different habitat and locations in the reserve as possible within the time given, each site varied slightly in historical land use, time since re-wilding, area, vicinity to agricultural land, vegetation composition and current management. Some of the large patchy forests had a pitfall trap placed at two separate locations of the forest, due to their contrasting characteristics and size (*Fig. 4*).

Nearly all of the different regions within the Dunsany Estate consist of patchy habitat and a high diversity of vegetation. Most have a range of native and non-native species, particularly in the forested areas, with patches of waterlogged wetland regions throughout both forests and grassland. In general all open sites were typically wet grassland, which was evident from the vegetation present.

Table 1: Pitfall Trap Site names, their abbreviations, grid references and habitat type

Site Name	Symbol	Habitat type	Grid Reference
River Forest 1	RF1	Forested	N 9157554287
River Forest 2	RF2	Forested	N 9085854617
Duck Pond Forest 1	DPF1	Forested	N 9112455234
Duck Pond Forest 2	DPF2	Forested	N 9081855041
Rose Garden Trees	RGT	Forested	N 9130755082
Plantation 1	PL1	Forested	N 9187855004
Old Plantation	OP	Forested	N 9042854834
Bluebell Forest	BF	Forested	N 9137454703
Athronen Forest	ATF	Forested	N 9061155527
Big Meadow	BM	Grassland	N 9154254488
Crop Meadow	CM	Grassland	N 9146955359
Sheep Meadow	SM	Grassland	N 9111754961
Wetlands	WT	Grassland	N 9214554879
Cricket Field	CF	Grassland	N 9074754886
Floodplains	FP	Grassland	N 9182354632
Athronen Grassland	ATG	Grassland	N 9034755353
Rose Garden Grassland	RGG	Grassland	N 9133355028

Figure 3: Pitfall trap locations in the Dunsany Estate. Image was taken from the 2017 Google Earth satellite image. Pitfall trap site names and their habitat types are written in Table 1.

Figure 1: Pitfall trap locations at Dunsany Nature Reserve, using Google Earth satellite imagery from 2017. Site names and their associated symbols are found in Table 1.

The different regions (summarised in Appendix Tables 2 and 3) were as follows:

2.1.1 Forest habitat regions:

River Forest (RF1, RF2)

This forest is a mix of both native and non-native vegetation species, with patchy canopy cover and a river running through it. The arrangement of the trees in certain regions within this forest appear as if they were planted along an old path (100+ years ago) where some derelict bridges and gateways can still be seen here. The river forest is one of the largest forest patches within this study, and is surrounded by Dunsany grassland on one side of it, and a small road on the other side that separates the forest from agricultural field, garden lawns and other forest area.

The canopy cover above RF1 consisted of Beech (*Fagus sylvatica* L.*)*, as the dominant tree species in the canopy. Sycamore (*Acer pseudoplanatus* L.), Ash (*Fraxinus excelsior* L.) and some conifer species were also present. The pitfall traps were surrounded by Common Box shrub (*Buxus sempervirens* L.), which was growing throughout the forest. The herb layer was scarce, with a few Herb-Robert (*Geranium robertianum* L.), and a very small number of *F. sylvatica* saplings. The pitfall trap RF1 site was placed near the river, on a raised bank above the river channel. The ground was covered in deciduous leaf litter and some areas of bare ground.

The second pitfall trap RF2 is on the other end of the River Forest. The canopy cover was mostly Yew (*Taxus baccata* L.**)** that resulted in a sparser leaf litter layer on the ground. There was bare ground and some moss also covering the ground in areas. The herbaceous layer had a small number of ferns, *G. robertianum*, and Brambles (*Rubus fructicosus* L.), however this was not dense. Compared to all other forest regions, RF2 appeared to be the most disturbed by cutting, and had a large amount of dead wood and fallen trees surrounding the pitfall trap plots, as well as a frequently used path. The pitfall traps were a further distance from the river, compared to RF1, however the ground was much more waterlogged. The area surrounding the pitfall trap location had a large patch of invasive Cherry Laurel (*Prunus laurocerasus* L.) and exotic coniferous species, as well as *A. pseudoplanatus*, *F. sylvatica* and *F. excelsior* saplings.

Duck Pond Forest (DPF1, DPF2)

The Duckpond Forest is one of the largest woodland areas in this study. It borders a large arable crop and is across a road from the main castle grounds.

The DPF1 pitfall trap site was on a side of the forest that was in between a road and an arable crop, close to a heavily waterlogged area of small ponds within the forest. The canopy cover consisted of a mix of deciduous species, with 1 or 2 coniferous trees present. Directly above the pitfall trap was an Oak (*Quercus sp.* L.) canopy. *A. pseudoplanatus*, Hazel (*Corylus avellana* L.) and some *F. sylvatica* were in the understory. This area had abundant *F. excelsior* saplings. The ground was covered in deciduous leaf litter and the herb layer was a moderate abundance of *G. robertianum*, a mix of fern species and herbs such as Enchanters Nightshade (*Circaea lutetiana* L.*),* and patches of moss.

The DPF2 pitfall traps are on the opposite side of the forest adjacent to the Cricket Field grassland area. This side of the Duckpond forest is also an extremely patchy habitat, with regions of very dense canopy, and other regions where it is more open. There was a small a coniferous plantation patch on the edge of the forest, however the pitfall traps were placed at a distance from this. Large *A. pseudoplanatus* trees were the dominant canopy species. *F. excelsior*, Horse Chestnut (*Aesculus hippocastanum L.*) and *P. laurocerasus* were also present in the surrounding area. At the ground level, the pitfall traps were in a small open area, where there was a mixture of moss, grass, sparse leaf litter and bare ground. There were some fern species and *G. robertianum* present too; however, the herb layer at the immediate pitfall trap area was sparser than the surrounding vegetation that was abundant in grasses and Nettles (*Urtica dioica* L.) and Golden Saxifrage (*Chrysosplenium oppositifolum* L.). It was evident that this region was heavily disturbed by deer, which is the likely cause of some of the bare ground as well as a lack of saplings or vegetation around the pitfall trap region.

Relative to other forest sites, Duckpond forest is thought to be the one of the most undisturbed by human visitations due to its location away from the main Dunsany grounds and lack of clear pathways.

Athronen Forest (ATF)

The Athronen forest is a small isolated forest patch, surrounded by arable crop. It is a long, narrow, woodland area on a slight slope. The forest shape and canopy has a high amount of forest edge, allowing light to enter. The canopy cover was mostly *F. excelsior* and Elm (*Ulmus glabra* Huds.), which resulted in a relatively open canopy compared to the other forest sites. This was observed particularly at the beginning of the sample period, as the *F. excelsior* trees were defoliated due to an Ash Sawfly (*Tomostethus nigritus* Fabricus 1804) infestation. The herbaceous layer was very dense *G. robertianum*, *R. fructicosus* and Hogweed (*Heracleum sphondylium* L.), with a covering of moss at the ground level. Like the majority of Dunsany forests, there are patches throughout the small forest with increased canopy cover and non-native species further from the pitfall trap site. This site is particularly undisturbed by humans due to its location and inaccessibility.

Rose Garden Wooded Area (RGF)

The Rose Garden is a small area of mostly planted exotic trees near to the Dunsany Castle. This area was formerly a decorative gardens approximately 100 years ago, which has since then been rewilded. The canopy above the pitfall traps is a region of mature coniferous trees, with species such as Scots Pine (*Pinus sylvestris* L.), *Larix* spp., Douglas Fir (*Pseudotsuga menziesii* (Mirb.) Franco) and *T. baccata*. There are young deciduous *A. pseudoplanatus* trees nearby, as well as other exotic trees and shrubs. It is fairly open canopy, with a very dense herbaceous layer of *U. dioica*, *R. fructicosus*, thistles, some *G. robertianum* and a ground layer of moss and ivy with some bare ground. The small patch of trees is surrounded by rewilded Dunsany grasslands.

Small mixed plantation (PL1)

This plantation is around 20 years old. It consists of a mix of Pine and *Quercus* trees, arranged in rows with drainage ditches that run along its length There is very little light penetration onto the forest floor in this patch because the trees are so densely packed. The canopy directly above the traps was *Quercus* surrounded by conifer species. For this reason, there is primarily *Quercus* leaf litter covering the ground and little to no herbaceous layer. There are some small saplings of *A. pseudoplanatus* and *F. excelsior*, and two old tree stumps that are covered in moss and fern species. This plantation is adjacent to Dunsany grassland on one side, and a wall that separates the forest from the road on the other side. This patch is relatively small and thin, and at one end connects to a small deciduous tree patch.

Old Coniferous plantation (OP)

The coniferous trees in this plantation are very mature, and have not undergone the typical felling cycles of a usual plantation of its age. Many of the trees have lost their foliage, which has resulted in a much more open canopy than expected. Due to the amount of light present in this forest, there is a large amount of regeneration of a variety of species occurring in the understory. This includes *F. excelsior*, Holly (*Ilex aquifolium* Linnaeus*)*, *A. pseudoplanatus*, *Quercus* and *F. sylvatica*. These young deciduous trees are a range of different sizes and ages. There is a dense herb layer of *R. fructicosus* and *G. robertianum*. The ground is different from all other forests sites, being covered with a very deep, thick layer of conifer needle litter instead of the typical brown soil in other sites. There are other patches within this forest that appear more typical of a plantation forest, with less heterogeneous vegetation structure. This forest patch is at the periphery of a larger deciduous forest, adjacent to an arable crop with a road alongside.

Bluebell Forest (BF)

This is a relatively small forest patch in close proximity to the castle. It consists of a mix of tree species, including *A. pseudoplanatus*, *F. sylvatica*, *F. excelsior* and a few coniferous species. The ground flora of this patch has a bloom of wildflowers in spring time, but was relatively sparse in herbaceous plants during the sample period, having small amounts of *H. sphondylium* and *B. sempervirens* around the periphery of the forest patch. This small forest is surrounded by rewilded grasslands that were once agricultural pastures and has an established and frequently used path in its centre.

2.1.2 Grassland habitat regions:

Front lawn/Big Meadow (BM)

The front lawn is the largest grassland patch. It is evident from Google Earth satellite image of 2013, that the pitfall trap site is in an area that was previously been cut for silage or hay. This area has many small wet patches of Silverweed (*Potentilla anserina* (L.) Rydb.) and Rushes (*Juncus spp*.) within the tall grass swards of this grassland, as well patches of thistles and *U. dioica* around the perimeter and surrounding the small number of trees present. The pitfall site is in an area of this grassland that borders the River Forest 1 and Bluebell forest, and has some elevated hills and trees scattered throughout it.

Rose Garden grassland area (RGG)

This is the smallest grassland patch, next to RGT. It differs from other grassland sites due to its small size and surrounding trees. This site was a decorative garden at the turn of the century, and since has been used for agriculture, as seen in the Google Earth imagery from 2013.

Back lawn/Sheep meadow (SM)

On Google Earth it is apparent that this large grassland area was previously a grazed by sheep, which can be seen in the satellite image from 2013. Similar to the Front Lawn region, this is a patchy grassland consisting of a range of tall bunch grass species. It is adjacent to the Durhams Field, an alder plantation, River Forest 2 and the Rose Garden region.

Wetland (WT)

This habitat is frequently flooded, and is abundant with wetland vegetation indicators. There is a large gully within this grassland area that is permanently full of water, and has *Juncus spp*. and Iris (*Iris pseudacorus* L.) growing within it. The pitfall trap site is next to the gully, in between the *Juncus* and the *I. pseudacorus* plants. Due to the large gully, it can be assumed there was not as intensive agricultural practices and heavy vehicle disturbance along this region of the grassland, which is supported by the lack of visible vehicle lines as shown by the past Google Earth images.

Floodplain (FP)

This is a small circular patch within the Front Lawn, that floods in winter (see Google Earth, 2018). Originally, in July, this circular patch consisted of *Juncus spp.* in the centre surrounded with bare ground. As the sampling period progressed there was a lot of rapid growth of short grass and *P. anserina*, this fresh grass was noticeably grazed by the deer. There are several of these patches in this region of the Front lawn that all consists in a dip in the ground and are very waterlogged and positioned along a line of trees. Similar to the wetland, it is likely that agricultural vehicles would have avoided these wet patches, however it is completely surrounded by grassland area that was cut for silage in the past Google Earth satellite images from 2013 (Randall Plunkett, pers comm, 2020)

Durhams Field/ Crop meadow (CM)

This field was previously used for arable crops, up to 6 years ago. It is the most recently rewilded area, and the tillage lines are still visible as parallel lines of *Juncus spp*. and Grass. The perimeter of this grassland patch consists of Ragwort (*Senecio jacobea* L.). This is also one of the only grassland sites that has a large amount of tree saplings scattered throughout. Interestingly, some saplings are of species that are not commonly found in the forested areas of Dunsany.

Cricket Field (CF)

The Cricket Field is the oldest rewilding site. It was previously grazed by cattle, approximately 10 years ago. It is surrounded by Dunsany forests and nearby the same crop that borders the Duckpond Forest. The field has a large ditch around its perimeter and some *Quercus* trees growing within it. There have been some ideas to plant trees in this site and connect the two forest patches on either side of the grasslands. This field appears to be one of the most diverse, patchy grassland regions, due to the vegetation composition present.

Athronen Crop Edge (ATG)

This is a small patch of grassland at the edge of a large arable crop. The barley crop is the same that surrounds Athronen Forest. There is a river and road on the other side of the grassland patch. The pitfall trap site is on raised ground and seems drier and less patchy than the other grassland regions. There are *I. aquifolium* saplings and some tree cover along the river adjacent to this small grassland patch, which connects it with other small patches of tall grass along the crop boundary.

2.2 Pitfall traps

At each of the 17 sites, a set of 5 pitfall traps were arranged in a square, of sides 2m, with the fifth trap in the middle. These traps were set flush with the ground level. The traps consisted of 2 plastic cups, 10.5cm length and 8.4cm lid diameter, which were slotted together to make an inner cup and an outer cup and filled ¼ full of water and a drop of detergent. The inner cup had a small hole in the bottom for drainage of the water when collecting the samples, while the outer cup remained in the ground. In order to prevent unwanted bycatch of small mammals, a circular piece of chicken wire was wedged approximately an inch below the surface of the cup.

2.3 Carabid sampling

The samples were collected from the pitfall traps once a week for 6 weeks, starting from 16th of July 2020 until the 27th August, following an initial test sample week that was not included in the data. Specimens from each cup were put into sample jars with 70% ethanol as preservative. Carabid beetles were identified to the species level using Luff (2007) and Forsythe (2000) as identification keys with additional assistance using the Ground Beetles of Ireland website (National Museums Northern Ireland, 2006) with a hand lens and digital microscope (Rotek Technology Co., Ltd).

2.4 Qualitative habitat assessment

For additional notes to the carabid baseline data, a qualitative assessment of the surrounding environment at each pitfall trap site was done, which included approximate area (ha) of the habitat patch, canopy cover, vegetation composition and structure, evidence of deer presence and ground cover. Any other features of interest was noted, including other species that were seen during the sampling time period in order to build up a more extensive biodiversity list at the reserve. These lists can be seen in *Appendix 4.*

2.5 Data analysis

Invertebrate counts of each of the 5 pitfall traps within sample sites was pooled and the species richness and total abundance of each species was calculated for each site and per week. The proportion of species per site was calculated to give an indication of the most dominant species present in each location, which can be compared and discussed with regard to their ecology and habitat preferences. Total weekly abundances were also compared to the weekly rainfall (mm) using R software (R Core Team, 2017) and figures were conducted using the package ggplot2 (H. Wickham, 2009) to investigate whether rainfall had an influence on the number of species caught each week. Rainfall data were taken from the Met Eireann Daily Weather Data of the Dunsany Weather Station (MetEireann).

The carabid data were compared and analysed initially by non-metric multidimensional scaling ordination to look at differences in composition and cluster analysis to find community groups. This was done in PC-Ord Version 4.01, using the Sorenson (Bray-Curtis) distance measure. The stability criteria was 0.00001, and there was 40 runs with the real data and 50 runs with randomised data used to generate a Monte Carlo analysis of the solution. The cluster analysis utilised Lance and William's flexible data method (Lance and Williams, 1967), with parameter beta set at -0.25 following McCune & Grace (2002).

3 Results

In the 6 week sampling period, 5510 individuals of 27 species of Carabidae were found in total (*Table 2).* 18 of the species have not been recorded in County Meath before (*Apenndix 2)*. Due to the morphological similarity between *Pterostichus nigrita*[1] and *Pterostichus rhaectus*, the distinction of species could not be completely identified and was recorded as *Pterostichus nigrita.*

[1] Names of species together with Authorities is in Table 1

Pterostichus melanarius was the most frequently caught species, common to all sites, however, was generally more abundant in the grassland regions compared to the forests. *Pterostichus madidus* was common to all sites apart from Big Meadow. Many other species were only found in abundance in one or two sites, and there was a noticeable difference in abundance and species richness between grassland and forest communities. *Pterostichus nigrita* had the highest abundance of individuals caught throughout the sampling period, due to its exceptionally high abundance in the Floodplain site. The least abundant species were only found once, these were *Carabus nemoralis* in the Rose Garden Tree patch, *Agonum marginatum* found in the Floodplain, *Notiophilus biguttatus* in Athronen Forest and *Anchomenus dorsalis* in the River Forest 2.

Table 2: Carabidae species total abundance at each location in Dunsany

Species	RF1	RF2	DPF1	DPF2	RGT	PL1	OP	BF	ATF	BM	CM	SM	WT	CF	FP	ATG	RGG	Total
Abax parallelepipedus (Piller & Mitterpacher 1783)	45	54	56	92	41	52	180	32	50	1	—	—	2	3	—	44	13	665
Agonum emarginatum (Gyllenhal 1827)	—	—	2	—	—	—	—	—	—	—	—	—	6	—	—	—	—	8
Agonum fuliginosum (Panzer 1809)	—	—	—	—	—	—	—	—	—	1	—	—	2	4	59	—	1	67
Agonum marginatum (Linnaeus 1758)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	2
Amara communis (Panzer 1797)	—	—	—	—	—	—	—	—	—	—	3	1	—	28	—	—	—	32
Amara lunicollis Schiödte 1837	—	—	—	—	—	—	—	—	—	—	2	1	—	—	—	—	—	3
Anchomenus dorsalis (Pontoppidan 1763)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Bembidion obtusum Audinet-Serville 1821	—	—	—	—	—	—	—	—	—	—	—	1	2	—	—	1	4	8
Bembidion aenum Germar 1824	—	—	—	—	—	—	—	—	—	—	—	—	4	—	3	—	—	7
Calathus melanocephalus (Linnaeus 1758)	—	—	—	—	—	—	—	1	—	4	3	1	—	1	—	—	—	10
Calathus rotundicollis Dejean 1828	13	16	10	37	—	1	—	—	—	—	—	—	—	2	—	—	2	81
Carabus granulatus Linnaeus 1758	—	1	3	—	2	—	—	—	—	6	12	30	6	12	44	—	123	239
Carabus nemoralis Müller 1764	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
Clivina fossor (Linnaeus 1758)	—	—	1	—	1	—	—	—	—	1	3	3	1	5	—	—	4	19
Curtonotus aucilus (Panzer 1796)	—	—	1	—	3	—	1	—	1	—	—	3	—	10	2	2	—	23
Harpalus rufipes (Degeer 1774)	3	—	1	—	3	1	—	5	—	7	13	4	—	8	9	—	1	55
Loricera pilicornis (Fabricius 1775)	—	3	5	16	11	1	1	—	—	1	—	—	—	—	—	—	—	38
Nebria brevicollis (Fabricius 1792)	—	1	26	4	—	1	—	7	1	—	—	—	—	—	—	—	—	40
Notophilus biguttatus (Fabricius 1779)	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1
Pterostichus madidus (Fabricius 1775)	87	97	84	52	4	134	24	255	161	—	1	1	2	2	7	238	4	1153
Pterostichus melanarius (Illiger 1798)	17	9	114	10	16	18	2	32	4	217	85	218	23	189	366	2	90	1412
Pterostichus niger (Schaller 1783)	6	1	1	2	10	1	—	6	—	119	95	67	33	33	358	4	118	854
Pterostichus nigrita (Paykull 1790)	—	—	5	6	13	—	—	—	—	—	—	3	9	1	424	—	37	498
Pterostichus strenuus Panzer 1796	—	—	1	—	3	—	—	—	—	1	6	4	3	12	8	—	2	40
.*Pterostichus vernalis* (Panzer 1795)	—	—	—	—	1	—	—	—	—	3	9	—	3	9	19	—	8	52
Poecilus versicolor (Sturm 1824)	—	—	—	—	—	—	—	—	—	54	11	75	1	8	7	2	28	186
Trechus obtusus Erichson 1837	3	—	—	1	—	—	6	—	—	3	1	—	—	1	—	—	—	15
No. of individuals	174	183	310	220	109	209	214	338	218	418	244	412	97	328	1308	293	435	5510
Species number	7	9	14	9	13	8	6	7	6	13	13	14	14	17	13	7	14	27

3.1 NMS ordination and Cluster analysis

The NMS ordination was done, where a 2-dimentional solution was recommended. The final stress value was 5.01 which indicated that this is an excellent representation of the data, and significantly lower than the stress obtained by Monte Carlo randomisation of the data (p=0.0195. There is a very clear, noticeable pattern of sites in ordination space. The forest sites were all positioned at higher values along Axis 2, whereas the grassland sites are positioned at the lower end of this axis, with the exception of Athronen Grassland, which is found within a dense cluster of forest sites (*Fig. 5)*. This suggests that there is a clear distinction of carabid communities in the forest and grassland habitats. The species ordination similarly shows that the majority of species have closely clustered at the lower end of axis 1 and 2, at the grassland sites, and species found in forest sites are at the higher values of axis 1 and 2. The species in forest sites are more spread out compared to those associated with the grassland samples (*Fig. 6).*

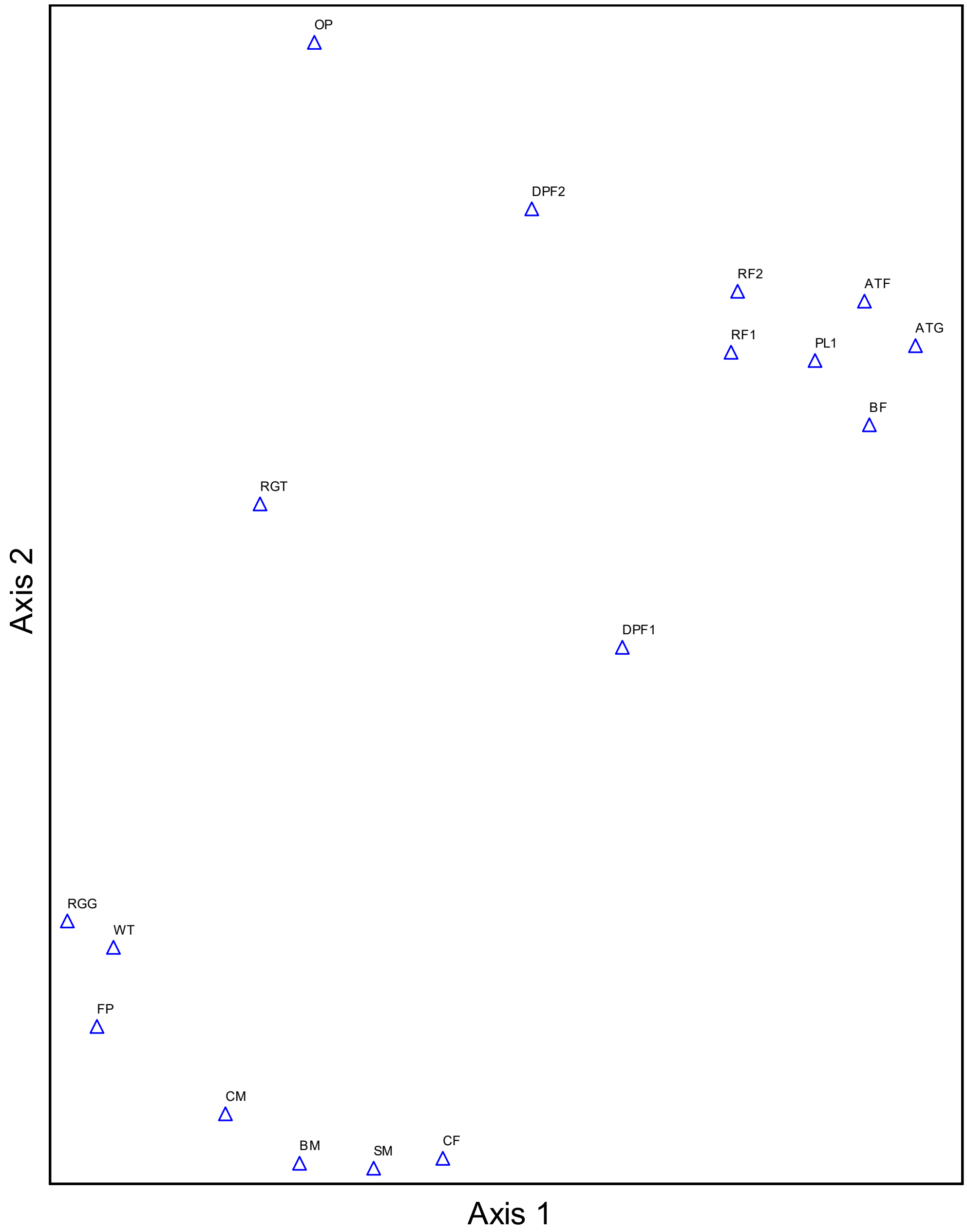

Figure 4: NMS Ordination of Dunsany pitfall trap sites. Pitfall trap site names and their associated symbols and habitat type are stated in Table 1.

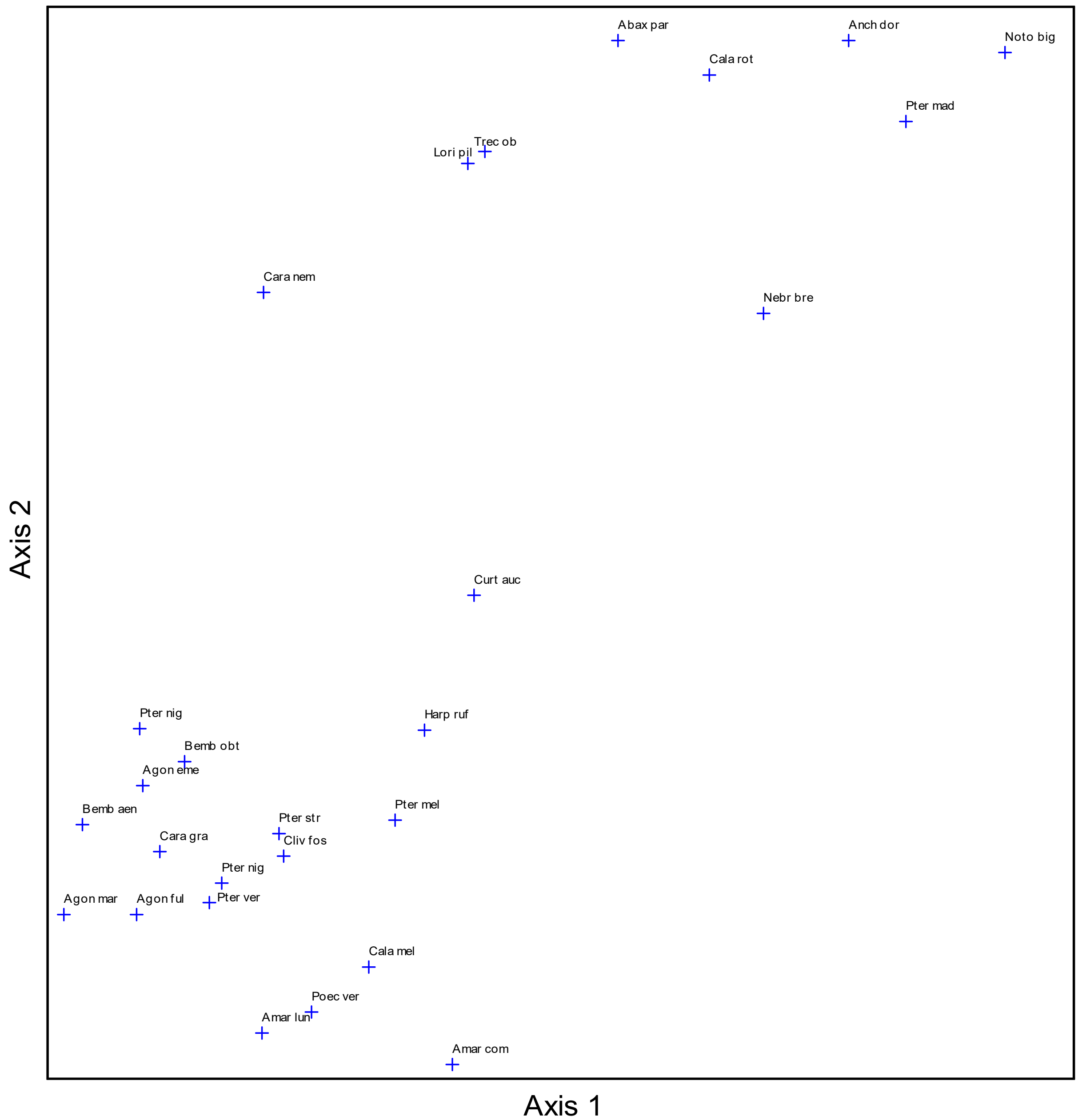

Figure 6: NMS ordination of Carabid species at Dunsany. Species names and their associated abbreviations are found in Table 3

Table 3: Species names and their symbols used in Figure 6.

Species	Symbol
Abax parallelepipedus (Piller & Mitterpacher 1783)	Abax par
Agonum emarginatum (Gyllenhal 1827)	Agon eme
Agonum fuliginosum (Panzer 1809)	Agon ful
Agonum marginatum (Linnaeus 1758)	Agon mar
Amara communis (Panzer 1797)	Amar com
Amara lunicollis Schiödte 1837	Amar lun
Anchomenus dorsalis (Pontoppidan 1763)	Anch dor
Bembidion obtusum Audinet-Serville 1821	Bemb obt
Bembidion aenum Germar 1824	Bemb aen
Calathus melanocephalus (Linnaeus 1758)	Cala mel
Calathus rotundicollis Dejean 1828	Cala rot
Carabus granulatus Linnaeus 1758	Cara gra
Carabus nemoralis Müller 1764	Cara nem
Clivina fossor (Linnaeus 1758)	Cliv fos
Curtonotus aucilus (Panzer 1796)	Curt auc
Harpalus rufipes (Degeer 1774)	Harp ruf
Loricera pilicornis (Fabricius 1775)	Lori pil
Nebria brevicollis (Fabricius 1792)	Nebr bre
Notophilus biguttatus (Fabricius 1779)	Noto big
Pterostichus madidus (Fabricius 1775)	Pter mad
Pterostichus melanarius (Illiger 1798)	Pter mel
Pterostichus niger (Schaller 1783)	Pter nig
Pterostichus nigrita (Paykull 1790)	Pter nigr
Pterostichus strenuus Panzer 1796	Pter str
.*Pterostichus vernalis* (Panzer 1795)	Pter ver
Poecilus versicolor (Sturm 1824)	Poec ver
Trechus obtusus Erichson 1837	Trec obt

The cluster analysis dendrogram (*Fig 7.*) shows an initial split between forest sites together with Athronen grassland from the grassland sites , and confirming the habitat spilt seen in NMS ordination. The sites that are close in geographical locations are similarly close in cluster groupings, such as the two river forest sites, two Athronen sites, which have grouped together with Bluebell forest. The adjacent grasslands, Big Meadow and Sheep Meadow are also closely grouped. Sheep Meadow and Big Meadow have grouped together with Cricket Field, whereas Wetland, Floodplain and Rose Garden Grassland are arranged in a separate cluster with Crop Meadow.

Other sites, such as Duckpond Forest 2, Old Plantation and Rose Garden Trees are separated from the other forested sites. Duckpond Forest 1 is branched off from this cluster and appears to be relatively distinct from all other forest sites (*Fig. 7)*. Consideration of the results of cluster analysis and NMS ordination suggest that 4 groups seems to be appropriate. These groups coincide with the most abundant species within each location (*Table 4*), which is displayed by overlaying these onto the ordination plots (*Fig 8*).

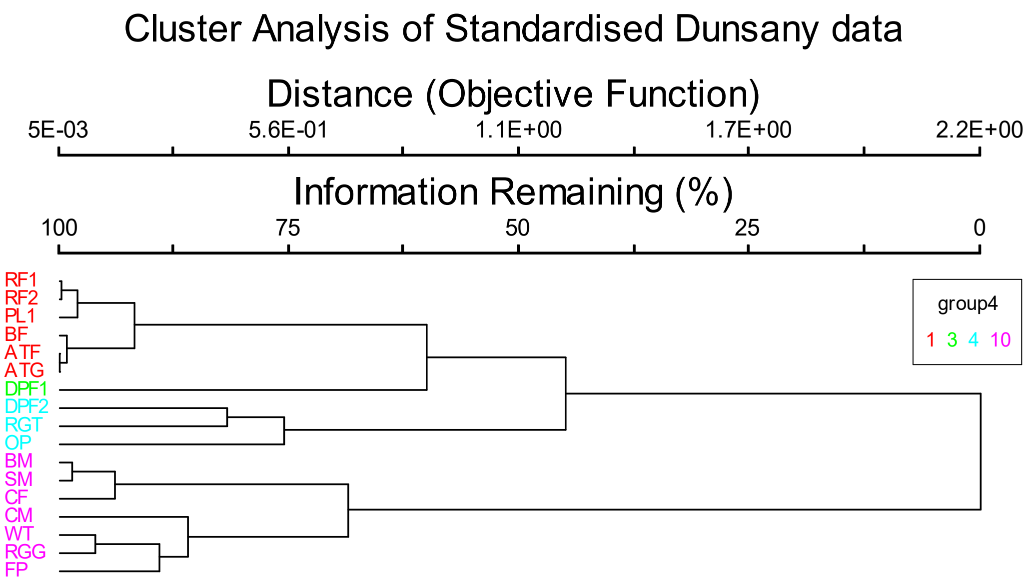

Figure 7: Cluster analysis dendrogram of Dunsany pitfall trap sites. Pitfall trap site names and their associated symbols and habitat type are stated in Table 1.

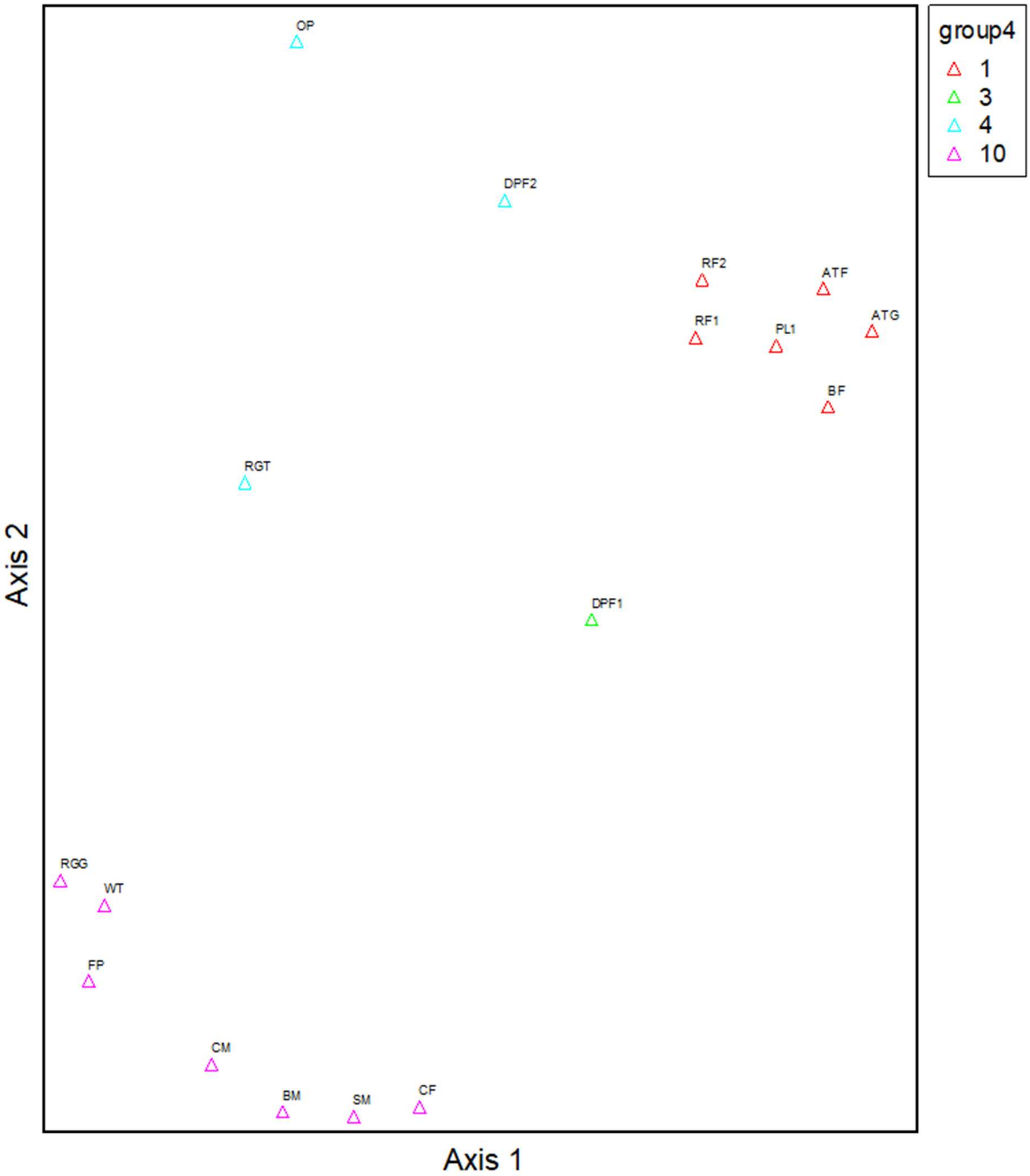

Figure 8: Ordination and cluster analysis overlayed to show 4 distinct cluster groups of Dunsany sites. Pitfall trap site names and their associated symbols and habitat type are stated in Table 1.

Table 4: The first, second and third most abundant carabid species in each site, their allocated group in cluster analysis and percentage abundance within each site. Site names for each abbreviation can be found in Table 1.

Sites	Dominant Species 1	Percentage Abundance	Dominant Species 2	Percentage Abundance	Dominant Species 3	Percentage Abundance	Cluster group
RF1	*P. madidus*	50	*A. parallelepipedis*	25.86	*P. melanarius*	9.77	1
RF2	*P. madidus*	53.01	*A. parallelepipedis*	29.51	*C. rotundicollis*	8.74	1
PL1	*P. madidus*	64.11	*A. parallelepipedis*	24.88	*P. melanarius*	8.61	1
BF	*P. madidus*	75.44	*A. parallelepipedis*	9.47	*P. melanarius*	9.47	1
ATF	*P. madidus*	73.85	*A. parallelepipedis*	22.94	*P. melanarius*	1.83	1
ATG	*P. madidus*	81.23	*A. parallelepipedis*	15.02	*P. niger*	1.37	1
RGT	*A. parallelepipedus*	37.61	*P. madidus*	14.68	*P. nigrita*	11.93	2
DPF2	*A. parallelepipedus*	41.82	*P. madidus*	23.64	*C. rotundicollis*	16.82	2
OP	*A. parallelepipedus*	84.11	*P. madidus*	11.21	*T. obtusus*	2.8	2
DPF1	*P. melanarius*	36.77	*P. madidus*	27.1	*A. parellelepipedus*	18.06	3
BM	*P. melanarius*	51.91	*P. niger*	28.47	*Poecilus versicolor*	12.92	4
SM	*P. melanarius*	52.91	*Poecilus versicolor*	18.2	*P. niger*	16.26	4
CF	*P. melanarius*	57.62	*P. niger*	10.06	*A. communis*	8.54	4
CM	*P. niger*	38.93	*P. melanarius*	34.84	*Harpalus rufipes*	5.33	4
WT	*P. niger*	34.02	*P. melanarius*	23.71	*P. nigrita*	9.28	4
FP	*P. nigrita*	32.42	*P. melanarius*	27.98	*P. niger*	27.37	4
RGG	*C. granulatus*	28.28	*P. niger*	27.13	*P. melanarius*	20.69	4

Group 1: A forest community which includes River Forest 1, River Forest 2, Bluebell Forest, Athronen Forest and Plantation 1, and includes the grassland Athronen grassland. All sites within this group had *P. madidus* as its dominant species, followed by *A. parallelepipedus* as its 2nd dominant species *(Fig. 9 and 10)*.

Group 2: This is the second forest community consisting of Duckpond Forest 2, Old Plantation and Rose Garden Trees. This group differs from the first forest community as it is *A. parallelepipedus* dominant habitat and also has a high abundance of *Loricera pilicornis*, compared to other sites (*Fig. 10).*

Group 3: This cluster just consists of Duck Pond Forest 1, which has a species community that is mixed between forest associated and grassland associated species. *P. melanarius* is the most dominant species, which is more abundant in grasslands *P. madidus* and *A. parallelepipedus* are 2nd and 3rd dominant as in the forest communities in group 1 (*Fig 9, 10 and 11*) The high abundance of *N. brevicollis* in this forest is also a distinguishing factor of Duckpond Forest 1 compared to other groups.

Group 4: This is the grassland community, which has a large abundance of species that are not commonly found in the forest locations. It is typically abundant in by *P. melanarius*, *P. niger*, *P. versicolor* and *C. granulatus*, which are scarce or not present in other groups *(Fig 11 and 12)*

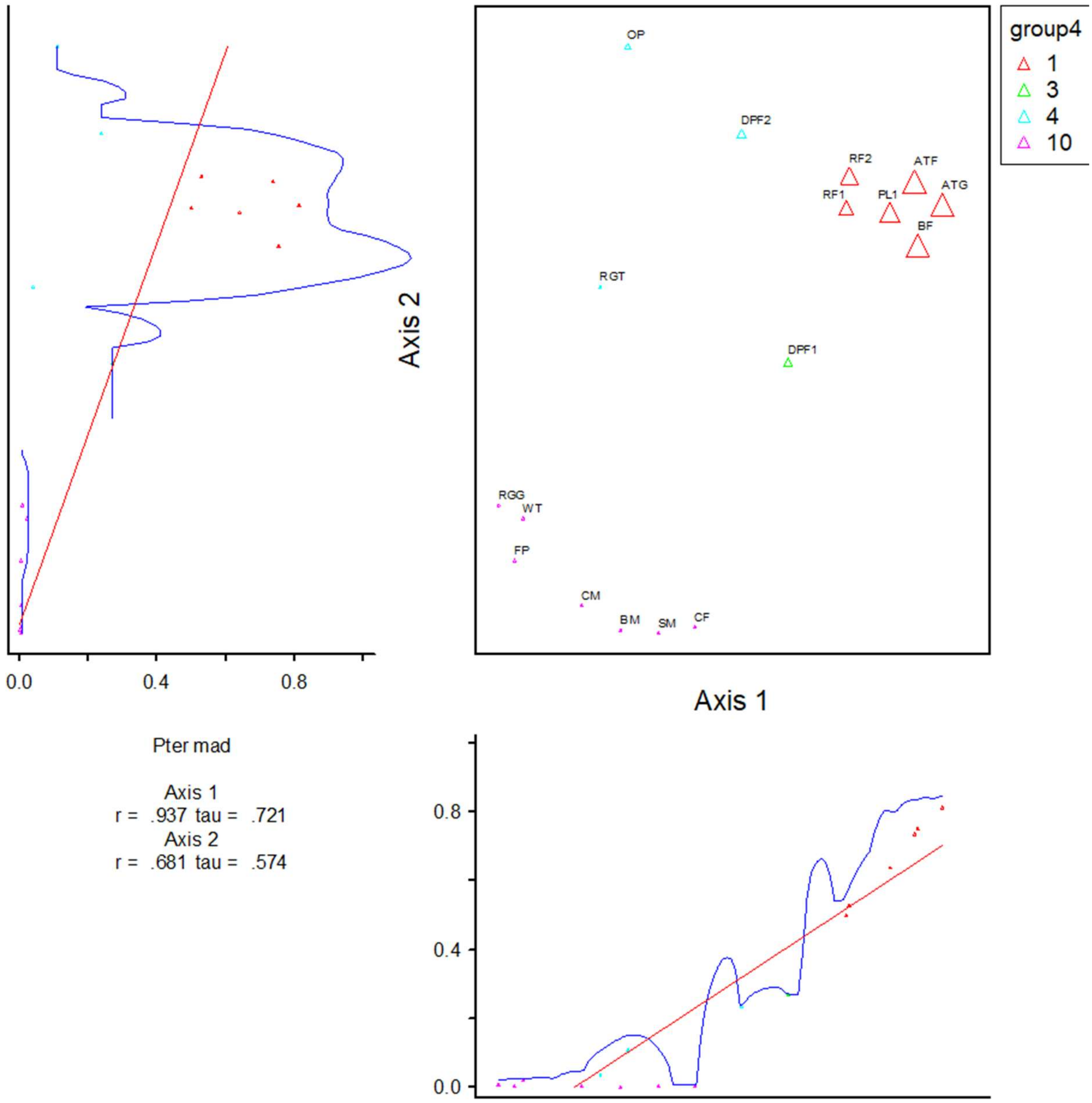

Figure 9: Ordination and cluster analysis graph with Pterostichus madidus overlayed to show its abundance, particularly in Group 1 forest habitats (red)

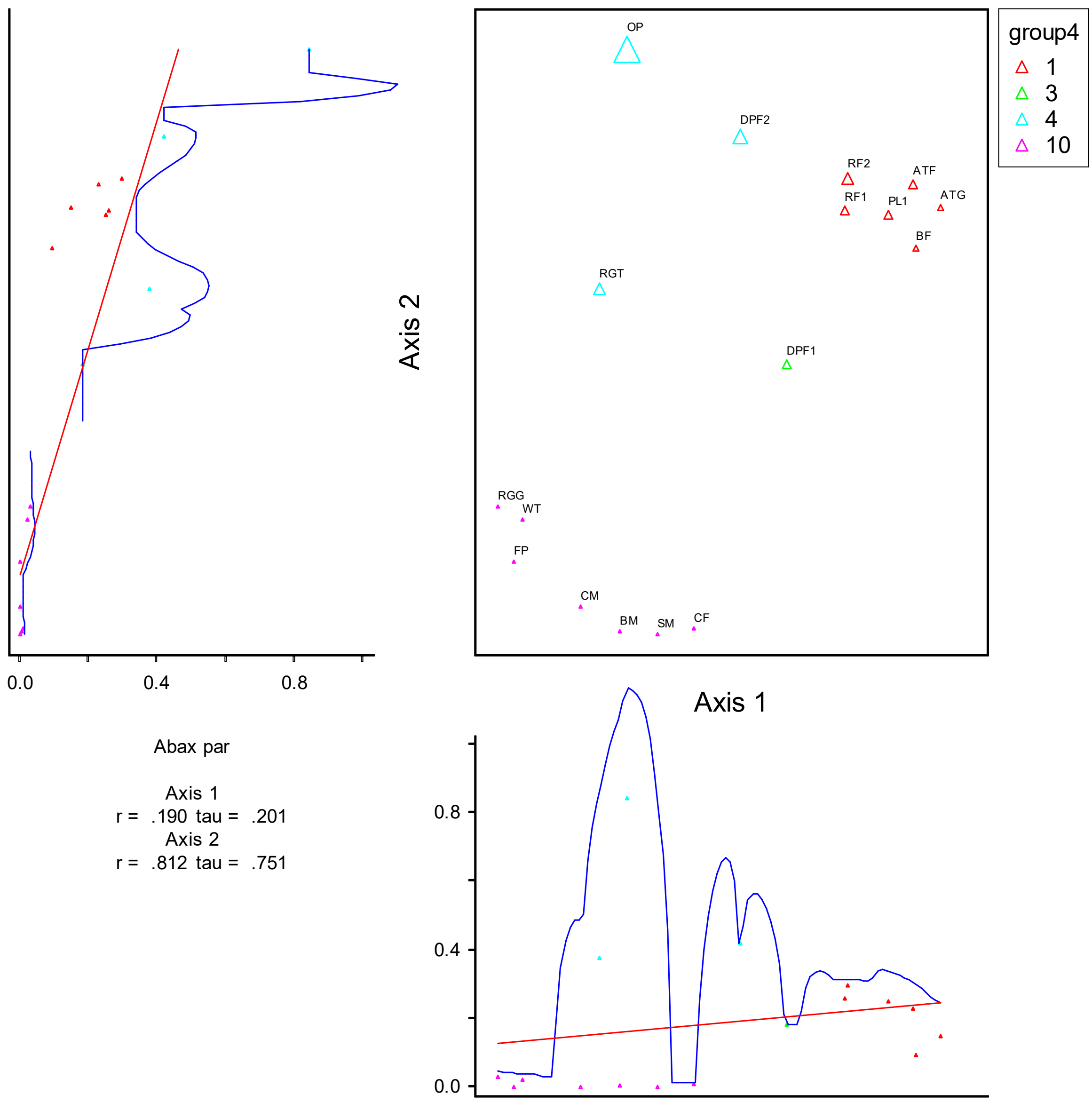

Figure 10: Ordination and cluster analysis graph with Abax parallelepipedus overlayed to show its abundance, particularly in Group 2 forest habitats (blue)

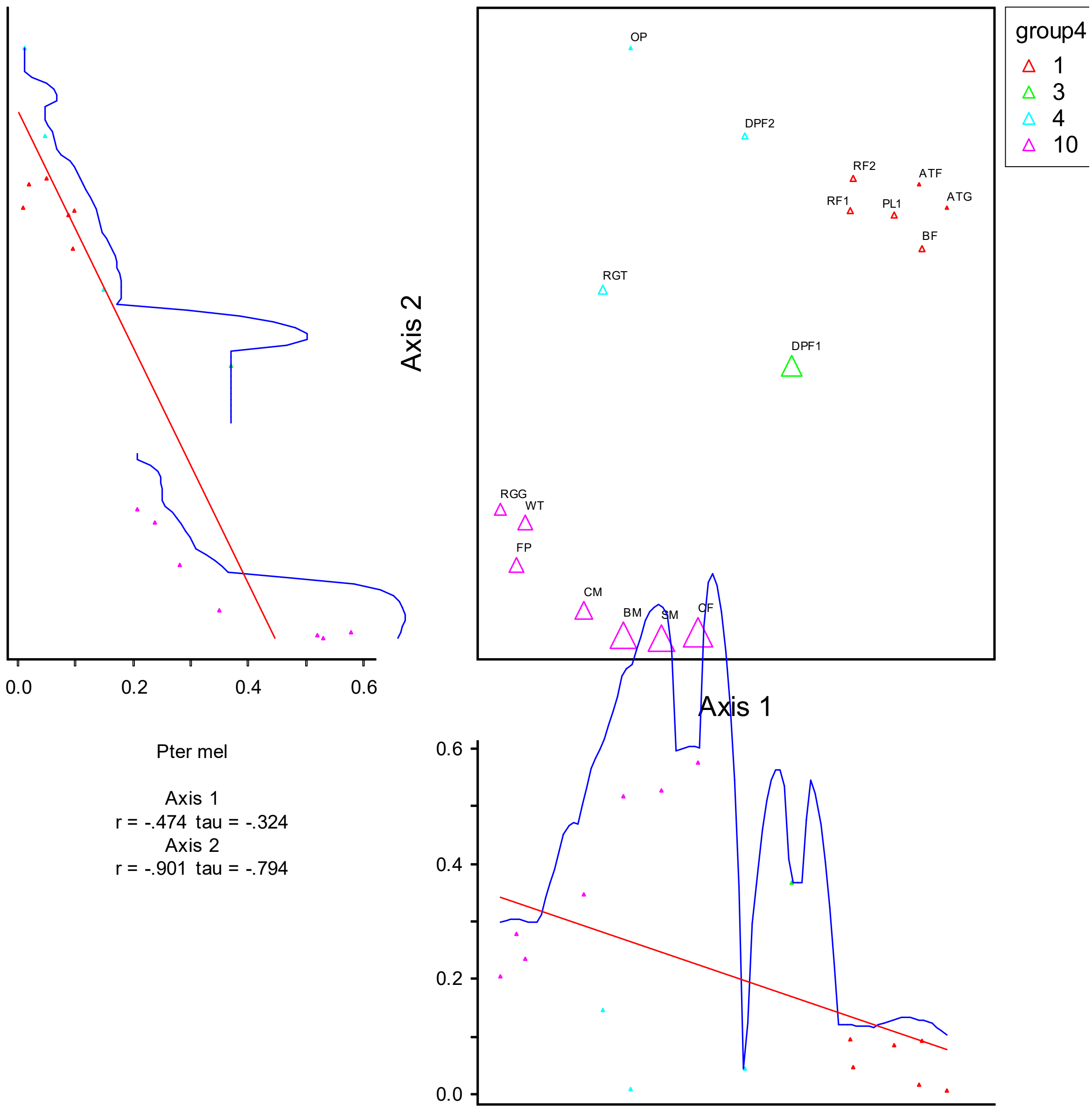

Figure 11: Ordination and cluster analysis graph with Pterostichus melanarius overlayed to show its dominance in Group 3 forest habitats (green) , and also Group 4 grasslands (pink)

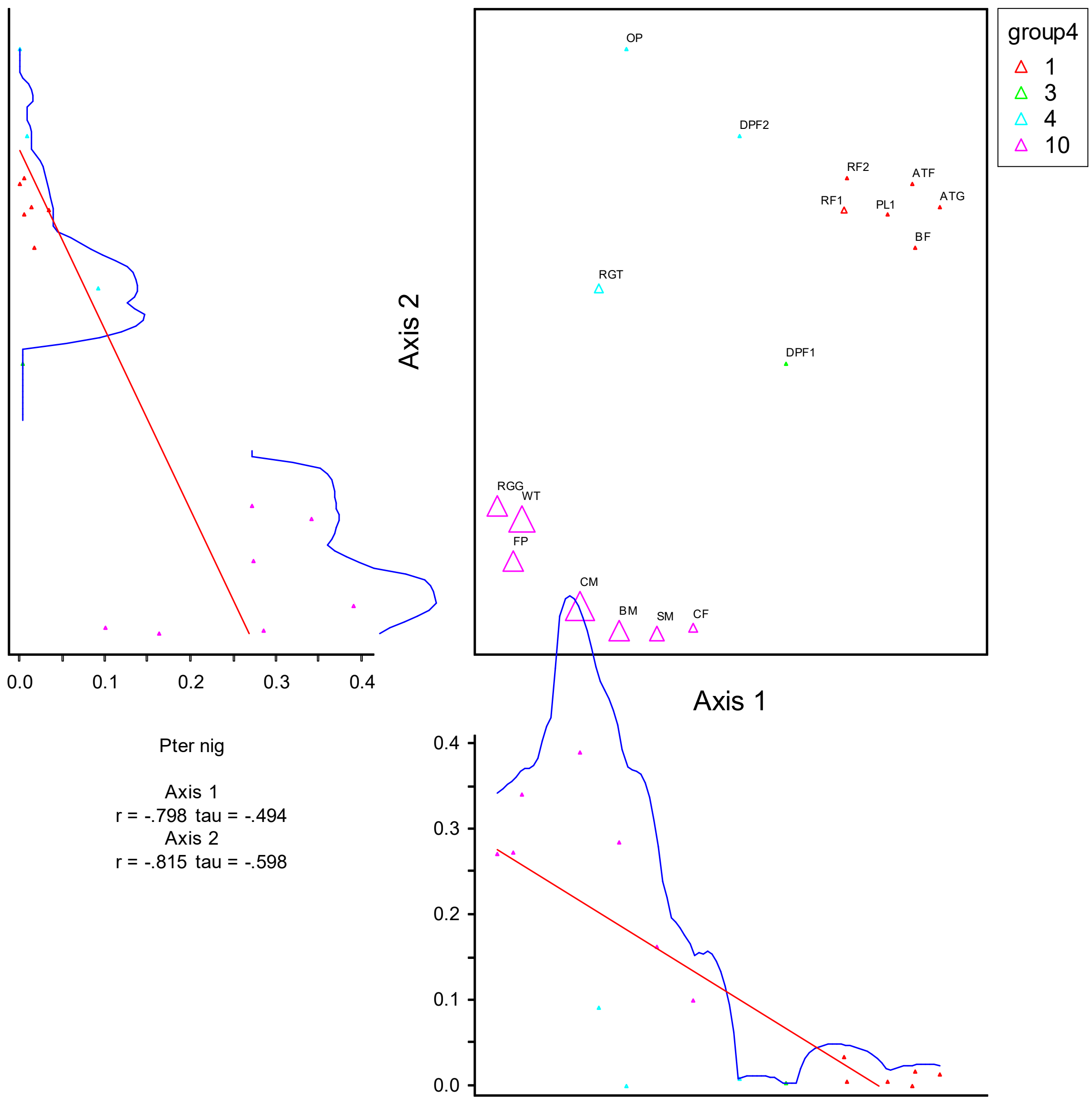

Figure 12: Ordination and cluster analysis graph with Pterostichus niger overlayed to show its abundance in Group 4 grassland habitats (pink)

3.2 Diversity, Species richness and total abundance at each location

The Wetland, Rose Garden Trees and Rose Garden Grassland were the most diverse sites (*Table 5*). The two Athronen locations and the Old Plantation was the least diverse of the sites, as they mainly consisted of *P. madidus* and *A. paralellepipedus*, with few other species.

Table 5: Diversity indices and evenness scores for each Dunsany location

Site	Species richness	Shannon index	Shannon evenness	Simpson's index	Simpson's evenness	Cluster group
RF1	7	1.37	0.2	3	0.43	1
RF2	9	1.24	0.14	2.64	0.29	1
PL1	8	0.97	0.12	2.08	0.26	1
BF	7	0.89	0.13	1.7	0.24	1
ATF	6	0.71	0.12	1.67	0.28	1
ATG	7	0.63	0.09	1.46	0.21	1
RGT	13	1.97	0.15	5	0.38	2
DPF2	9	1.57	0.17	3.74	0.42	2
OP	6	0.58	0.1	1.39	0.23	2
DPF1	14	1.65	0.12	4	0.29	3
BM	13	1.28	0.1	2.72	0.21	4
CM	13	1.64	0.13	3.54	0.27	4
SM	14	1.4	0.1	2.9	0.21	4
WT	14	2.03	0.15	5.16	0.37	4
CF	17	1.66	0.1	2.81	0.17	4
FP	13	1.55	0.12	3.82	0.29	4
RGG	14	1.81	0.13	4.78	0.34	4

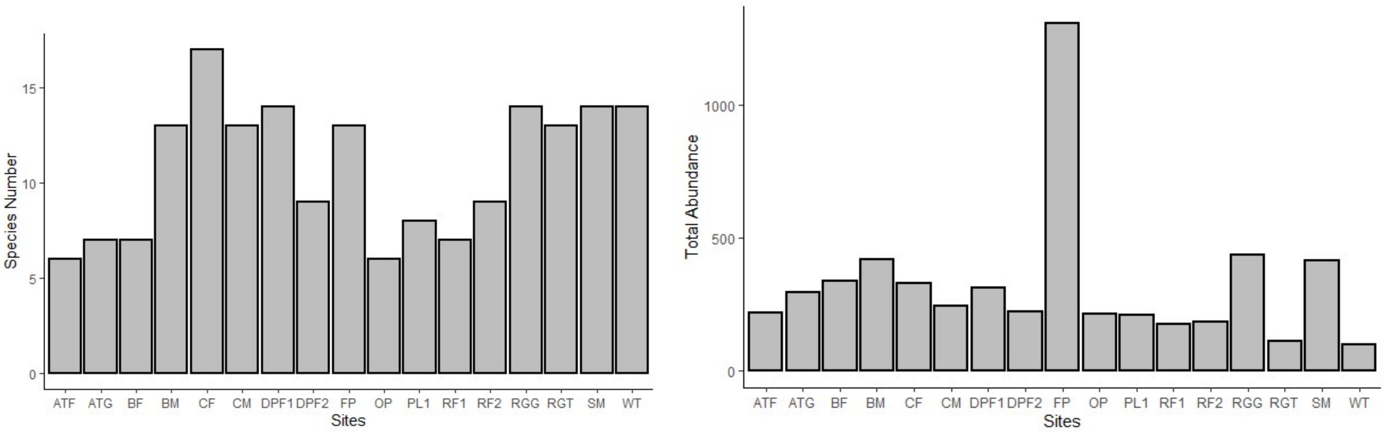

Figure 13: Species Richness and Total Abundance graphs for each Dunsany pitfall trap site. Pitfall trap site names and their associated symbols and habitat type are stated in Table 1.

3.2.1 Grassland locations

In general, the grassland locations tended to have higher species richness than most of the forests (*Fig 13)*. the Cricket Field had the highest total number of species out of all sites, whereas the Floodplain had the highest number of individuals due to exceptionally large numbers of *P. nigrita* and *P. niger* at the Floodplain site each week (*Fig. 13 and 15*)

The other grassland locations, Big Meadow, Sheep Meadow, and Crop Meadow, around the Dunsany castle, were all similar in their species number and total abundances (*Fig. 13*). The Wetland was comparable to other grassland sites in species richness, however, had an unusually low total abundance. The number of individuals caught at this site gradually decreased throughout the sampling period. This decline was thought to be due to the pitfall trap placement within a large ants nest. This negatively affected data collection at this site as the disturbance of the ants nest lead to a high abundance of ants in the pitfall traps which was thought to be related to the decreasing abundance of Carabidae.

Athronen Grassland had the lowest number of species compared to other grassland sites. This small grassland patch consisted of mostly *P. madidus* and *A. parallelepipedus*, which was more similar to that of Athronen Forest relative to the other grassland locations. This further supports its position within the Forest group 1 in the ordination and cluster analysis.

3.2.2 Forest locations

The forest locations varied greatly in diversity. Duckpond Forest 1 had the highest total number of species, and one of the highest total abundances of individuals. The Old Plantation and Athronen Forest had the least amount of species out of all of the sites. The Rose Garden Trees had a high species number, however, the least amount of individuals found out of the forest sites. Bluebell Forest had the highest total abundance of all the forest locations, however it was not as species-rich as other forests sites such as the Duckpond forests or the River forest 1 (*Fig. 13*)

3.3 Weekly Variation and Rainfall

The weather throughout the sampling period was very variable. There were two weeks of hot dry weather (Weeks 1 and 4) and also two stormy weeks of heavy rainfall (Weeks 2 and 6). The weather noticeably affected the sample size per week (*Fig 14*).

There was a significant negative correlation with total abundance of beetles caught and weekly rainfall (correlation = -0.93, p=0.006). The overall carabid activity during hot, sunny weeks was higher compared to the weeks of high rainfall. Additionally, various traps in Wetland, Rose Garden Grassland and Floodplain overflowed during weeks 2 and 6 due the heavy rainfall. This could have also lead to the decreased number of individuals caught during these weeks.

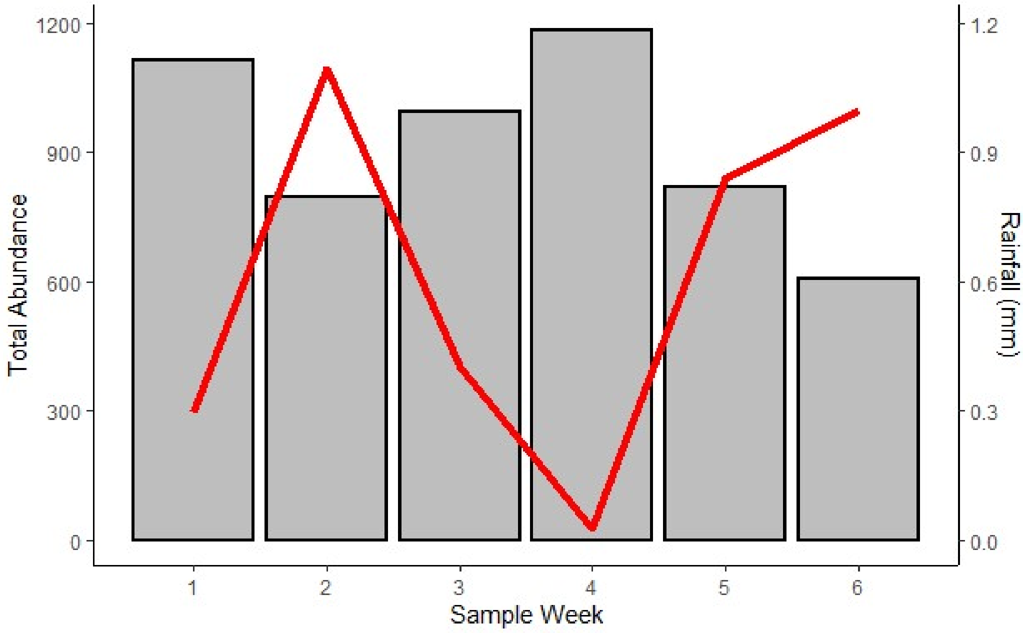

Figure 14: Weekly Rainfall (mm) (line) overlayed on the Total abundance of Carabid beetles per week (columns)

Most of the dominant species followed this negative association with rainfall, such as *P. madidus and P. melanarius.* There were other species that did not, for example, both *Nebria brevicollis* had a higher abundance in the weeks of high rainfall, however this was not significant (*Fig 15*). Most other species were not sufficiently abundant each week to observe reliable weekly variations. The abundance of *Carabus granulatus* was a gradual decline throughout the sampling period, completely unrelated to the rainfall data, suggesting there is other biological or ecological reasons for their weekly variations in abundance over time (*Fig 15*). When looking at the weekly Floodplain data, there is an interesting shift in abundance of *P. nigrita* with *P. niger. P. nigrita* is at a very high abundance in Week 1-3, followed by a reduction in their individual numbers and a rise in *P. niger* and *P. melanarius (Fig. 15)*. This change coincided with a rapid growth of vegetation, following the heavy rainfall in week 2, where the bare ground had a dense covering of grass and *P. anserina* (*Fig 15*). The determining factors for the variation of activity densities throughout the sample period cannot be defined by the scope of this study, however, these can be further discussed and suggestions made to whether this is a competitive interaction or phenological, based on the literature of carabid species traits.

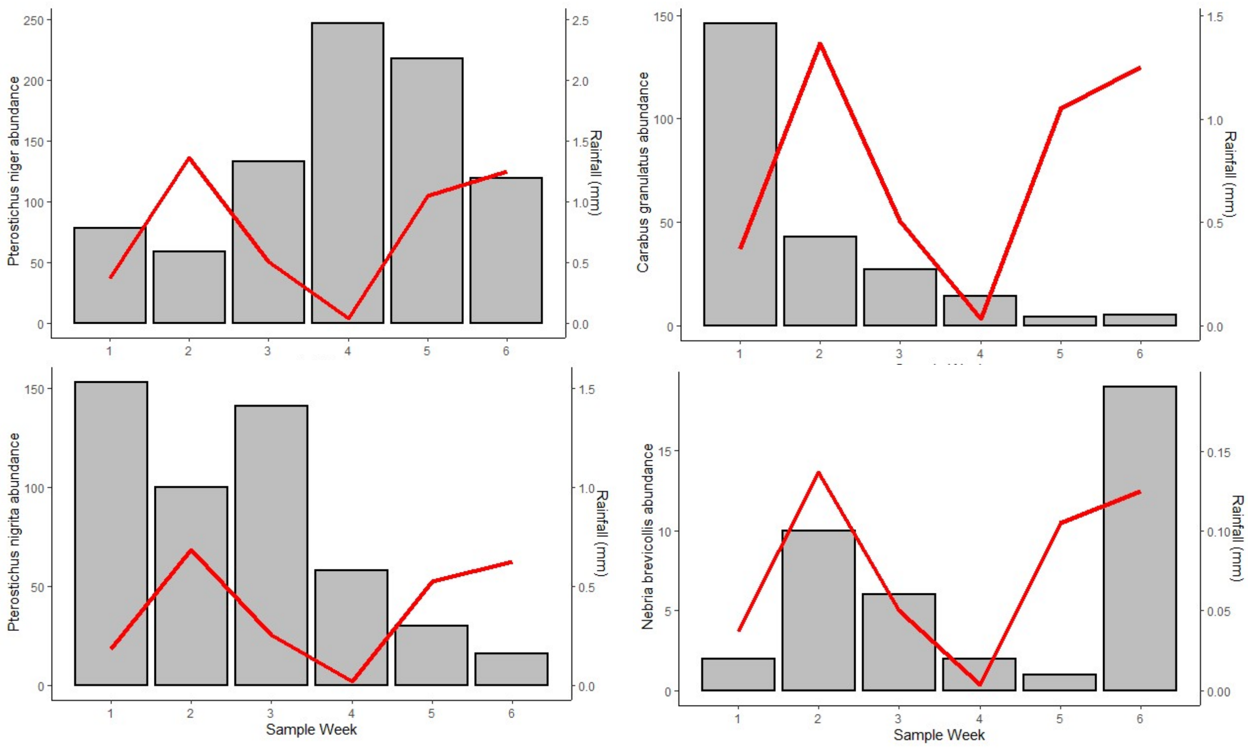

Figure 15: Weekly total abundances of 4 different carabid species (columns) to provide examples of the species-specific variation per week, and weekly rainfall (lines) overlayed onto each graph. Pterostichus niger (top left), Pterostichus nigrita (top right) and their weekly abundance at the Floodplain pitfall trap site. Carabus granulatus (top right) and Nebria brevicollis (bottom right) and their overall abundance per week.

4 Discussion

The 17 different locations sampled at Dunsany estate were grouped into 4 distinct carabid communities that may indicate habitat differentiation between sites, in particular, between the grassland and forest habitat. These four groups and their associated species composition will be discussed, with regard to their known ecological habitat requirements and physiological traits. The ecology of dominant species can be used as indicators for ecological processes that are occurring, in the context of the different microclimates, and also within the heterogenous landscape of Dunsany and its surrounding environment.

4.1 Forest habitats: Group 1 and 2

Group 1 and 2 were closest in ordination space, and also the two main forest communities. Although similar, they differed in their dominant species, where *P. madidus* was most dominant in all group 1 forests and *A. parallelepipedus* was most dominant in group 2, however both species were common throughout all forest habitats present.

4.1.1 *Pterostichus madidus* dominance in group 1

P. madidus is an medium sized nocturnal and omnivorous, which is generally considered to be a forest generalist (Thiele, 1977; Cole et al., 2002). It is often the most common and abundant species in carabid studies, particularly when sampling forests of Britain and Ireland (Blake et al., 1994; Barsoum et al., 2014; Eyre et al., 2013; Fuller et al., 2008). This species was strongly associated with forests habitat at Dunsany, however it is often seen as a habitat generalist and an important aphid predator for agricultural crops, in grassland and other open habitat studies (Lyons et al., 2017; Blake et al., 1994; Blake et al., 2003; Winder et al., 2005). Within open habitats, it is found at a higher abundance in arable crops that have wooded boundaries compared to those without (Eyre et al., 2013).

Many studies have shown that *P. madidus* abundance is strongly correlated with leaf litter layer in forests (Poole et al., 2003; Fuller et al., 2008). This has been thought to be a determining factor in studies that have a found greater abundance of this species in mature deciduous forest compared to coniferous plantations or regenerating forest (Fahy and Gormally, 1998; Poole et al., 2003; Fuller et al., 2008).

In Dunsany, all group 1 forests had a deciduous leaf litter layer covering and sparse herb layer, with the exception of the two Athronen sites. As Plantation 1 contains a mixture of *Quercus* and coniferous species and it had a leaf litter layer of deciduous leaves, it is therefore is not a typical coniferous monoculture plantation compared to other forest studies. This is potentially one of the reasons why the coniferous plantation was not distinct in ordination from other deciduous woodland sites, as might expected from the literature (Fahy and Gormally, 1998; Fuller et al., 2008; Butterfield et al., 1995). In addition to this, the lack of plantation clear-fell cycles and other management distinguishes this forest from other typical plantations. Its microclimate conditions are likely to be comparable to the other group 1 forests, due to the similarities in leaf litter, vegetation structure and canopy cover. Its grouping with the other deciduous forests supports Barsoum et al. (2014) who stated that forest stand type did not have a significant effect on species composition. However, the resulting leaf litter which was comparable to group 1 forests, as well as the fact that it is connected to other forest regions are both likely determining factors for this grouping. The microclimatic conditions require further quantitative assessment for these suggestions to be statistically supported in these habitats.

Athronen forest is relatively open, and the ground was covered in moss underneath a dense vegetation layer of mostly *G. robertianum.* This forest, together with the Athronen grassland are both small isolated patches, surrounded by crop that borders a stone wall. A study by Neumann et al. (2016) looked at the carabid diversity on a heterogenous landscape scale and found that, compared to most forest species, *Abax parallelepipedus* and *P. madidus* were not as negatively affected by patch isolation. Their occurrence in isolated woodland patches within an agricultural landscape was thought to be a result of their poor dispersal abilities, being large flightless beetles. Consequently, in isolated patches such as Athronen, they could persist as remnants of a larger forest network that no longer exists (Neumann et al., 2016; Neumann et al., 2017; Fournier and Loreau, 2001). In addition to this, *P. madidus,* was shown to populate the forest edge and was unaffected by increased transport routes and urbanisation (Neumann et al., 2016; Gaublomme et al., 2008). It is eurytopic and abundant in a broader range of more open habitats than many forest specialists, which further explains its dominance in the small patchy forests of group 1 such as Bluebell Forrest, Athronen Grasslands and Plantation 1 (Anderson, 1997; Anderson, 2000; Luff, 1998; Luff, 2007).

4.1.2 Other forest species in group 1 and 2

Calathus rotundicollis was present in nearly all forest habitat, and the 3rd most abundant species in River forest 2. This is a woodland species (Neumann et al., 2017; Luff, 1998; Luff, 2007). In other forest studies, it has been exclusive to mature deciduous forests compared to conifers or young regenerating forests in Ireland (Poole et al., 2003; Fahy and Gormally, 1998). In Dunsany, it was most numerous in the River forest and Duckpond forest, which are the two largest and most connected forest patches. Although this species is a forest generalist, the strong association of *C. rotundicollis* with mature deciduous forests in other studies could indicate that, relative to the other Dunsany woodlands, these two forests are the most likely to contain forest specialists. Further sampling of different patches within these forests could be done to explore this prediction. They have the largest area and their size and shape suggests there is less forest edge in these forests which is more suitable for forest specialist species (Gaublomme et al., 2008).

There were various species that were typical of open habitat, such as *Notiophilus biggutatus* and *Anchomenus dorsalis* (Luff, 2007; Anderson, 2000*)*. Both *Notiophilus biggutatus* and *Loricera pilicornis* are specialist *Collembola* predators. These two species, and *Anchomenus dorsalis*, were grouped together by ecological traits in Cole (2002), and are associated with open clearfell regions, agricultural crops and grassland with high fertiliser input as these habitats have high densities of *Collembola* prey populations(Fahy and Gormally, 1998; Ings and Hartley, 1999; Eyre et al., 2013; Schneider et al., 2016; Blake et al., 1994). Within this study, these three species were only found in the Dunsany forests.

Schneider et al. (2016) identified *Anchomenus dorsalis* as a dominant crop species involved in spill over of carabid from crop to semi-natural habitat after crop harvests. Moreover, *N. biggutatus* is macropterous and a good disperser that could populate these forests as a refuge and have temporal abundance dependent on productivity and disturbance of the surrounding grassland habitat (Schneider et al., 2016; Fournier and Loreau, 2001). Only a singular specimen of each of these species was found in this study, however, their occurrence in the forest habitat should be further examined to determine whether they are a spill-over species that inhabit the forests as a seasonal refuge, or found at very low numbers in these forests by random occurrence.

Although widespread, *L. pilicornis* is occasionally considered a forest dwelling species in other Irish carabid studies (Poole et al., 2003; Fahy and Gormally, 1998; Day et al., 1993; Anderson, 1997). This species requires damp, shady soil and its association with woodlands is also supported in open habitat studies such as Eyre et al., (2013) who found it was more abundant in crops with low disturbance and woodland surrounding it. *L. pilicornis* was most abundant in group 2 forests, particularly Duckpond forest 2 and Rose Garden Trees, which suggests these forests are abundant in the preferred *Collembola* prey species for *L. pilicornis*, that hunt by using their long antennal setae to trap small *Collembola* species (Hintzpeter and Bauer, 2009).

4.1.3 *Abax parallelepipedus* dominance in group 2

The three forests in group 2 differed from the group 1 cluster by the dominance of *Abax parallelepipedus.* As mentioned before, it is a large flightless forest generalist, abundant in nearly all forest studies. Compared to *P. madidus*, it is more exclusive to forest habitat, and damp forest conditions (Toïgo et al., 2013; Lövei and Sunderland, 1996; Thiele, 1977; Barsoum et al., 2014). In the study by Poole et al., (2003), *A. parallelepipedus* was not one of the species that correlated with leaf litter layer in forests. Interestingly, the 3 pitfall trap locations in group 2 did not have much leaf litter layer compared to those of group 1, and therefore this could be a possible explanation to why this species is more dominant in these habitats. Additionally, Poole et al. (2003) found that *A. parallelepipedus* was more abundant in a regenerating forest that had an open canopy and dense layer of *R. fructicosus* and shrubs compared to the mature deciduous forest. This is very similar to the conditions of Old Plantation and Rose Garden Trees, where the open coniferous canopy has resulted in a herb layer densely covered with *U. dioica*, *R. fructicosus* and shrub, as well as the large amount of regeneration at Old Plantation. The slight differences in leaf litter and herbaceous cover could further explain the relatively high abundance of *A. paralllelepipedus* compared to *P. madidus* in group 2 forests compared to group 1.

The highest abundance of *Trechus obtusus* out of all of the Dunsany sites was in Old Plantation. *T. obtusus* is a common, widespread habitat generalist species (Anderson, 1997; Luff, 2007). Its occurrence in Old Plantation is comparable to Ings & Hartley, (1999), where it was highest in an old regenerated *P. sylvestris* plantation with ground flora that caused a dense shady microclimate. *T. obtusus* has been described as a heathland species (Anderson, 1997). Its presence in forests, such as Old Plantation, could be explained as 'persisting' in suitable forest edges and after the conversion of habitat into agriculture, as suggested with other heathland species by Neumann et al. (2017). Its relatively higher occurrence in forest compared to grasslands within this study would need to be examined further as the species was found in insufficient densities to draw any conclusions about its habitat preferences. The presence of heathland and grassland species in forest edges adjacent to arable crops at Dunsany would be an interesting topic of research when compared to historical land compositions, and would illustrate the importance of such habitats in a wooded-agricultural landscape matrix in Ireland.

4.2 Group 3: Duckpond forest 1

The Duckpond forest 1 was not only in a distinct cluster in the dendogram compared to other forest groups, but also the most species-rich of all the forest habitats. *P. melanarius* was the most dominant species in this habitat, despite its higher proportion in grassland habitats at Dunsany. *P. melanarius* is a very common generalist in nearly all habitat types, including coniferous, deciduous semi-natural, and agricultural habitats (Day et al., 1993; Toïgo et al., 2013; Andersen, 1999; Anderson, 2000; Winder et al., 2005; Luff, 1998). As with *P. madidus*, it is an important aphid predator in crop habitats, and its abundance is positively correlated with leaf litter layer in forest habitat (Winder et al., 2005; Poole et al., 2003; Lövei and Sunderland, 1996).

Duck Pond Forest 1 also had a relatively large abundance of *Nebria brevicollis.* This species is also ubiquitously found in all habitat types, however in the context of Dunsany, this species was much higher in the forests. *N. brevicollis* is very strongly associated with leaf litter layer and dead wood, and they are more abundant in mature deciduous forests compared to pine plantations (Fuller et al., 2008; Fahy and Gormally, 1998). The species composition and diversity of this side of the Duckpond forest was unique to the other two forest groups as, although *P. madidus* and *A. parallelepipedus* were dominant species, the composition consisted of a higher proportion of open habitat generalists than the other forests.

There are some possibilities to why this is. Duck Pond Forest is surrounded by an arable crop, and a road. Although it is a large forest, the pitfall trap site was relatively close to the forest edge. Forest edges tend to be more abundant in open habitat and generalist species (Gaublomme et al., 2008). The habitat patchiness of the Duckpond forest has resulted in many small regions of open habitat within this forest, which would benefit open habitat species (Toïgo et al., 2013). Moreover, Duck Pond Forest 1 could be an important crop edge refuge site for species such as *P. melanarius* that feed on crop pests.

Furthermore, the large wet areas of bare ground near Duck Pond Forest 1 pitfall traps may have influenced the species composition, with regard to hygrophilous species such as *A. emerginatum* and *P. nigrita* (Anderson, 2000). The presence of hygrophilous species could be more strongly influenced by the presence of high soil moisture and low disturbance rather than habitat type. These large wet pond regions could be investigated further with respect to their biodiverrsity value and species composition in a forest-wetland habitat.

The diversity and species richnesss of Duck Pond Forest 1 is comparable to the Rose Garden Trees in Group 2 forests. Its high diversity was mostly due to the combination of both grassland-associated and forest-associated species. Rose Garden Trees was an extremely small forest patch surrounded by the rewilded Dunsany grasslands of Rose Garden Grass and Sheep meadow, and therefore would also have a lot of forest edge effects. Generally, the forests with the highest diversity and species richness in Dunsany were due to higher proportions of open habitat species compared to the other forests.

4.3 Group 4: The Grassland habitat

All of the grasslands throughout Dunsany had comparable species composition, and therefore were grouped together in the ordination and cluster analysis. There was no clear differentiation dependent on historical land use or succession stage, however, further dissussion of the species present and their relative abundance can still indicate some possible environmental conditions in each of the sites. Perner and Malt (2003) suggested that the restoration from agricultural land to grassland can be apparent in the carabid communities from up to 3-5 years. All of the Dunsany fields have exceeded this time, thus it is possible that following the 3-5 year succession period the variation in species composition evened out.

4.3.1 Succession and species abundance

Despite the lack of distinction in the ordination, the grassland with the highest species richness was Cricket Field, the oldest site which was previously cattle grazed as well. This site had the largest abundance of *Amara* species. These are phytophagous species, generally prefering ungrazed, semi-natural grasslands (Lyons et al., 2017; Thiele, 1977; Cole et al., 2002). Their abundance is correlated with weed densities in agricultural studies (Andersen, 1999). This site was assumed to have the most diverse vegetation, which is likely related to its large abundance of phytophagous species. *Amara communis* was also found at low numbers in other grasslands throughout Dunsany, and is the most moisture tolerant species of this genus (Luff, 1998). As *Amara* species are good dispersers, it could be predicted that the future abundance of phytophagous carabids will be associated with changes in vegetation diversity.

Crop Meadow was the most recent addition to the rewilding area, and unique compared to the other grassland regions because it was tilled for arable crop. This was evident on visiting the site due to the visible parrallel furrows, which have created alternating rows of *Juncus spp.* and grasses across the field. A notable difference in the dominant species found in this site is the high proportion of *Harpalus rufipes.* This species is a polyphagous speices associated with dry, higly disturbed agricultural ground, particularily arable crop (Andersen, 1999; Eyre et al., 2013; Lövei and Sunderland, 1996; Anderson, 1997). When comparing tillage regimes, Andersen et al. (1999) found that it was more abundant in fields that were tilled compared to no-tillage, possibly due to a benefit from the increased amount of bare ground in tilled fields.

Whether the high abundance of this species indicates the relatively recent change in land use within Crop Meadow cannot be confirmed by the scope of this research, however its dominance in consecutive years is a point of interest. If *H. rufipes* shows a decline in abundance within this field, it is possible the current populations shown in this study are an indication of the past land uses and earlier successional stage of this grassland compared to the other sites. On the other hand, this species is also a good disperser, and is found throughout grassland patches and hedgerows, especially those adjacent to arable crops (Anderson, 1997; Anderson, 2000; Wamser et al., 2012; Eyre et al., 2013). Its dominance in this grassland would need to be futher investigated over time and compared to other grasslands, adjacent arable crops and, if possible, any new rewilding sites that are established in future.

Generally, the indicator for succession from agricultural land is the increasing presence of hygrophilous species (Perner and Malt, 2003). An investigation of the relative abundances of xerophillic species associated with crops, such as *H. rufipes,* compared to the hygrophillic species associated with low management intensity could be done over time to explore this. The parallel lines of compaction in this field have created an unusual arrangement of waterlogged regions and drier regions, and Crop Meadow had a mix of moisture associatied species, for example high abundance of hygrophillic *Carabus granulatus,* and also dry grassland associated *Poecilus versicolor* (Luff, 1998; Luff, 2007). The mix in composition of moisture associated and xerophillic species was characteristic of all the grassland habitat within Dunsany. Sheep Meadow, Big Meadow and Crop Meadow are adjoining grasslands, and all found to be comparable in carabid diversity and composition.

4.3.2 The waterlogged regions of Dunsany

There were 3 sites that flooded during the rainy weeks of sampling: Wetland, Rose Garden Grassland and Floodplains. These sites also formed a close cluster in the dendrogram, likely because they all have a high proportion of hygophillic species. There were two dominant species, *Pterostichus nigrita/rhaectus*, and *Carabus granulatus*, in these locations that are associated with waterlogged environements such as bogs (Anderson, 2000; Thiele, 1977; Luff, 1998; Luff, 2007; Anderson, 1997). Blake (2003) grouped a community of *P. nigrita* with *A. fuliginosum* as indicators for wetland areas alongside reedbeds, mires and fens. In accordance with this, both species were present in the wetland and floodplain areas of Dunsany.

A singular *Agonum marginatum* was found in the first sampling week at the FP site. This species is common in flooded habitats such as turloughs (Ní Bhriain et al., 2002). Its is associated with wet clay vegetated shores and riverbeds and lakes, and its high abundance in turloughs was suggested to be associated with a large amount of bare ground in one of the more grazed site(Ní Bhriain et al., 2002; Anderson, 1997). This could be indicative of the type of habitat at this floodplain region, where there was only wet bare ground and *Juncus spp.* present during the first two weeks of sampling followed by flooding and vegetative growth after high rainfall.

Further studies could investigate the apparent change in species abundance that occurred throughout the sampling period at Floodplain and whether this is associated with the change in vegetation structure. There was a decline in *P. nigrita* and increase of *P. niger* and *P. melanarius*. This could be due to ecological factors, showing a reciporical abundance of competing species or alternatively, the dense vegetation could have restricted movement for the smaller, macropterous *P. nigrita*, which resulted in less induviduals falling into the traps. *P. niger* and *P. melanarius* are both large and brachypterous, and therefore may have higher mobiility when walking through the grass (Lövei and Sunderland, 1996). Although *P. niger* is wingless, and therefore has low dispersal ability on a larger scale, it has also been desbribed as having a high dispersal power over land (Neumann et al., 2017; Lövei and Sunderland, 1996).

4.3.3 Large flightless carabid species

P. niger and *P. melanarius* are the two most dominant species throughout the grassland habitats. Blake (1994) suggested that larger carabids, such as these of the *Pterostichus* and *Carabus* genus are often indicative of undisturbed, uncultivated habitat (Blake et al., 1994). *P. niger* is associated with open habitat in the UK and Ireland as it is more abundant in grasslands and forest clearings, however is generally considered a forest species thoughout Europe(Toïgo et al., 2013; Magura et al., 2003; Day et al., 1993; Ings and Hartley, 1999; Luff, 1998). In Dunsany, *P. niger* was generally more abundant in the waterlogged locations such as Wetlands and Rose Garden Grassland, which is interesting as it was described by Anderson (1996) as inhabiting drier habitat that *P. melanarius.*

The large *Pterostichus* and *Carabus* species are mentioned frequently in carabid diversity studies, as having a high biodiveristy and conservation value that may be under threat by large scale landscape conversion from semi-natural habitat to agriculture (Neumann et al., 2016; Neumann et al., 2017; Cole et al., 2002; Blake et al., 1994). *Carabus granulatus* and *Carabus nemoralis* are both considered common, widespread species throughout Ireland; however, *C. nemoralis* is relatively underrecorded in this region of the island (Anderson, 2000; National Museums Northern Ireland, 2006). *C. nemoralis* was part of the same ecological group as the large *Carabus* group classified as very sensitive to management intensity and habitat quality. Structural heterogeneity has a bottom up affect on large carabids, that prefer dense vegetation for suitable microclimate (Brose, 2003) The presence of common large predators that are similar in habitat requirements at Dunsany can indicate suitability of habitat for these other large, habitat-sensitive beetles from this genus.

4.4 Carabid diversity and habitat differentiation

Eyre and Luff (1994) suggested that forest habitat in Britain and Ireland are too small and isolated for the disctinct forest communities found elsewhere in Europe. This was further supported by Blake et al. (2003) who could not distiguish forest and open habitat when using carabid communities as habitat classifications. Habitat quality can often be analysed using relative proportions of specialist to generalist species, or good dispersers and poor dispersers (Fournier and Loreau, 2001; Wamser et al., 2012). This study has shown a clear distinction in the species composition of forest and grassland habitat, which indicates there is habitat differentiation; however, few of the species present are generally known as the rare forest specialists associated with semi-natural habitat. The majority of species found were forest generalists and those with high dispersal abilities. It is important to discuss some reasons to why this might be:

- Short sampling period

This study had a very short in its sampling time, therefore was limited by season and sampling effort. Further sampling of these areas would increase likelihood of finding rarer, less abundant species. As many carabids have 2 year lifecycles, there are variations in yearly abundances of species (Lövei and Sunderland, 1996; Johan Kotze et al., 2011). In addition to this, some species are seasonal in their activities, and can be found in higher densities in the Autumn or Spring (Fahy and Gormally, 1998). This indicates that sampling over a longer timeframe would provide information that is a much more accurate representation of the carabid communities present throughout the year.

Within the 6 weeks during this study, there were two weeks of heavy rainfall, and also two very dry heatwaves, which affected the activity levels of some of the carabid species. A longer timeframe would have provided more variation of weather patterns and buffered the weeks of more extreme weather conditions and, hence, given a more reliable representation of the carabids present at this time.

- Age of Dunsany Habitats

The recolonisation of typical forest associated species is thought to take up to around 50 years after stand establishment (Magura et al., 2003). Some of the forests of Dunsany are much younger than this, and have patches of older species, beside patches of more recently planted trees. Abandonment of management regimes in forests, as in Toigo et al., (2013), suggested that the 15-45 year old forests had not yet developed the distinctive habitat characteristics needed for forest specialists. Dunsany could be regarded as too recently developed as a rewilding site for the environment to have reached its most suitable conditions for the rare forest specialist species. Despite this, there is good differentiation amoung the locations sampled within this study.

Toigo et al. (2013) also found that the unmanaged forests were beneficial for both forest specialists and open habitat species, as there was more horizontal heterogeneity of open and closed canopy compared to actively managed forests. The role of abandonment on carabid species was observed to be very dependent on the forest developmental stage, exotic plantation, species composition and heterogenetiy of structure and canopy cover (Toïgo et al., 2013). This is relevant to the forest patches of Dunsany as all of these features are patchy throughout the estate.

- Size and Connectivity of habitat patches

It has been suggested that colonisation of specialist species into suitable habitat can take 80+ years, dependent on its degree of connectivity to other habitat (Neumann et al., 2016; Neumann et al., 2017). Communities in some forest fragments are remnent populations of the past environment that have persisted in contemporary habitat patches that were once part of much larger woodland and heathland mosaics (Barsoum et al., 2014; Neumann et al., 2016; Neumann et al., 2017; Day et al., 1993). The connectivity of habitats is important for habitat quality and conservation. Mature, undisturbed hedgerows act as short term habitat refuges for species of poor dispersal abilities and allow for colonisation into new or more suitable habitat (Fournier and Loreau, 2001). Semi-natural woodland patches have been shown by Fournier and Loreau (2001) to be dominated by generalist species with high dispersal ability in an agricultural landscape. This was because these species can leave disturbed environments and colonise high quality habitat more readily, compared to the large flightless species. In this study, hedgerows were shown to be extremely valuable for biodiversity and the survival of sedentry specialists.

Remnant woodland patches and connecting hedgerows are vital habitat, however their size and shape is important (Fournier and Loreau, 2001; Gaublomme et al., 2008). As aforementioned, forest edges tend to be more beneficial for generalists and open habitat species. Forest specialists increase in abundance and species richness further into woodland from the edge, where there is a more closed canopy and increased dampness. Dunsany forests vary in size and shape. It is possible that the more isolated, smaller patches such as Bluebell and Athronen are too small to provide the suitable conditions for forest specialists, while being important refuge sites for forest generalists and open habitat species (Fournier and Loreau, 2001; Pywell et al., 2005; Gaublomme et al., 2008).

4.5 Outlook

This initial baseline data have given a brief insight into the carabid communities of Dunsany habitat patches. This baseline can be used to establish further research of the biodiversity, ecological processes, and succession of habitat at the site. This information should be combined with other analysis, such as the vegetation diversity, structure and regeneration, a soil analysis, and also other invertebrate taxa such as Aranaea or Syrphidae for a complete biodiversity assesment (Pywell et al., 2005; Sommaggio, 1999).

- Monitoring yearly and seasonal change

This data can be built upon anually to provide an insight on the yearly change of species composition. A comparison of pitfall trap samples at different times of the year would give insight to the seasonal importance of some of the locations as overwintering refuges, and post harvest-spillover refuges, while showing the natural seasonality of the species present at the site. For example, *Nebria brevicollis* was found to be more abundant in Autumn sampling compared to earlier seasons (Fahy and Gormally, 1998).

As there are species in this study which are known to be predators of pest species and crop inhabitants, their abundance within the Dunsany habitat may change dependening on the season, agricultural disturbance and productivity levels (Schneider et al., 2016). With further analysis and sampling, a study could be made to investigate the spillover movement and rate of carabid and other invertebrates from crop to rewilding site and vice versa, and how this is affected by relative production of adjacent habitat. This will provide an indepth understanding of the biodiversity value of the rewilding site for both conservation and the surrounding agriculture.

Monitoring the carabid populations over repeated years will facilitate analysis of diversity change over a long time period as futher sucession occurs. In future, colonisation of more, rarer carabid species may occur. Moreover, the plans to plant more trees will eventually connect and expand forest patches, and it will be interesting to compare this initial dataset with future populations. This initial data has also elucidated, for the first time, locations with similar carabid communities that can reliably be used as replicates in future research and hypothesis testing.

- Further sampling of Dunsany habitat and other locations

More extensive analysis could be carried out of the Wetland and Floodplain regions. In the Floodplain, the shift in species abundance could be analysed to give an explanation for the results in this study and whether this was an ecological interaction, structural/mobility changes or just a seasonal or random change in occurence.
There were a few comparable Floodplain habitats near the pitfall trap site, which could be used as replicates in order to do so. An additional study of the wetland area that is not disturbed or affected by ants would improve understanding of this location.

In this study all pitfall trap sites were placed in and around the main Dunsany Estate area, however there are other forest patches outside of this region that are still yet to be assessed. Within the forest patches assessed in this study, the size, shape, edge habitat and patchiness could be important factors determining carabid communities and could be analysed, particularily in Duck Pond Forst and River Forest, as they were the biggest forests yet differed in their shape and structure. They both also had large regions of *P. laurocerasus* tree dominance, intermixed within the forest. The effect of large *P. laurocerasus* tree patches on invertebrate communities would be an interesting study, as they are known to change the toxicity of soil, and vegetation structure of the ground underneath, therefore could influence the species composition of carabid beetles that inhabit these patches. The *P. laurocerasus* trees were close to some of the pitfall trap sites, however there was no pitfall traps placed directly adjacent to them.

Eventually, a landscape heterogeneity study that combines the entire landscape matix of hedgerows, forest patches, grasslands and their connectivity could be assessed and applied to conservation management at the site. Increasing connectivity of forest patches seems like an appropriate goal for future conservation (Fournier and Loreau, 2001; Neumann et al., 2016).

5 Conclusion

It is apparent, that there is a need for more undisturbed habitat in Ireland, to help maintain and reduce the loss of biodiversity in invertebrates and other species that are persisting in the agricultural landscapes in Ireland. Dunsany has the potential to be an important wildlife refuge due to its lack of anthropogenic disturbance and agricultural management. This study has provided the first information of the different species of carabid present at the site. It has shown habitat differentiation between forests and grassland. Forest generalists such as *A. parallelepipedus, P. madidus, C. rotundicollis* and *L. pilicornis* are distinctive species within forest habitat communities. The grasslands are generally more diverse and species rich, where *P. melanarius, P. niger, C. granulatus, P. versicolor* and *H. rufipes* amoung others are characteristics of these communities. The forest groups can be futher grouped into 3 different communities that differ slightly in their species composition. These differences are potentially due to variaitons in microclimate, patch size and fragmentation, which are all characteristics that could be tested in future research.

The ecological traits of carabid species can often indicate environmental conditions and habitat quality. The grassland habitat in Dunsany had a combination of hygrophillic species and those that are more numerous in semi-natural grassland, also an abundance of common agruculturally associated species. The forest habitat had mostly forest generalists and open habitat species. As the rewilding project is established further, these are topics of interest for conservation practices at the site. This initial baseline data could give rise to future research and monitoring of carabid and other bioindicator species and how this will change over time.

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7 Appendix

Appendix 1: list of Carabidae and their Tribes. Sources of past records of these species in County Meath (where possible)

Species	Tribe	Record in Meath
Abax paralellepipedus	Pterostichini (Bonelli 1810)	National Biodiversity Data Centre (Biodiversity Ireland, 2020)
Agonum emerginatum	Sphodrini (Laporte, 1834)	-
Agonum fuliginosum	Sphodrini (Laporte, 1834)	-
Agonum marginatum	Sphodrini (Laporte, 1834)	-
Amara communis	Zabrini (Bonelli, 1810)	-
Amara lunicollis	Zabrini (Bonelli, 1810)	-
Anchomenus dorsalis	Platynini (Laporte, 1834)	Ground Beetles of Ireland website (National Museums Northern Ireland, 2006)
Bembidion obtusum	Bembidiini (Stevens, 1827)	-
Bembidion aenum	Bembidiini (Stevens, 1827)	Ground Beetles of Ireland website (National Museums Northern Ireland, 2006)
Calathus melanocephalus	Sphodrini (Laporte, 1834)	-
Calathus rotundicollis	Sphodrini (Laporte, 1834)	-
Carabus granulatus	Carabini (Latreille, 1802)	National Biodiversity Data Centre (Biodiversity Ireland, 2020)
Carabus nemoralis	Carabini (Latreille, 1802)	-
Clivina fossor	Scaritini (Bonelli, 1810)	-
Curtonotus aucilus	Zabrini (Bonelli, 1810)	-
Harpalus rufipes	Harpalini (Bonelli, 1810)	-
Loricera pilicornis	Locerini (Bonelli, 1810)	-
Nebria brevicollis	Nebrini (Laporte, 1834)	Ground Beetles of Ireland website (National Museums Northern Ireland, 2006)
Notophilus biguttatus	Notiophilini (Motschulsky, 1850)	-
Pterostichus madidus	Pterostichini (Bonelli, 1810)	-
Pterostichus melanarius	Pterostichini (Bonelli, 1810)	-
Pterostichus niger	Pterostichini (Bonelli, 1810)	-
Pterostichus nigrita	Pterostichini (Bonelli, 1810)	-
Pterostichus strenuus	Pterostichini (Bonelli, 1810)	Ground Beetles of Ireland website (National Museums Northern Ireland, 2006)
Pterostichus vernalis	Pterostichini (Bonelli, 1810)	-
Poecilus versicolor	Pterostichini (Bonelli, 1810)	Ground Beetles of Ireland website (National Museums Northern Ireland, 2006)
Trechus obtusus	Trechini (Bonelli, 1810)	Ground Beetles of Ireland website (National Museums Northern Ireland, 2006)

Appendix Table 2: Additional notes and habitat information of the grassland locations at Dunsany

Grassland habitat	Area (ha)	Surrounding habitat	Previous land use	Rewilding Age	Additional information
Big Meadow	30.8	RF1, BF, SM	Silage	7 years	In the centre of the white poplar and aspen tree, when walking from FP.
Cricket Field	2.61	DPF2, Forest	Cattle grazed	>10 years	Potential tree planting site to connect adjacent forests, field is surrounded by a deep ditch
Crop meadow	8.81	RGT, roadside	Arable crop	6 years	Abundant with saplings, ragwort around field edges. Can see tillage lines from past land use.
Floodplain	0.14	BM	Agricultural	7 years	Vegetation growth covered bare ground Week 3. Pitfall trap flooding.
RG grass	0.85	RGT	Silage	7 years	Some pitfall traps prone to flooding on very wet weeks
Sheep meadow	17.8	CM, BM, BF, RGT	Sheep grazed	7 years	Some saplings here, but not very frequent.
Wetland	1.13	BM, forest	Agricultural	7 years	Permanently flooded region beside traps. Pitfall trap flooded
Athronen Grassland	0.67	Arable crop	Crop edge	unknown	Traps on the top of a slight hill, saplings of holly found in this patch.

Appendix Table 3: Additional notes and habitat information of the forest locations at Dunsany

Forested Habitat	Area (ha)	Surrounding habitat	Canopy %	Canopy species	Ground layer	Herb Layer	Additional information
Bluebell Forest	2.21	BM, SM	70	Sycamore	Leaf litter	Sparse	Wildflowers such as bluebells in Spring
River forest 1	18.9	BM, RF2	90	Beech	Leaf litter cover	Sparse, Box shrub	Traps on elevated ground beside river
River forest 2	18.9	SM	60	Yew	Pine needles, bare ground, moss	Moderate	Deadwood, path and river nearby
Plantation 1	1	BM	80	Oak	Leaf litter	Sparse	Young Sycamore and Ash shoots around trap
Athronen Forest	9.13	Arable crop	50	Ash	Moss cover	Dense	On a slope. Lots of deer present
RG trees	1.28	RGG	30	Coniferous	Moss and vine cover	Dense	Some tree felling occurred around week 2-3
Old plantation	2.33	Arable crop	20	Coniferous	Thick layer of pine needle	Dense	Deciduous tree regeneration.
Duck pond Forest 2	16	CF, crop	70	Sycamore	Moss, leaf litter and bare ground	Sparse	Area surrounded by laurel, grass growth at week 5-6
Duck pond Forest 1	16	Arable Crop, road	60	Oak	Leaf litter	Moderate	Traps near small ponds within the forest

Appendix 4: List of other animal species found at Dunsany Nature Reserve, by either pitfall trap, opportunistic catches or sightings

Butterflies:

- Meadow brown (*Maniola jurtina* Linnaeus 1758)
- Ringlet (*Aphantopus hyperantus* Linnaeus 1758)
- Small tortoiseshell (*Aglais urticae* Linnaeus 1758)
- Speckled wood (*Pararge aegeria* Linnaeus 1758)
- Peacock (*Inachis io* Linnaeus 1758)
- Silver-washed fritillary (*Argynnis paphia* Linnaeus 1758)
- Large white (*Pieris brassicae* Linnaeus 1758)

Ordonata:

- Banded Demoiselle Damselfly (*Calopteryx splendens* Harris 1780)
- Large red damselfly (*Pyrrhosoma nymphula* Sulzer 1776)

Coleoptera:

- Banded Sexton Beetle (*Nicrophorus investigator* Zetterstedt 1824)
- Black Snail Beetle (*Silpha atrata* Linnaeus 1758)
- Devils Coach Horse (*Ocypus olens* Müller, 1764)
- Rove Beetle (*Stapylinus caesareus* Cederhjelm 1798)
- 7 spot ladybird (*Coccinella septempunctata* Linnaeus 1758)
- 14 spot ladybird (*Propylea quattuordecimpunctata* Linnaeus 1758)
- Forest shield bug (*Pentatoma rufipes* Linnaeus 1758)
- Common Red Soldier Beetle (*Rhagonycha fulva* Scopoli 1763)

Other invertebrates:

- European nursery web spider (*Pisaura mirabilis* Clerk 1757)
- Cross orb-weaver (*Araneus diadematus* Clerck 1758)
- Red velvet mite (Trombidiidae sp.)
- Grasshopper (Orthoptera sp.)
- Hoverfly (Syrphidae sp.)
- Red tailed bumblebee (*Bombus lapidaries* Linnaeus 1758)

Birds:

- Buzzards (*Buteo buteo* Linnaeus 1758)
- Yellowhammer (*Emberiza citrinella* Linnaeus, 1758)
- Grasshopper warbler (*Locustella naevia* Boddaert, 1783)
- Great Spotted Woodpecker (*Dendrocopos majoras* Linnaeus 1758)
- Eurasian Wren (*Troglodytes troglodytes* Linnaeus 1758)
- Great tit (*Parus major* Linnaeus 1758)
- Common Chaffinch (*Fringilla coelebs* Linnaeus 1758)
- Black cap (*Sylvia atricapilla* Linnaeus, 1758)
- Eurasian Jay (*Garrulus glandarius* Linnaeus, 1758)

Mammals

- Pygmy shrew (Sorex minutus Linnaeus, 1766)
- Field mouse (Apodemus sylvaticus Linnaeus 1758)
- Red Deer (*Cervus elaphus* Linnaeus, 1758)

Appendix 5: Other species mentioned in the text, their common name, scientific name and authorities

Tree Species:

- Ash (*Fraxinus excelsior* L.)
- Oak (*Quercus sp.* L.)
- Holly (*Ilex aquifolium.* Linnaeus*)*
- Sycamore (*Acer pseudoplanatus* L.)
- Beech (*Fagus sylvatica* L.*)*
- Hazel (*Corylus avellana* L.)
- Horse Chestnut (*Aesculus hippocastanum L.*)
- Elm (*Ulmus glabra* Huds.*)*
- Yew (*Taxus baccata L.)*
- Scots Pine (*Pinus sylvestris* L.),
- Douglas Fir (*Pseudotsuga menziesii* (Mirb.) Franco)
- Cherry Laurel (*Prunus laurocerasus L.*)

Herbs and other plants

- Common Box shrub (*Buxus sempervirens* L.)
- Herb-Robert (*Geranium robertianum* L.)
- Enchanters Nightshade (*Circaea lutetiana* L.*)*
- Hogweed (*Heracleum sphondylium* L.),
- Nettle (*Urtica dioica L.)*
- Brambles (*Rubus fructicosus* L.)
- Golden Saxifrage (*Chrysosplenium oppositifolum* L.*)*
- Silverweed (*Potentilla anserina (L.) Rydb.*)
- Yellow Iris (*Iris pseudacorus* L.)
- Ragwort (*Senecio jacobea* L.).

- Shield fern (*Polystichum setiferum* (Forssk.) Woynar)
- Lady fern (*Athyrium filix-femina* (L.) Roth)
- Male fern (*Dryopteris filix-mas* (L.) Schott)
- Harts-toungue fern (*Asplenium scolopendrium* L.)

Mammals:

- Red Fox (*Vulpes vulpes* Linnaeus, 1758)
- European Badger (*Meles meles* Linnaeus 1758)

Birds:

- Skylark (*Alauda arvensis* Linnaeus, 1758),
- Lapwing (*Vanellus vanellus* Linnaeus, 1758)

Invertebrates:

- Springtail species (*Collembola* Lubbock, 1871)
- Ash Sawfly (*Tomostethus nigritus* Fabricus 1804)