Effect of Tree Age on the Carbon Sequestration in the Native Forest of Farlow Wood, Northern Ireland

MSc Ecological Management and Conservation Biology

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Skills and Experiences

Throughout this placement experience, I have had the opportunity to gain new skills and improve on ones previously obtained while reflecting on my ability to carry out each skill. First I will talk about the several skills gained and developed in the field, to begin with, my identification skills have improved greatly in terms of plants as before this I had been primarily involved with marine and freshwater organisms such as coral species. By collecting tree age data has allowed me to develop a non-invasive process by using equations and species co-efficient, therefore evolving my mathematical skills. In conjunction with these mathematical skills, I have developed my statistical analysis of data by learning new codes in the program R Studio via ggplot2 and new statistical tests such as Kendall's rank correlation and normality tests. A new computing skill that I have gained is that of mapping but physically and digitally. Each of the maps needed GPS locations of each tree, once found a hand-drawn map was created with the general location of each tree and to scale. The locations were added to excel sheets in a format that could be used in the program ArcGIS. This skill can be used in other projects in the future.

However not all the skills I gain were in the field but at home, due to the global pandemic of Covid-19 this placement was one like no other and I have had to adapt to an ever-changing situation. First of was my communication skills have been developed, in a normal situation work placement would have been carried out with in-person meetings with my supervisor and the organization's team almost daily. I have been fortunate enough to still be able to have a few of these meetings occur across the month and when these did not occur I had digital zoom meetings with my supervisor bi-weekly as well as being able to communicate through email. This meant that I had to improve my communication skills quickly to get across my ideas as well as discussing ideas with the team to improve my team-building skills. However, my independent thinking was the main skill to be improved as I have had to adapt to working from home. This has improved my perseverance as well as building up my confidence in making my own decisions. Overall, I am very lucky and grateful that I have been able to carry out this placement opportunity as many of peers have been unable to due to Covid-19. I will use not only the physical skills gain but the mental skills as well by carrying these over to my everyday life i.e. Communication and will help me further my career.

Abstract

Carbon sequestration is an essential process that can provide us with information about the area and the ecosystems within it. This information can be vital as being a part of strategies to reduce global CO_2 emissions. In 2018 the levels of atmospheric carbon dioxide (CO_2) reached 407.4 ± 0.1ppm with an annual increase of CO_2 levels of approximately 2.3 ppm. Carbon sequestration is the process of capturing and securing carbon, and if the carbon were not stored it would be released back into the atmosphere again. This study based in Farlow Wood, Northern Ireland has investigated how much carbon is sequestered within the forest, how the amount of carbon sequestered is affected by the age of the trees. The study also compared the relationship of age and carbon sequestration in Farlow Wood to other global forests. Tree age was calculated by using equations and species co-efficient values and by measuring the circumference. Species and diameter were used to calculate carbon sequestration. These calculations were made for all 703 trees in Farlow Wood. All three of the aims set were achieved with all of our alternative hypothesis' being accepted and statistically significant. Results included that Farlow Wood has currently sequestered approximately 2403.25 metric tons. When looking at the aim of age affects carbon sequestration there is a strong, non-linear, positive correlation between the two variables. The results for aim 3 showed that Farlow Wood follows the same positive correlation pattern for age vs carbon sequestration to a large majority of global forests. However, when comparing these to an Estonian forest there was the opposite effect of a negative correlation. There could have been many factors that could have caused this result such as soil nutrient composition and species biodiversity. Overall this study will provide information to the organisation that can be used in conjunction with a management plan to be able to increase biodiversity and tree numbers, therefore, increasing carbon sequestration in the area and contributing to the reduction of global atmospheric CO_2.

1. Introduction

Across the world, forests are an essential ecosystem for economic and environmental roles. There are several types of forest, including native and non-native woodlands. Non-native woodlands can be defined as a "species collection that is thriving outside of their natural range and can disperse outside of this range". The majority of the species in these collections are defined as an exotic, alien, or allochthonous to these areas (Sloan and Sayer, 2015; Essl *et al.*, 2018). Both, directly and indirectly, these species can be introduced for aesthetic purposes e.g. creations of exotic garden estates or commercial aspects e.g. plantation forests (Brus *et al.*, 2019). Whereas native woodland is defined as a "collection of naturally occurring species that have not been purposely introduced by humans to an area". These woodlands are known to be able to regenerate with human assistance if the original native woodland has been disturbed or destroyed (Brown, 1997; Government, 2011). 3,999 million hectares of land across the globe is covered with forests (Commission, 2019b). Around 13% of the UK is covered by woods which is a total of 3.19 million hectares. Northern Ireland presents the lowest percentage of woodland cover in the UK with 8% (Commission, 2019a). Even though it is a low percentage this small amount will still contribute to a reduction in global atmospheric CO_2.

Atmospheric carbon dioxide (CO_2) has reached an ultimate high in 2018 with the global level being 407.4 ± 0.1ppm, the highest in the last 800,000 years. Over the last 10 years, there has been an annual increase in CO_2 levels of approximately 2.3 ppm. This is a dramatic difference between that of the levels in the 1960s which are 0.6 ± 0.1 ppm per year. CO_2 absorbs and radiates heat causing around two/thirds of the global total energy imbalance increasing the Earth's temperature (Lindsey, 2020). Trees are an essential component in the actions of trying to reduce these levels by undergoing the process of carbon sequestration. This is defined as the "process of capturing and securing carbon storage, that if it was not stored it would, in turn, be released to, or persist in the atmosphere"(Herzog and Golomb, 2004). It stores the carbon in several distinct pools including above-ground growing biomass and below-ground soil with all pools strongly linked together (Gren and Aklilu, 2016). In 2020 there is an estimated amount of 10.9 million tonnes of carbon dioxide sequestered in living biomass found in UK forests per year. This figure is projected to decrease to 9.4 million tonnes per year due to the removal of storage pools by changes in land use and forestry (Research, 2018).

This study will focus on a particular woodland area named Farlow Wood; it is located in Country Londonderry in Northern Ireland. It is a private woodland site that contains the historical building of Sampson's Tower which was built in 1860 in memory of Arthur Sampson who worked for 34years as a fishmonger for the London Worshipful Company of Fishmongers(Lueg, 2016). On the site the tower is not the only feature of interest but so is the flora that makes up the woodland. It is believed that Farlow Woods is around 350 years old (Glens, 2020) however the earliest recordings of tree plantations are in 1784 (McCracken and McCracken, 1984). It was recorded on April 1st, 1784 that around 350 were planted on the private land by John Sterling. The total trees can be broken down into 40 apple trees, 150 cherry trees, and 148 sycamore trees. The plantation of these tree species in the area was encouraged for several reasons, one includes incentives from planting both hedgerows in conjunction with trees. Some of these incentives were created by The Dublin Society who offered the first premium for planting trees in 1741 and then added hedges to the premium in 1759. Farmers and landlords who fooled the rules of the premiums were awarded money and medals. Plantation of certain species also occurred due to are amounts of deforestation for the timber to be sold to traveling sawmills (McCracken and McCracken, 1984).

With the removal of trees and the natural succession have caused a change in the composition of forest species. This change in the composition will in turn change the overall age and carbon sequestration amount for the total forest. Due to the lack of data for the tree species planted in 1784, carbon sequestration cannot be calculated. However, comparisons to other forests worldwide can be made to determine if the carbon sequestration occurring in Farlow Wood is at its full potential. If it is not, then a management plan can be put in place to improve the efficiency of the site.

1.1 Aim

The aims of this study are as follows:

- To determine the amount of carbon sequestered by the trees found in Farlow Wood
- To determine if the age of trees affect the amount of carbon sequestered in Farlow Wood
- To compare the relationship of age and carbon sequestered in Farlow Wood to other global forests

1.2 Hypothesis

Based on these aims, I have several predictions related to each aim:

Hypothesis 1

- Null (H_0): There will no carbon sequestered by the trees in Farlow Wood
- H_1: There will be carbon sequestered by the trees in Farlow Wood

Hypothesis 2

- Null (H_0): Age will not affect the amount of carbon sequestered by trees in Farlow Wood
- H_1: Age will affect the amount of carbon sequestered by the trees in Farlow Wood

Hypothesis 3

- Null (H_0): There will be no significant comparisons on the relationships between Farlow Wood and Global Forests
- H_1: There will be significant comparisons between Farlow Wood and global forests

2. Methodology and Materials

The method and materials stated below were used to carry out the study:

2.1 Field Survey

The site is located to the northwest of Limavady and approximately 1.28 miles from the market town and northeast of Ballykelly and is approximately 2.03 miles from the village. It is a total of 12 acres which is split into two different areas both of irregular shapes. Towards the back of the site in the northeast corner, the area consists of 5 acres of wetland which has the potential to be natural. The study focused on a section of the 7 acres of dry woodland at the front of the site. This site is of interest as it is located to the northwest of the River Roe and its tributaries ASSI (Area of Scientific Interests) which contains Oakland habitats. Farlow Wood is also found within a priority habitat of local wildlife sites.

Divide the site into five sections, boundaries are selected according to the morphology and permanent physical features found in the site (i.e. Sampson's Tower). Survey each section individually, using the line of trees as a guide. Each tree is numbered begin at one using wooden discs with the number written on it using a chalk marker **(figure 1)**.

Figure 1: An image showing the numbering marker of each individual tree

2.2 Species Identification

Remove and number a leaf from each tree surveyed. Place on a white background and use the 'PictureThis' app to identify each tree species. Confirm the identification of the species using an ID (Collins British Tree Guide). If the leaf is not within reaching distance, identify the tree bark. Use this data to identify the genus, insert it into an excel, and use it to estimate the age of each tree. Determine if the species is hardwood or softwood.

2.3 Girth Measurements and Age Estimation

Use a soft measuring tape, measure around the trunk of the individual tree at a height of 1m. Measure circumference to the nearest 0.5 inches. Data may need to be converted to centimetres or the diameter of the trunk may need to be calculated and to get the estimated age of each tree use the equations in **figure 2**. The growth rates and growth factor for each tree species can be substituted in using the values from **table 1**. If the growth rate for a species cannot be found use the value of 2.5 as this is an average.

$$(a) \quad Estimated\ Age = \frac{Circumference\ (cm)}{Growth\ Rate}$$

$$(b) \quad Estimated\ Age = Diameter\ (inches) \times Growth\ Factor$$

$$(c) \quad Diameter = \frac{Circumference}{\pi}$$

Figure 2: Equations used for age estimation calculations.

Table 1: Table containing the growth rates and growth factors for each species. Some of these values were calculated from others(Benning, 2013; Pihlens, 2016).

Tree Species	Growth Rate	Growth Factor
Average	2.5	3.5
Silver Birch	1.59	5
Downy Birch	1.59	5
Paper-bark Birch	1.59	5
Common Ash	1.86	4.5
European Mountain Ash	1.74	4.5
Common Oak	1.88	4.25
Swamp White Oak	1.88	4.25
Downy Oak	1.88	4.25
Sessile Oak	1.88	4.25
Sycamore	2.75	3
European Beech	1.88	4
Common Hawthorn	2.5	3.5
Sweet Cherry	1.59	5
Black Alder	2.5	3.5

2.4 Carbon Sequestration Calculation

Calculate biomass (M) of each tree using the diameter (D) and species-specific allometric coefficients (a and b) found in **Table 2**. Calculate the approximate mass of carbon atoms being stored in kilograms. The decisions of whether the tree species is hardwood or softwood is needed. Calculate carbon absorbed by multiplying the mass of carbon atoms by 3.67. (1kg of carbon is equivalent to 3.67kg of CO_2). To get the carbon sequestered in Metric Tons divide by 1000. To complete this use the following equations:

$$(a)\ M = aD^b$$

$$(b)\ Tree\ biomass\ (M)\ x\ 0.521\ (hardwood) = mass\ of\ carbon\ stored(kg)$$

$$Tree\ biomass\ (M)\ x\ 0.498\ (softwood) = mass\ of\ carbon\ stored\ (kg)$$

$$(c)\ Mass\ of\ carbon\ stored\ x\ 3.67 = CO2\ absorbed\ (kg)$$

Figure 3: Equations used for carbon sequestration calculations in order of use.

Table 2: Table containing the species-specific allometric coefficients (a and b).

Tree Species	a-coefficient	b-coefficient
Silver Birch	0.22	2.37
Downy Birch	0.22	2.37
Paper-bark Birch	0.22	2.37
Common Ash	0.16	2.35
European Mountain Ash	0.16	2.35
Common Oak	0.06	2.69
Swamp White Oak	0.06	2.69
Downy Oak	0.06	2.69
Sessile Oak	0.06	2.69
Sycamore	0.17	2.52
European Beech	0.20	2.39
Common Hawthorn	0.18	2.48
Sweet Cherry	0.16	2.19
Black Alder	0.09	2.35

3. Results

Using the statistical program RStudio 3.4.2 to calculate all the basic statistical analyses the following results were found.

3.1 Aim 1

Aim 1 was to determine the total amount of carbon that was sequestered by the trees in Farlow Wood, this was broken down into sections and species. **Figure 4** shows both the breakdown of carbon sequestered in each section and the total amount of 2403.25 metric tons. Section 5 has sequestered the largest amount of carbon at 922.43 metric tons and section 1 has sequestered the lowest carbon level with just 221.67 metric tons. Sequestration amounts of other sections can be found in **Table 3**. One-way ANOVA was used for statistical analysis and produced $P < 7.56\times10^{-6}$ which means that our result is statistically significant and with strong evidence, we can reject the null hypothesis and accept our alternative hypothesis of 'There will be carbon sequestered by the trees in Farlow Wood'.

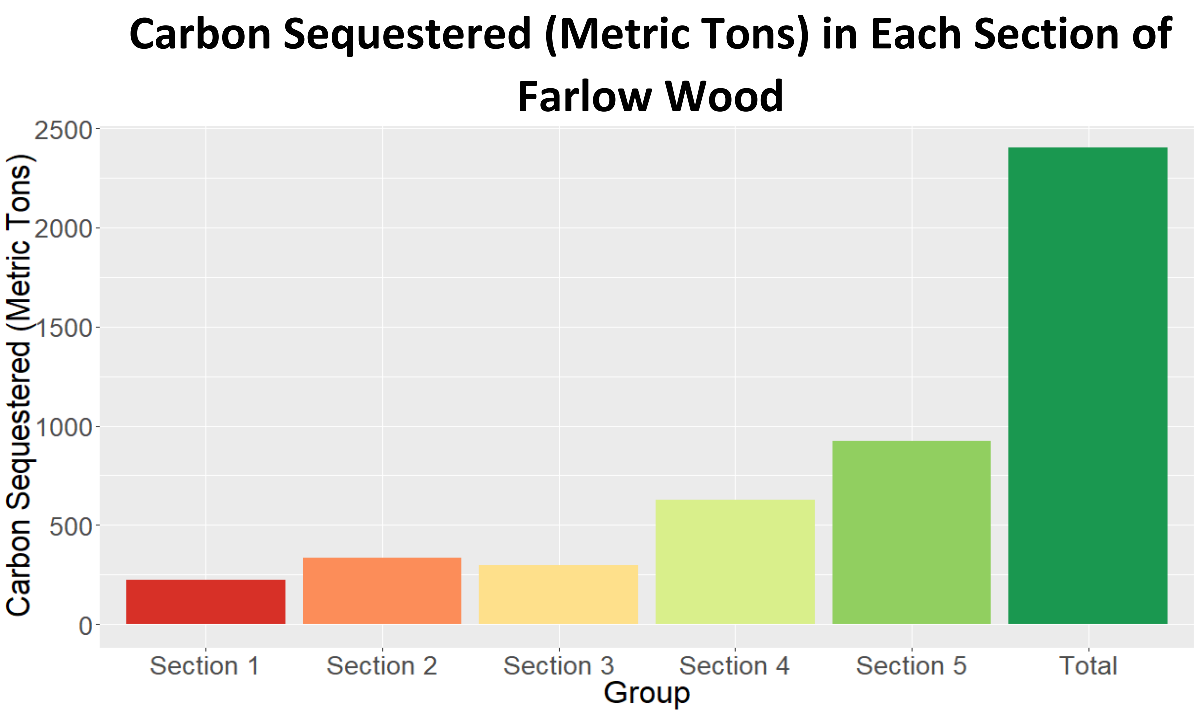

Figure 4: Graph showing the amount of carbon sequestration undergone in each section of Farlow Wood. The total amount is also shown with a dark green colouration. Each colour represents a different section.

Table 3: Table containing the amounts of carbon sequestered in metric tons in each of the five sections in Farlow Wood. There is also a total amount of carbon sequestered for the complete area surveyed.

Total	CO2 Absorbed (metric tons)
Whole Woods	2403.25
Section 1	221.67
Section 2	333.13
Section 3	298.06
Section 4	627.96
Section 5	922.43

Each species found in Farlow Wood was also analysed statistically which can be seen in **Figure 5**. The oak species sequestering the most at 850.28 metric tons and alder species have the lowest amount of 0.84 metric tons. The remaining 7 species carbon sequestration amounts can be seen in **Table 4**. Once again, a one-way ANOVA was undertaken, and it results in $P < 3.54 \times 10^{-15}$ which is below the significance value of 0.05 and therefore giving us a statistically significant result.

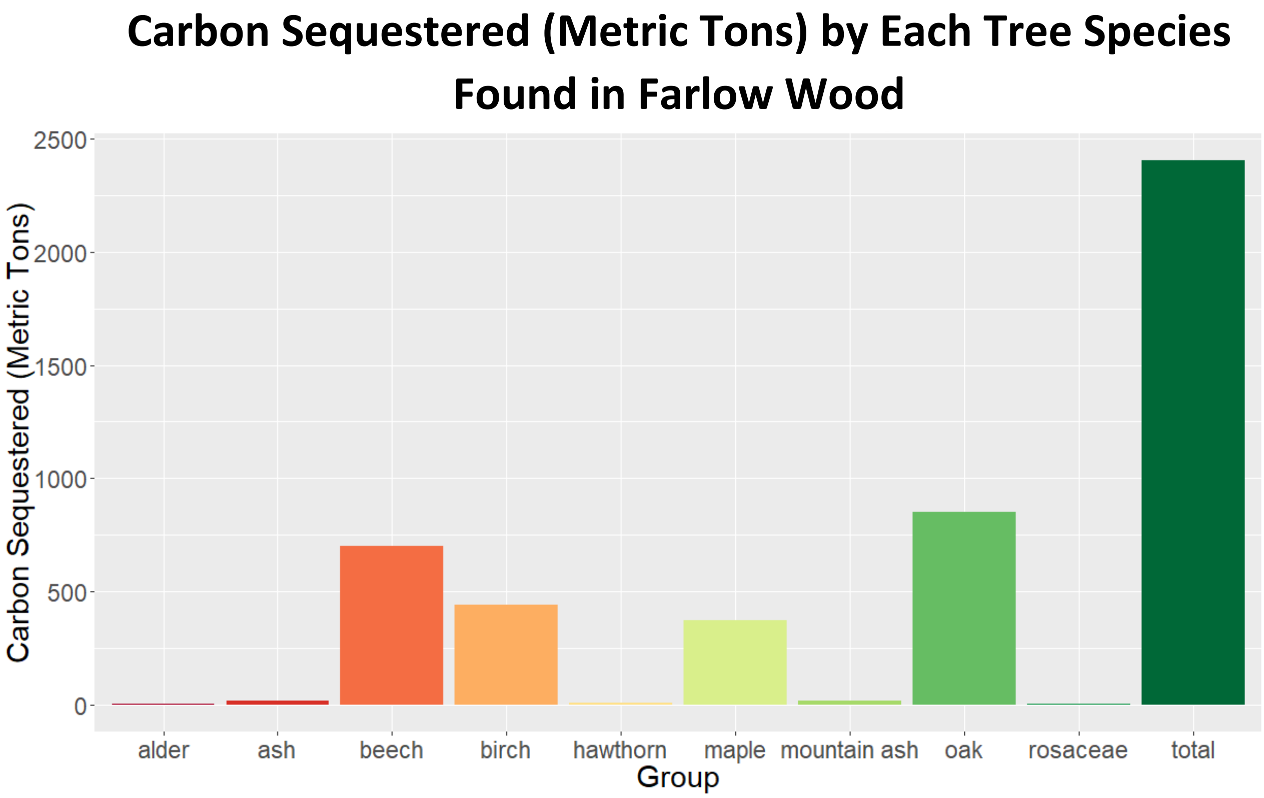

Figure 5: Graph showing the amount of carbon sequestrated by each of the 9 species found in Farlow Wood. The total amount is also shown with a dark green colouration. Each colour represents a different species.

Table 4: Table containing the amounts of carbon sequestered in metric tons by each of the tree species found in Farlow Wood. There is also a total amount of carbon sequestered for the complete area surveyed.

Total	CO2 Absorbed (metric tons)
Whole Woods	2403.25
Alder	0.84
Ash	16.7
Beech	701.1
Birch	439.56
Hawthorn	5.64
Maple	371.04
Mountain Ash	17.18
Oak	850.28
Rosaceae	0.91

3.2 Aim 2

Aim 2 was to determine if there was an effect of age on carbon sequestration in Farlow Wood. **Figure 6** shows six graphs labelled A-F and shows the data collected for each section and the whole woods, respectively. Each graph shows non-linear data points, and the best fit line has a relatively steep gradient representing a strong, positive correlation between age and carbon sequestration. As age increases so do the amount of carbon sequestration however it does not occur until a certain age, normally around 25 years old for sections 1,3 and 5 (A, C, D) and for sections 2, 4, and the whole woods it is around 50 years old. Once these trees reach these ages the carbon sequestration amount increases dramatically. Section 1 has the strongest correlation with the steepest gradient whereas section 5 has the weakest correlation. At ages 0-50 there is an average amount of carbon sequestration of around 2 metric tons, ages 51-100 the carbon sequestration can range between 2-10 metric tons dependent on species. Between 101-150 years old the average amount has a range of 10-17 metric tons and 150+ years old can reach an average of 25 metric tons. The main outlier is around 207 years old with it sequestering 50 metric tons of carbon. Looking at the total wood graph (F), the statistical analysis methods of the Shapiro Wilk test and the ggqqplot to test for normality. The data showed that it was not normal and non-linear so therefore Kendall's rank correlation test was carried out and resulted in $P < 2.2\text{x}10^{-16}$ which means the data is statistically significant. Our null hypothesis can be rejected and the alternative hypothesis of 'Age will affect the amount of carbon sequestered by the trees in Farlow Wood' will be accepted.

Effect of Age (Years) on Carbon Sequestration (Metric Tons) in Each Section of Farlow Wood, Northern Ireland

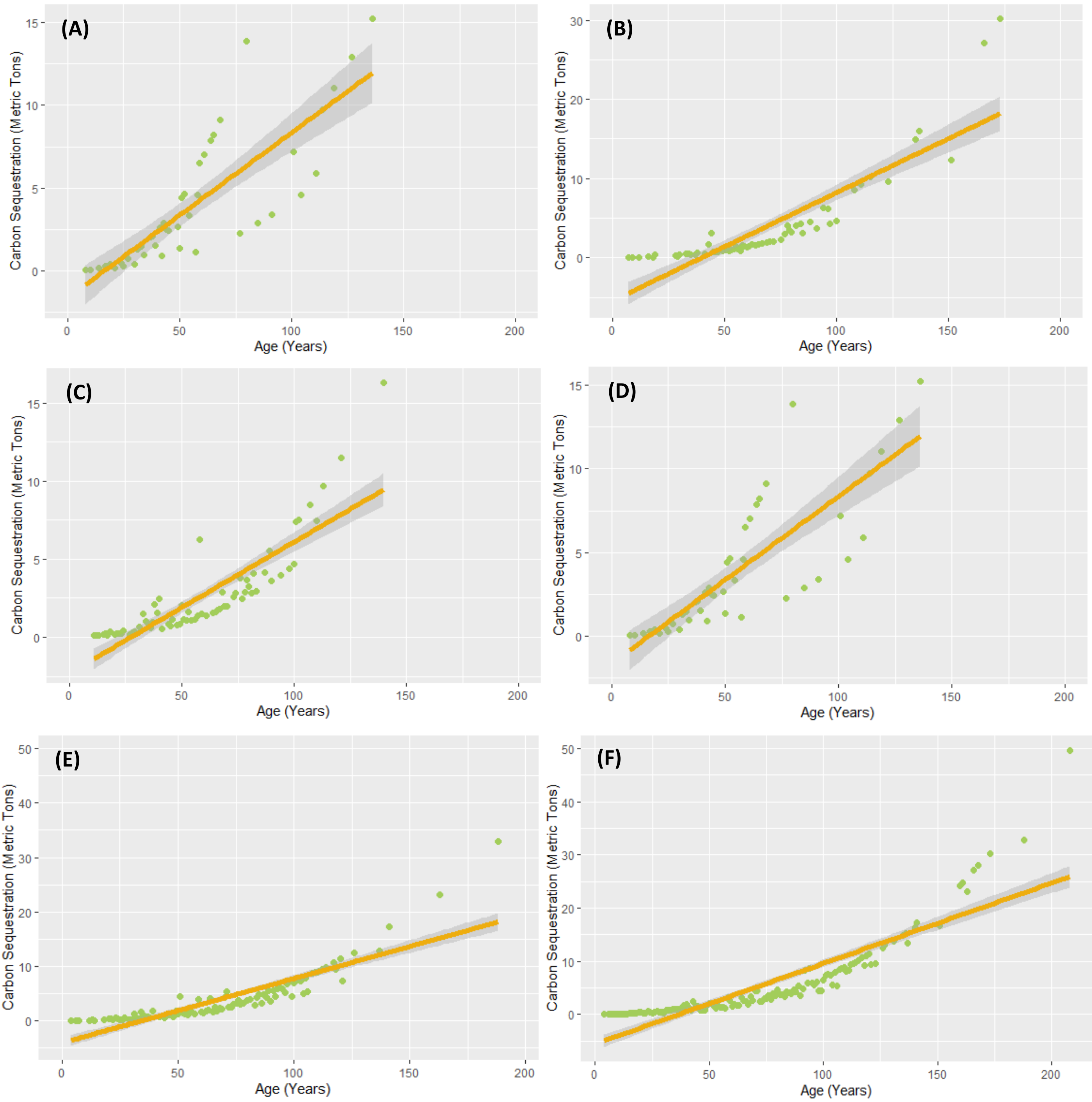

Figure 6: Collection scatter graphs showing the relationship between age (years) and carbon sequestration (metric tons). Each graph shows this relationship in each of the sections sampled (A-E: Section 1-5). Graph (F) show the relationship between age and carbon sequestration for the whole forest. Green circles represent the individual values for each age from 0-200 years old. The orange line is the best fit line showing a positive correlation between the two variables.

3.3 Aim 3

Aim 3 focuses on comparisons of the relationships between age and carbon sequestration in Farlow and other forests across the world. **Figure 7** is a collection of scatter graphs that show the relationship between age and carbon sequestration from 5 global forests. There are six graphs with A-E being a different forest and graph F showing every forest together. Each of the graph data points is different in linearity and the best fit line for the majority of our graphs (A, B, D, E) have a positive gradient with graph E (Himalayas) being the steepest and graph D (Canada) has the most gentle slope however all of these graphs represent a positive correlation between age and carbon sequestration. So as age increases so do the amount of carbon sequestration. Graph C (Estonia) however is different from the other graphs as it has a gentle but negative gradient meaning that in this forest as age increases the carbon sequestration amount decreases.

Graph F shows the data for each of the five forests in one graph for ease of comparison. As seen in graph F, Farlow Wood has the largest age range reach over 200 years old, other countries do not reach this age therefore it cannot be comparable. We can compare the trends of the countries up to the age of around 50 years old. The majority of the forest around the world tend to follow the same trends as those surveyed in Farlow Wood apart from the Estonian forests.

Statistical analysis was undertaken for all graphs and each of the p-values calculated can be found on the bottom right of the corresponding graph. This statistical analysis consisted of the statistical analysis methods of the Shapiro Wilk test and the ggqqplot to test for normality. Therefore, dependent on the normality and the linearity of the graph a statistic test was then chosen. One of the following tests were carried out: Spearman's rank correlation, Pearson's product-moment correlation, and Kendall's rank correlation. Focussing on graph F which shows the comparison between Farlow Wood and other forests across the globe. Data showed that it was not normal and non-linear so therefore Kendall's rank correlation test was carried out and resulted in a $P < 2.2\text{x}10^{-16}$ which means the data is statistically significant. Our null hypothesis can be rejected and the alternative hypothesis of 'There will be significant comparisons between Farlow Wood and global forests' will be accepted.

Comparisons of the Effects of Age on Carbon Sequestration in Farlow Wood, Northern Ireland, and other Global Forests

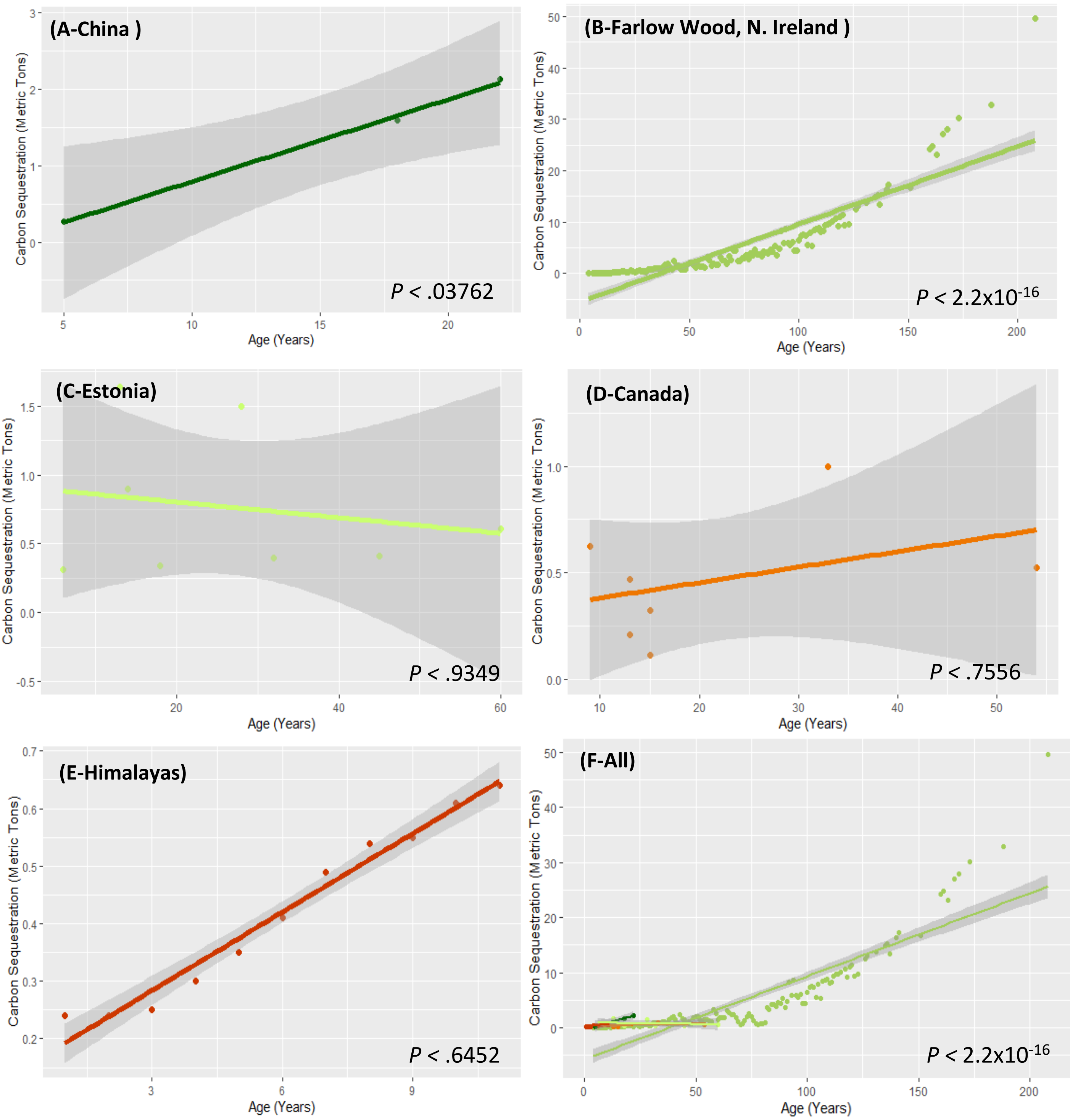

Figure 7: Collection of scatter graphs showing the relationship between age (years) and carbon sequestration (metric tons). Each graph shows this relationship in several different countries. Each colour represents a different forest and country, the circle is the individual data point and the line is one of best fit. Graphs A-E are in the following order (A) China- Dark green, (B) Farlow Wood, N.Ireland- Green, (C) Estonia- Light green, (D) Canada- Orange and (E) Himalayas- Red. Graph (F) show the relationship between age and carbon sequestration for each of the forests across the globe as a comparison. All data from these graphs were altered from relevant papers (Wu *et al.*, 2012; Uri *et al.*, 2012; Peichl *et al.*, 2006; Arora *et al.*, 2014)

4. Discussion

Carbon sequestration studies across the world have looked at several different variables that affect it this includes natural disaster such as bush fires (Murphy, RUSSELL-SMITH and Prior, 2010), species diversity (Ruiz-Benito *et al.*, 2014), and soil nutrient composition (Fornara, Banin and Crawley, 2013). This study has allowed the exploration of the untouched forest of Farlow Wood and has provided data that will achieve the aims set out and more in turn providing information for future conservation efforts. The aims set out were to establish in any of the trees in Farlow Wood were sequestering carbon and if so, how much of the carbon is being sequestered. Age was also another major variable in the study, this provided an aim to investigate as to whether age has a significant effect on the carbon sequestration in the forest as a whole or each section. Aim 3 focused on how carbon sequestration in Farlow Wood compared to the sequestration in other forests across the world.

4.1 Aim 1

Aim 1 allowed the study to determine if and how much carbon was being sequestered by the trees in Farlow Wood. From the graphs seen in **Figure 4** and **Table 3,** we can confirm that our aims and hypothesis for aim 1 are correct and have been achieved. In total, the trees in Farlow Wood have sequestered a total of 2403.25 Metric Tons of carbon, this is around 29.74 Metric Tons per year. Section 5 has stored the most amount of carbon out of all of the sections with a total of 922.43 Metric Tons and 38% of the total for Farlow Wood. Whereas section 1 has sequestered the lowest amount of carbon coming in at around 221.67 Metric Tons which is 9% of Farlow Woods total sequestration. On average a temperate forest such as Farlow Wood sequesters between 0.7 to 7.5 tonnes of carbon every year (Brown *et al.*, 1996) however Farlow Woods rates come in at around 11.5 tonnes per year which is slightly above the maximum rate of your typical forest.

Factors affecting the amount are numerous including climatic factors and soil composition however the main factors we can look at for Farlow Wood using our data is the age of the forest species and number of trees. Age will be explored in **Aim 2**. Section 5 had the highest amount of trees with 218 in total so therefore contributing to the largest carbon sequestered amount as stated above however species may also have an impact as the number of trees does not always correlate with sequestration as can be seen in **Table 5**. It is predicted that the larger number of trees in an area the more carbon sequestered however this is not the case as even though the smallest and largest sections have followed this hypothesis. This is proven by looking at sections 2 and 3 with having 111 and 147 respectively, in fact, section 2 has a higher total of sequestration at 333.12 Metric Tons compared to that of section 3's 298.06 Metric Tons.

Table 5: Table containing the amounts of carbon sequestered in metric tons in each of the five sections in Farlow Wood and the sum of trees in each section. There is also a total amount of carbon sequestered for the complete area surveyed.

Section	Tree Quantity	Carbon Sequestered (Metric Tons)
1	65	221.67
2	111	333.13
3	147	298.06
4	162	627.96
5	218	922.43
Whole Woods	703	2403.25

As seen the number of trees does not solely contribute to the amount of carbon sequestered therefore another factor such as species type can be looked at. Each section is dominated by different species, **Table 6** shows each section, dominant species in that area, and the average carbon sequestered by that species. The figures calculated for Farlow Wood follow similar results to those for other studies stated in **Table 6**. Section one sequesters the lowest carbon amount and section 5 the highest this pattern is followed by species contribution as well with both having the lowest sequestration per tree 2.92 Metric Tons and the highest of 5.75 Metric Tons. However, it does not explain why even though there is a larger sum of trees in section 3 there is a lower amount of carbon sequestered compared to that of section 2. This, therefore, means that there is more to than just tree quantity, species, and age that contributes to sequestration amounts.

Table 6: Table containing the dominant tree species in each section and the average carbon sequestration per tree for these species. Values in the carbon sequestration rate column have been calculated using data from other studies from across the globe.

Section	Dominant Tree Species	Av. Carbon Sequestered per Tree (Metric Tons)	Carbon Sequestration Rate (Other Studies)
1	Sycamore	2.92	3.2 (Beckert *et al.*, 2016)
2	Birch	2.02	2.24 (Uri *et al.*, 2012)
3	Beech	4.2	5.2 (Nord-Larsen *et al.*, 2019)
4	Oak	5.75	5.85 (Jina *et al.*, 2008)
5	Oak	5.75	N/A

4.2 Aim 2

Aim 2 allows the study to determine if there is a correlation between the explanatory variable of age and the response variable of carbon sequestration. From the multiple graphs in **Figure 6** we can see that our aim and hypothesis relating to this goal have been achieved with a non-linear, positive correlation between the two variables. This pattern is visible overall in the whole woods and each section. Each section of the woods sequesters at a different rate each year this is dependent on many factors as mentioned before, Farlow Wood in total sequesters on average around 30 Metric Tons every year. **Table 7** shows the sequestration rates of each section per year and the average ages for these sections, this generally follows the positive relationship of as age increases so do the carbon sequestration quantity.

Table 7: Table containing the sequestration rates in Metric Tons in each section per year and the average ages of each section.

Section	Average Age (Years)	Sequestration Rates per Year (Metric Tons)
1	50.17	3.57
2	65.35	3.81
3	54.32	4.52
4	64.38	7.62
5	72.02	10.21

It has been explained by looking at the graph (f) in **Figure 6** that even though our data has a positive correlation it is also non-linear. There is only a slight increase in carbon sequestration in the first few years of the tree's life. As trees capture carbon from the atmosphere and it is transformed into biomass etc. through the process of photosynthesis, there has to be a form of above-ground biomass (leaves, branches, stems) for this photosynthesis to occur (Sedjo and Sohngen, 2012; UNECE, 2005). Therefore, causing that slight increase at the beginning of the tree's life due to its lack of photosynthetic biomass. At around 25 years old there is a dramatic increase in the amount of carbon sequestered as each tree reaches optimum above-ground biomass production. Farlow Wood follows a similar pattern to a study carried out in a Downy Birch forest in Northern and Central Finland. The study found that carbon in the forest increased from 22.6 Mg ha^{-1} to 64.3 Mg ha^{-1} with an increase in tree age (Hytönen, Aro and Jylhä, 2018). Another study that occurred in a white pine forest near Simcoe, Southern Ontario, Canada also displays the positive relationship between age and carbon sequestration. Age was tested in stands of 2, 15, 30, and 65 years old. Carbon sequestration was found to increase as well with the following values corresponding with the age order (0.2, 30.1, 44.2, and 82.6 t C ha^{-1}) (Peichl and Arain, 2006). Eventually Farlow wood will reach an optimum level of carbon sequestration and age, this rate will continue until a certain age then it will begin to decrease. This is a common pattern in all trees as once maximum leaf area and photosynthesis are reached carbon will stop being captured and transformed therefore biomass production will stop (Ryan, Binkley and Fownes, 1997).

4.3 Aim 3

Aim 3 allowed the study to compare the data collected from Farlow Wood for age vs carbon sequestration to other global forests. Our aim and hypothesis were achieved and statistically significant this is represented in **Figure 7**. The majority of the graphs in this figure follow the same positive correlation as Farlow Wood apart from graph C. Each study has different levels of correlation some are not as strong as Farlow Wood this may be due to the lack of data collected or even it being a different type of forest i.e. Tropical or Boreal rather than the temperate forest that Farlow Wood is. Both Farlow Wood and Canada have a similar gradient due to even though they are different types of forest, their lower rates per year are very similar with Canada's boreal forest having a range of 0.8-2.4 tonnes compared to the temperate forests of 0.7-7.5 tonnes (Brown *et al.*, 1996). Whereas the forests of the Himalayas (graph e) are in the tropics/subtropics region (Jhariya, 2017) and therefore have a higher rate of sequestration at a range of 3.2-10 tonnes and a steeper gradient seen in **Figure 7 Graph E**.

Whereas graph C (Estonia) in **Figure 7** follows a different pattern with a negative correlation meaning that as age increase carbon sequestration decreases. This difference once again may be due to the lack of data points provided by the study with only 8 data points (Uri *et al.*, 2012) compared to that of Farlow's 134 data points. Another factor may be the lack of species diversity within the Estonian forest being primarily silver birch (*Betula pendula*) compared to the 14 different species in Farlow. It is known that there mutual benefitting between biodiversity and carbon sequestration as with an increase in the biodiversity in the area brings dominant species that strongly influence carbon sequestration rates and increases the total overall by capturing and transforming more atmospheric carbon (Díaz, Hector and Wardle, 2009). Soil is known to be the largest reservoir of terrestrial carbon across the globe and the nutrient composition of this effects carbon sequestration amounts as if the availability of the nutrient is low from increased agricultural material then the amount of carbon being captured within the soil decrease (Kirkby *et al.*, 2014). This therefore may be another factor that can cause a negative correlation dependent on the surrounding areas of the forest. Finally, climatic variability can have a major impact on sequestration rates as if temperatures are higher than one area compared to the other then this will result in an earlier leaf emergence and higher photosynthesis rates therefore more sequestration (Chen *et al.*, 1999). Other studies have found that in conjunction with temperature, precipitation also plays a role in sequestration rates as if the air is moist, pores in the tree biomass i.e. Leaves etc. can open up without having a net loss of carbon. Whereas if a drought occurred it will reduce rates and result in a net loss of carbon (Kwon *et al.*, 2006; Ramanujan, 2002).

4.4 Limitations

Even though this study has shown that there is carbon being sequestered in Farlow Wood and that there is a statistically significant relationship between the variables of age and carbon sequestration there has been limitations in the collection of the data to achieve this. These limitations include the identification of some species such as birch, in Farlow Wood, there were three different species of birch: downy, silver, and paper. Both an ID book and app were used to help to identify the difference in these however it was not always possible, so the trunk of the tree was used. To calculate the age a non-invasive method was used, this means that the data was only an approximate value as the invasive counting rings method was not an option. This non-invasive method used calculations and growth factors/rates to which some of these were not available for certain species in Farlow Wood, so an average of 3.5/2.5 was used. Age of deadwood was not found as the circumference at 1m could not be measured and the species could not be identified. Another limitation is that due to Covid-19 there has been a delay and backlog in the testing of soil samples, so the nutrient composition of the soil was not able to be investigated. The final limitation is also due to Covid-19 as it has put restrictions on travel and in-person contact causing the data collection to be longer than expected.

5. Conclusion

Overall, this study has shown that carbon is being sequestered in the forests of Ireland and the amount is comparable to that of other global forests as well as the rates having a relationship with the age of the tree. This information is important for the organisation as it can be used to help create a management plan for the forest as it can determine which trees may be coming to the end of their lifespan or reaching their maximum sequestration rate. It will also help develop a reforestation plan for the area to know which species sequester more and therefore more of these species can be planted all while keeping high biodiversity in the area. These plans will help promote more carbon sequestration and therefore resulting in a reduction in atmospheric carbon and a small contribution towards the fight against climate change.

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