Quantifying the Carbon Stock of Edinburgh's Roseburn Path

Group 3 – Carbon Sinks

Report Authors:

Group members worked collaboratively across different sections of the report. However, the table below shows the report sections for which group members took primary responsibility:

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Abstract:

The Central Scotland Green Network (CSGN) seeks to assess the value of green spaces in Edinburgh. Focusing upon the value of green spaces as carbon sinks, this report estimates the total carbon stock of the Roseburn path. This choice of study area is highly contemporary: an ongoing proposal to extend the tram network would replace the Roseburn path and its vegetation. Through the use of both field and remote sensing data, it is estimated that total aboveground biomass across the path is 1,469,366kg, with a standard error of 22%. From this, it is determined that the path has a carbon stock of 734,683kg. These findings present a useful first insight into this green space and are used to suggest that any carbon stock loss from a tramline development would soon be compensated by emissions reductions from reduced car travel. However, there is still considerable uncertainty around these results, and further study/an adapted methodology would be required to more accurately assess carbon stock.

1. Introduction:

In February 2024, the City of Edinburgh Council proposed an extension to the existing tram network. Figure 1 shows the favoured route for this extension, alongside alternative options.

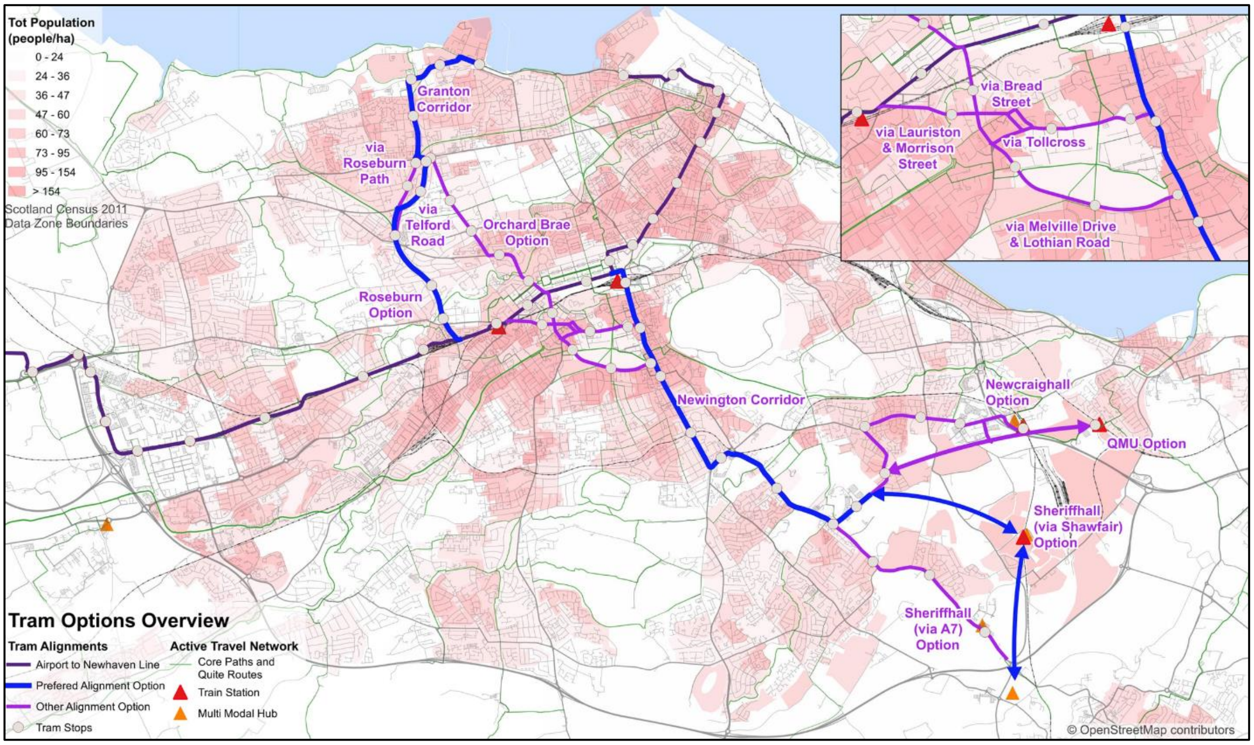

Figure 1: The proposed options for a tramline extension (City of Edinburgh Council, 2024). Although an alternative route is shown for the Roseburn Option (Orchard Brae Option), serious concerns have been raised about the viability of this alternative and thus minimum attention is given here (Bagshaw, 2024; City of Edinburgh Council, 2024).

The rationale for this proposal has social, economic, and environmental dimensions. Edinburgh continues to experience population growth, with population rising 14.7% between 2001 and 2022 (NRS, 2024). At the same time, the city is striving to reduce its car kilometres and achieve net zero by 2030 (Transport and Environment Committee, 2024). The council maintain that improving public transport is key to bridging these competing circumstances (City of Edinburgh Council, 2024). Moreover, expanding the tram network can be of economic gain, both generating and improving access to employment (Transport and Environment Committee, 2024).

While the proposal has yet to go to consultation (scheduled for Spring 2025), it has amassed considerable backlash. The Roseburn Path is a focal issue; the favoured tram route would entirely replace this path. According to the Save The Roseburn Path campaign (2024), this puts 3,500 trees at risk, equivalent to every tree in the Edinburgh Botanic Gardens. Thus, the path can be considered an important urban green space. The following report focuses on just one aspect of this debate and seeks to quantify the loss of carbon stock that would occur with the removal of the path. Ultimately, any carbon loss should be considered in the broader context.

2. Research Question & Objectives:

Research Question 1: What is the carbon stock of the Roseburn path?

Objective 1: To calculate aboveground biomass density (AGBD) across the Roseburn path.
Objective 2: To calculate the total carbon stock of the Roseburn path (using AGBD).
Objective 3: To produce a map of Relative Environmental Deprivation.

For the purpose of this report, Relative Environmental Deprivation is defined as, "the loss of carbon stock that would occur with the construction of a tramline (relative to current carbon stock)".

3. Literature Review:

There are many known benefits of urban green spaces (UGS). UGSs improve air quality (Junior, Bueno and da Silva, 2022), mitigate urban heat islands (Armson, Stringer and Ennos, 2012), and serve as ecological corridors that enhance biodiversity (Lepczyk *et al.,* 2017). Additionally, UGSs can promote mental and physical health (Jabbar, Yusoff and Shafie, 2021) by fostering social cohesion (Jennings and Bamkole, 2019) and encouraging physical activity (Richardson *et al*., 2013).

One further property of UGSs is their ability to sequester carbon (Wang, Feng and Ai, 2023; Dong *et al*., 2024). Trees in particular serve as significant carbon stocks, absorbing carbon dioxide (CO_2) and storing it in their wood, leaves, roots, and soil (Pregitzer *et al*., 2022). Aboveground biomass (AGB) refers to the total mass of living or dead organic matter above the soil surface (Wilkes *et al*., 2018) and can be measured or estimated both destructively and non-destructively (Kumar and Mutanga, 2017). Destructive methods involve harvesting and weighing tree parts. Non-destructive methods utilise remote sensing or field measurements. Remote sensing techniques are diverse: Zhu and Liu (2015) employ optical satellite imagery, while volume-based methods make use of terrestrial laser scanning (Disney *et al*., 2018; Kükenbrink *et al*., 2021). Field methods require the measurement of key variables (commonly tree diameter, height) which are then input to allometric equations (Vaz Monteiro, Doick and Handley, 2016). Frequently, a combination of remote sensing and fieldwork is used (Strohbach and Haase, 2012; Pandey *et al*., 2019). This allows for the upscaling of field data and can lead to increased accuracy (Tian *et al.*, 2023). For instance, Brovkina *et al.* (2017) demonstrate that integrating LiDAR data with ground measurements enhances AGB prediction.

4. Study Area:

The Roseburn path is an active travel route between northwest and central Edinburgh. The majority of the path is lined by vegetation, including shrubs and young and mature trees. Figure 2 shows the proposed tramline which would replace the entirety of the path. During 2023, Cycling Scotland (2024) recorded instances of 339,000 cyclists and 231,000 pedestrians using the route. Spanning 2,268m, the path connects many of Edinburgh's neighbourhoods (Figure 3).

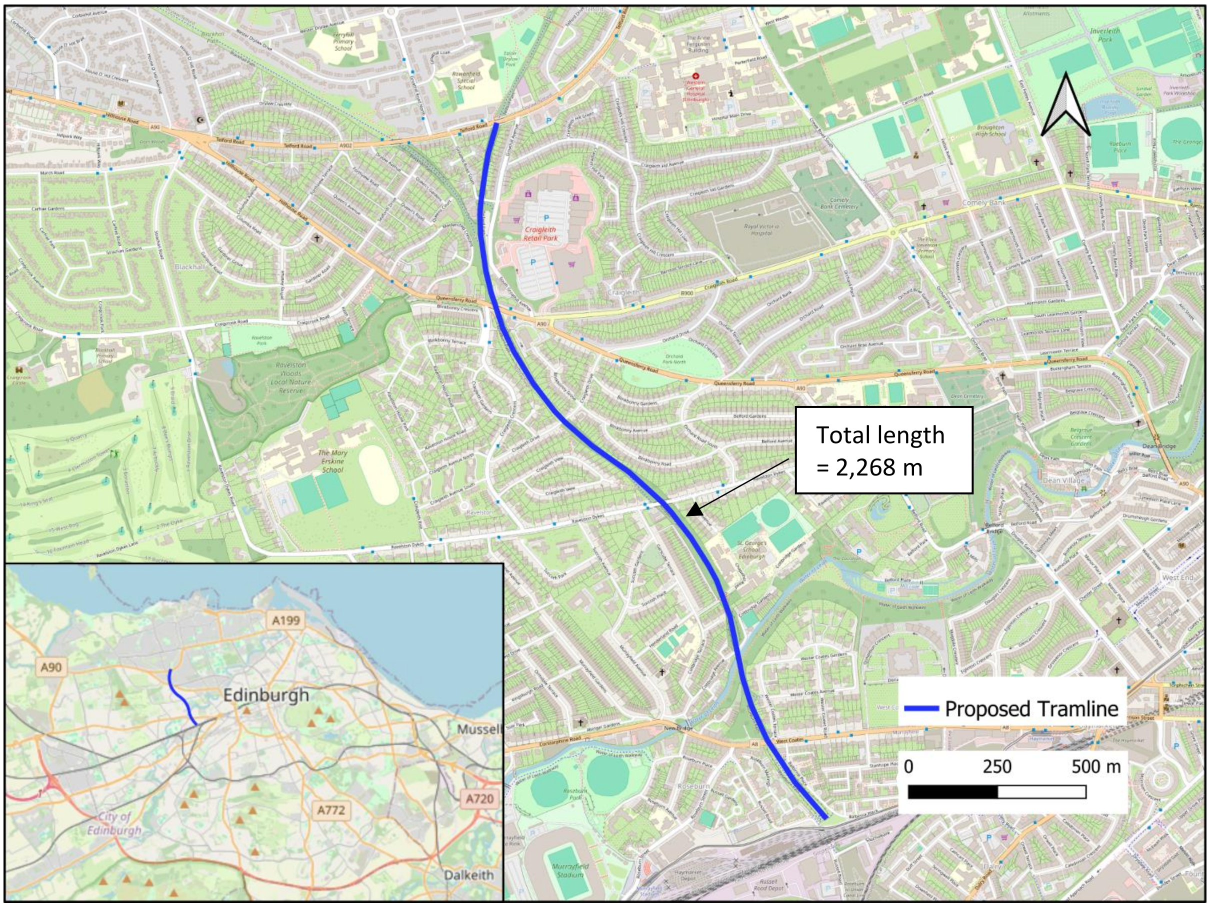

Figure 2: A map of the study area where the proposed tramline overlaps.

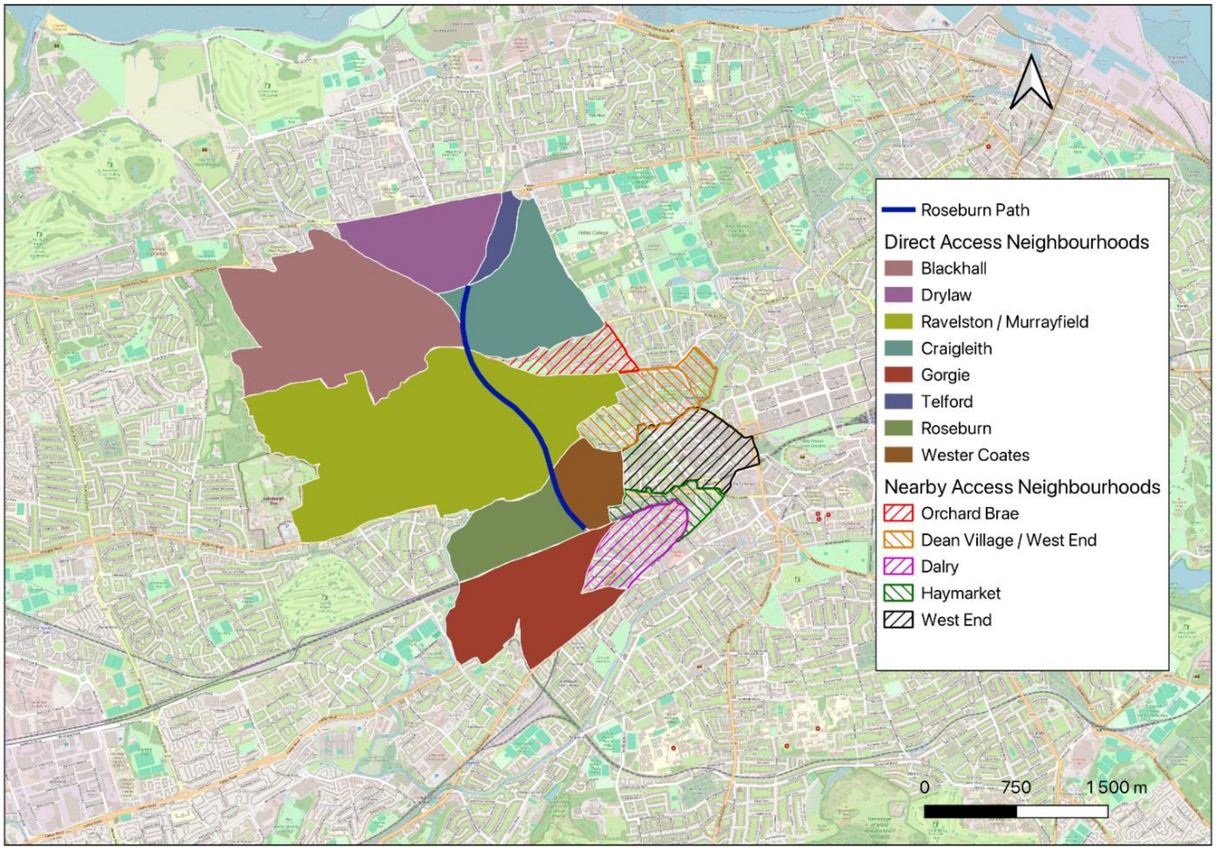

Figure 3: A map showing the neighbourhoods around the path with either direct access or nearby access. Natural neighbourhood boundaries were retrieved from the City of Edinburgh Council (2021a).

<u>5. Method:</u>

For this study, field measurements were used to calculate AGBD at the plot scale, with LiDAR data used to then upscale findings to the whole study area (following Lefsky *et al*., 2002). It was determined that using exclusively field techniques would have proven too time intensive. Meanwhile, approaches that rely solely upon remote sensing data (at the required resolution, e.g. Liu *et al*., 2023), use commercial imagery inaccessible to this study.

5.1 Sampling Strategy:

There is an observed relationship between biomass and canopy height (Lefsky *et al*., 2002). Therefore, a random stratified sampling approach was adopted, so that plot locations are representative of the varied canopy height. To produce a canopy height model (CHM) of the region, two LiDAR datasets were downloaded from the Scottish Remote Sensing Portal (50cm LiDAR for Scotland Phase 5 DSM, and 50cm LiDAR for Scotland Phase 5 DTM). The CHM was created by subtracting the DTM (digital terrain model) from the DSM (digital surface model). In Google Earth Pro, a shapefile of the study area was created, by manually delineating the path boundary. The CHM was then clipped to this shapefile (Figure 4a).

Using natural breaks, the CHM values were classified into three groups: high, medium, and low (Table 1). In QGIS, 30 random sampling points were generated, reflecting the proportion of each CHM category. Additional back-up points were generated for contingency (see Figure 4b for all points generated).

Figure 4: CHM of the Roseburn path (A) and the sampling plots identified by the random stratified strategy (B).

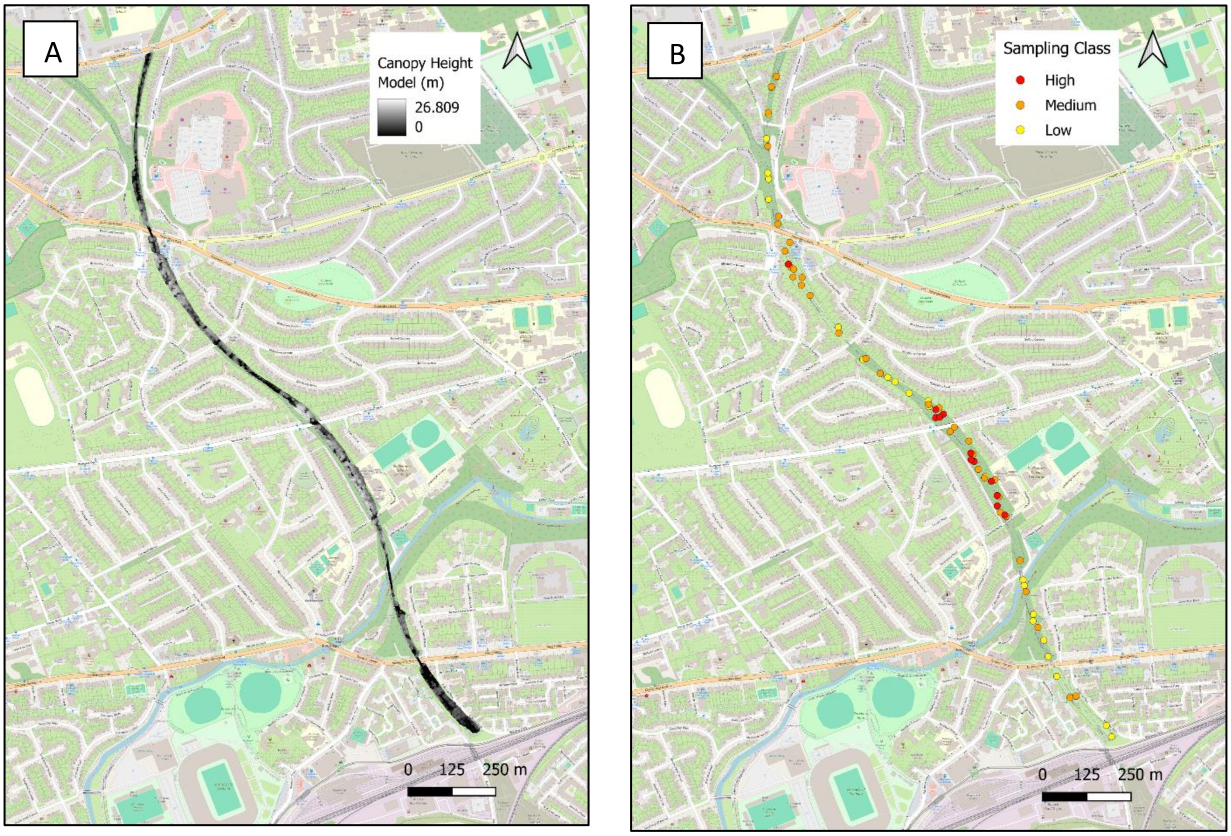

Table 1: CHM category ranges and subsequent ratios for proportional sampling.

CHM Category	CHM range	Ratio
Low	0 – 8 m	34%
Medium	8 – 18 m	54%
High	18 + m	12%

5.2 Fieldwork:

Prior to fieldwork, an Entity-Relationship model was designed (Appendix A) to identify the attributes needed for data collection (Table 2). Fieldwork was conducted over two days. Each sampling plot was located using a GPS, and a pole and a tape measure were used to determine a 3-metre radius. Every tree within the plot with a diameter at breast height (DBH) above 10cm was measured.

Table 2: Data attributes that were collected in the field.

Data collected	Additional Information
DBH	Trunks which split from one single tree were measured respectively and counted as several different individuals (if the DBH still exceeded 10cm)
Plot GPS	GPS was calibrated for durations over 5 minutes
Tree Species	Identified using reference guides and iNaturalist
Tree Photo	Recorded for cross reference of species ID in analysis

5.3 Data Processing:

From the literature, allometric equations for all recorded species were identified (Table 3). Using the DBH measurements and allometric equations, AGBD was calculated for all plots.

Table 3: Allometric equations used to calculate the dry-weight AGBD from DBH.

Common Name	Latin Name	Allometric Equation (including any dry-weight density scaling)	Reference
Maple Sycamore	Acer pseudoplatanus	$520 \times 0.0019421 \times DBH^{1.785}$	McPherson, van Doorn and Peper, 2016
Common Yew	Taxus baccata	$\exp(-0.7152+1.7029 \times \ln(DBH))$	Ismail *et al*., 2018
Hawthorn	Crataegus monogyna	$660 \times 0.0002835 \times DBH^{2.310647}$	McPherson, van Doorn and Peper, 2016
Birch	Betula pendula	$-0.28074+3.515265 \times DBH$	Ismail *et al*., 2018
Elm	Ulmus procera	$540 \times 0.0048879 \times (DBH^{1.613})$	McPherson, van Doorn and Peper, 2016
Oak	Quercus robur	$580 \times 0.000243 \times (DBH^{2.415})$	McPherson, van Doorn and Peper, 2016
Ash	Fraxinus excelsior	$530 \times 0.000589 \times (DBH^{2.206})$	McPherson, van Doorn and Peper, 2016
Willow	Salix	$\exp(-2.2094+2.3867 \times \ln(DBH))-\exp(-4.0813+5.8816/DBH)$	McPherson, van Doorn and Peper, 2016
Prunus	Prunus	$\exp(-2.76 \times DBH^{2.37})$	Rojas-García *et al*., 2015
Beech	Fagus	$0.1957+2.3916 \times (DBH)$	McPherson, van Doorn and Peper, 2016

Linear regression was used to model the relationship between canopy height and AGBD. To ensure that the model predicted areas of zero canopy height had no biomass value – as is known to be true in reality – the line was fitted through the origin. Figure 5 illustrates the result. An R^2 value of 0.56 indicates 56% of the variability is explained by the model, deemed sufficient to continue the analysis. To further assess the model's suitability, residual standard error was calculated in Python (Appendix B).

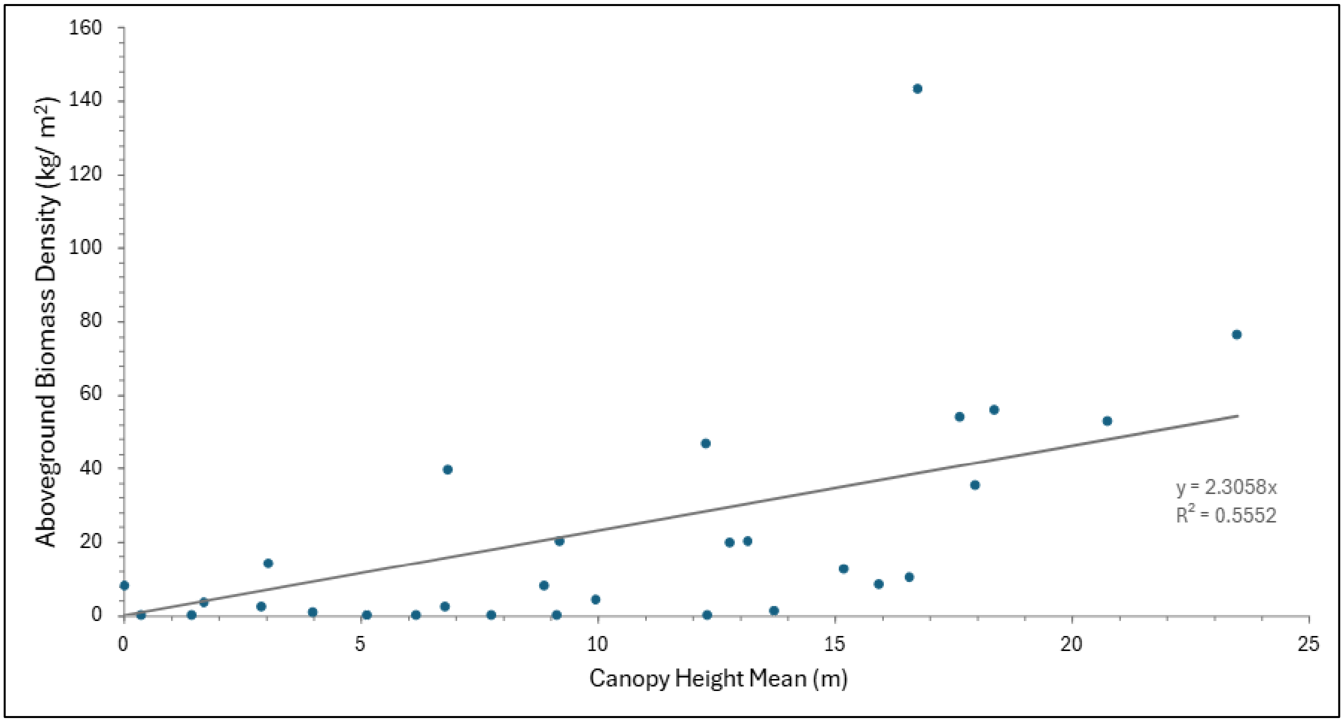

Figure 5: Regression model.

The results from the regression (y=2.3058x) were applied to the study area. As shown in Equation 1, 'x' was substituted for the CHM layer – this produced a continuous map of AGBD.

Equation 1: Relationship from the regression model used to create the AGBD map.

$$AGBD = 2.3058 * CHM$$

It is widely assumed that approximately 50% of AGB is carbon (Houghton, Hall and Goetz, 2009; Petrokofsky *et al*., 2012.) Applying this assumption to AGB values, it was then possible to map carbon and obtain a total value for the study area.

6. Results:

Figure 6a displays AGBD throughout the study area, with the highest values around the middle of the path. The total loss of biomass is estimated to be 1,469,366kg if the proposed tramline proceeds, equating to 734,683kg of carbon stock lost (Figure 6b).

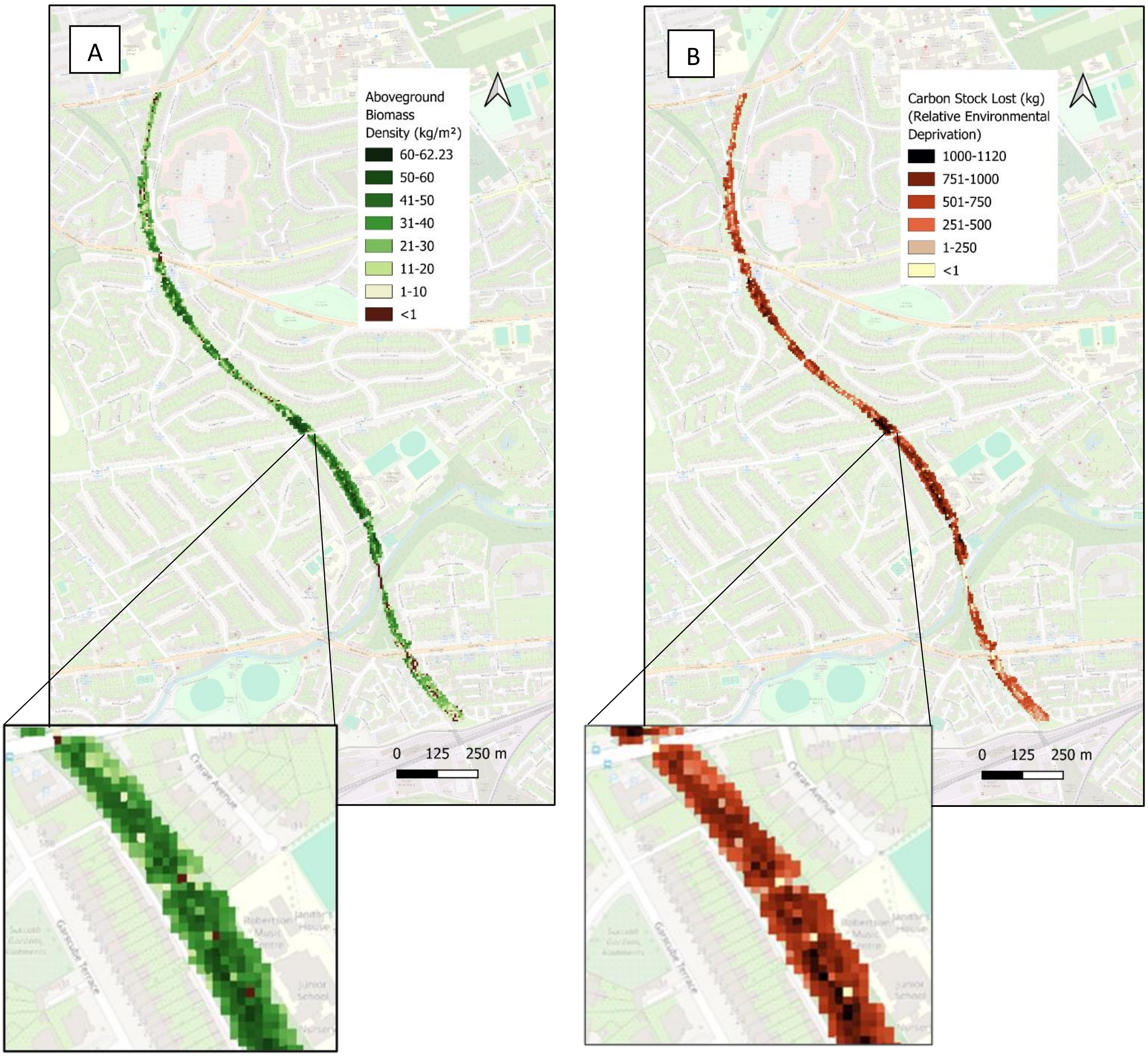

Figure 6: Aboveground biomass density map (A) and potential carbon loss map (B).Close-ups are provided to better highlight the variation within the path.

Figure 7 illustrates the standard error for AGBD, showing the average distance between observed values and the regression line. The standard error is 4.6478kg/m², with only 37% of data points within these bounds.

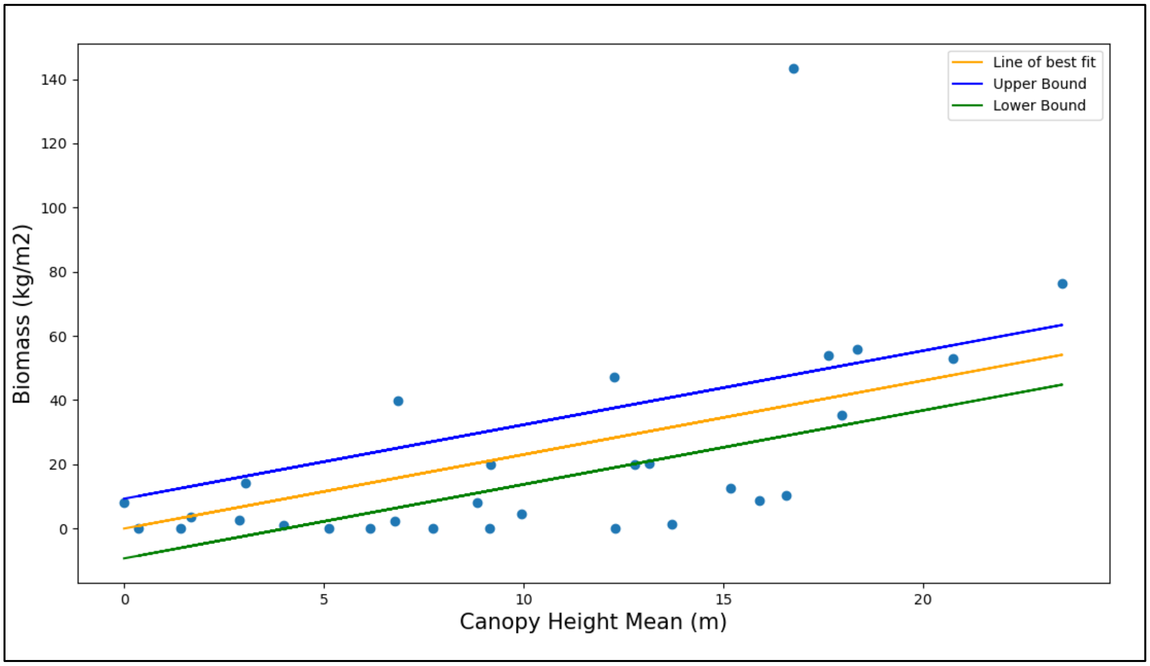

Figure 7: Graph illustrating the standard error (4.65kg/m²) – the average distance between the observed values and the regression line. Upper and lower bounds (± x2 standard error) show the range that most values are expected to fall within. See Appendix B for the Python code.

7. Discussion:

7.1 Method and Results:

Firstly, there is inherent uncertainty when calculating AGBD from allometric equations (Petrokofsky *et al*., 2012) but this was reduced by using species-specific biomass relationships. The use of allometric equations specific to urban environments could further increase the accuracy (Yoon *et al*., 2013), but few have been derived and tested (Zhao *et al*., 2023).

Secondly, the standard error of 4.65kg/m^2 (22%) highlights the weak fit of the regression model for calculating AGBD – Lefsky *et al*. (2002) had standard errors ranging from 2.5-12.6%. This could be due to the study area's topography, with the steep banks causing trees to overhang non-vegetated areas (Figure 8). Hence, the tree trunk (AGBD) is often not situated within the area of high CHM (Figure 9) and could account for instances of high CHM having low AGBD (Figure 10).

Thirdly, there is further uncertainty as it assumed that carbon accounts for 50% of AGB, yet some studies suggest this assumption may be an overestimation e.g. US Forest Service (2022) suggesting a value of 47.4%.

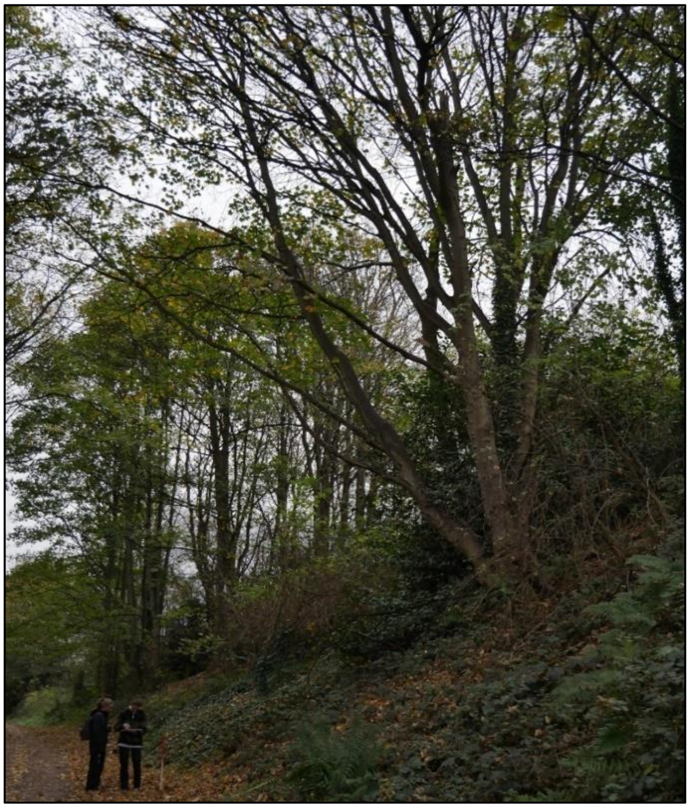

Figure 8: Photograph highlighting the topographic complexity of the study site. This is a plot where low AGBD was recorded, but CHM is high. This is because the cycle path is lined with steep banks, causing the branches from the trees to overhang.

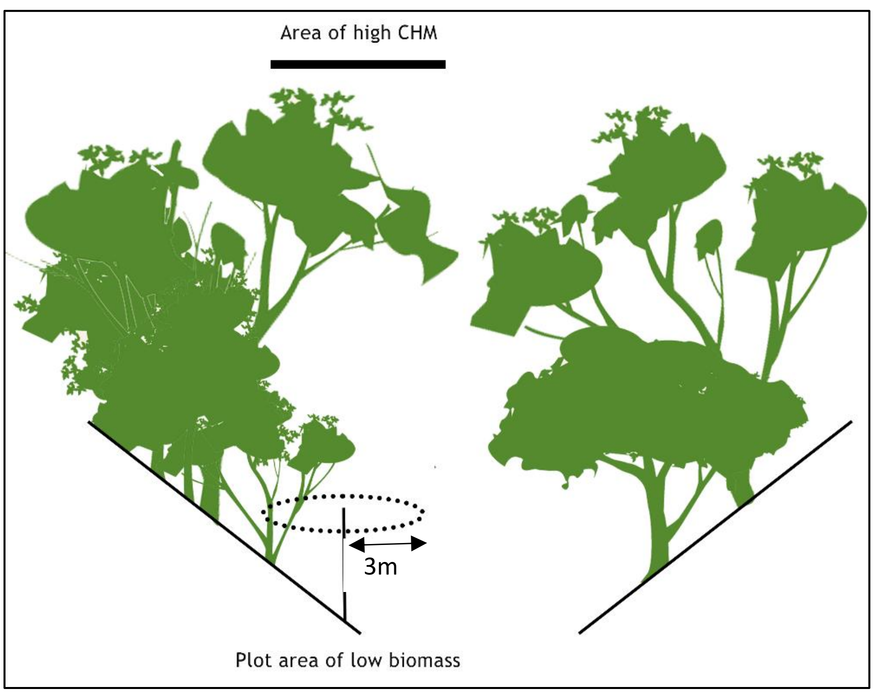

Figure 9: Diagram highlighting the influence of the steep banks and overhanging trees on the biomass measurements.

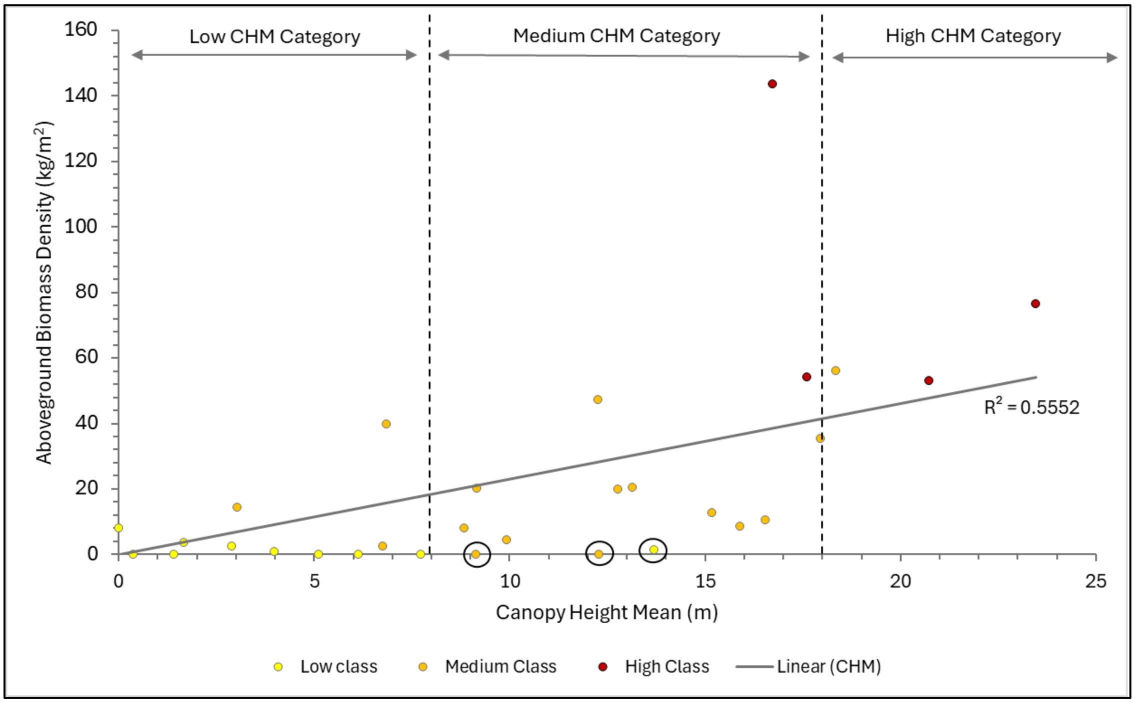

Figure 10: Graph highlights the distribution of CHM categories within the regression model. Emphasis is placed on the points where canopy height is relatively high, but ABGD is low. These points can help account for the poorer fit of the model.

7.2 Carbon Loss in a Wider Context:

To contextualise these findings, it is predicted that over 3.07 million tram journeys would have to be taken (instead of car journeys) to negate the 735,000kg of carbon stock loss (see calculations and assumptions in Appendix C). It is thought around 13.5 million trips would be made on the new tram route every year (Arthur, 2024) – therefore, the CO_2 savings from reduced car travel would soon cancel out the carbon loss from the path. It is important to note this does not factor in increased/reduced carbon emissions from (1) construction, (2) any replanting or (3) reduced active travel.

While this suggests there would be net carbon savings in the long-term, this proposal would hinder the council's progress to prioritise transport by foot and cycle (Active travel plan – City of Edinburgh Council, 2021b) and to have well-connected, healthy nature networks (Biodiversity Action Plan – City of Edinburgh Council, 2023). Moreover, Roseburn remains an important urban greenspace for mental (Jabbar, Yusoff and Shafie, 2021), physical (Richardson *et al.*, 2013) and environmental (Armson, Stringer and Ennos, 2012) reasons beyond carbon stock.

7.3 Future Research:

As this proposal has not yet gone to consultation, these preliminary findings could be utilised by interested parties (e.g. the council or the Save the Roseburn Path campaign) but further study should ideally be carried out to increase the validity of the AGBD estimations. It is recommended that error and uncertainty be further explored by including confidence intervals or mapping errors through a Monte Carlo simulation (Saarela *et al*., 2020). To increase the accuracy of the AGBD prediction, sample size could be increased (Petrokofsky *et al*., 2012) or alternative methods could be explored. For instance, terrestrial laser scanning (Disney *et al*., 2018) could help overcome the issues with tree overhang and the effect this had on the model fit. It may be that the complex topography of the Roseburn path is less suited to conventional biomass methodologies (like that adopted in this study) and that adopting a new methodology is advisable.

If the tram proposal were approved, future research could also explore how this project could be made less destructive to the environment and local communities. The viability of mitigation strategies, such as replanting or creating new active travel routes, could be probed and potentially make the tramline proposal more palatable.

8. Conclusion:

The proposal to replace the Roseburn path with a tramline has sparked much debate. Not only is this path an active travel route, but it contains around 3,500 trees. Through a hybrid approach of field and remote sensing techniques, this study estimates the carbon stock of the Roseburn path to be 734,683kg. To the authors' knowledge, this is the first attempt to quantify the carbon store of this path. These findings therefore offer a novel insight into the potential impact of extending the tram network.

It is important to note however, the uncertainty around this result. The regression analysis returned a relatively weak model, with considerable standard error (22%). These findings can serve as a useful starting point in consultation, however, for any application beyond this, the council may wish to explore alternative methods of calculation. Furthermore, when considering these findings in the broader context, it is believed any loss of carbon would soon be compensated by CO_2 savings made from reduced car travel. Therefore, the greatest impact of losing the Roseburn path may relate more to its ecological properties, and its value as an active travel route.

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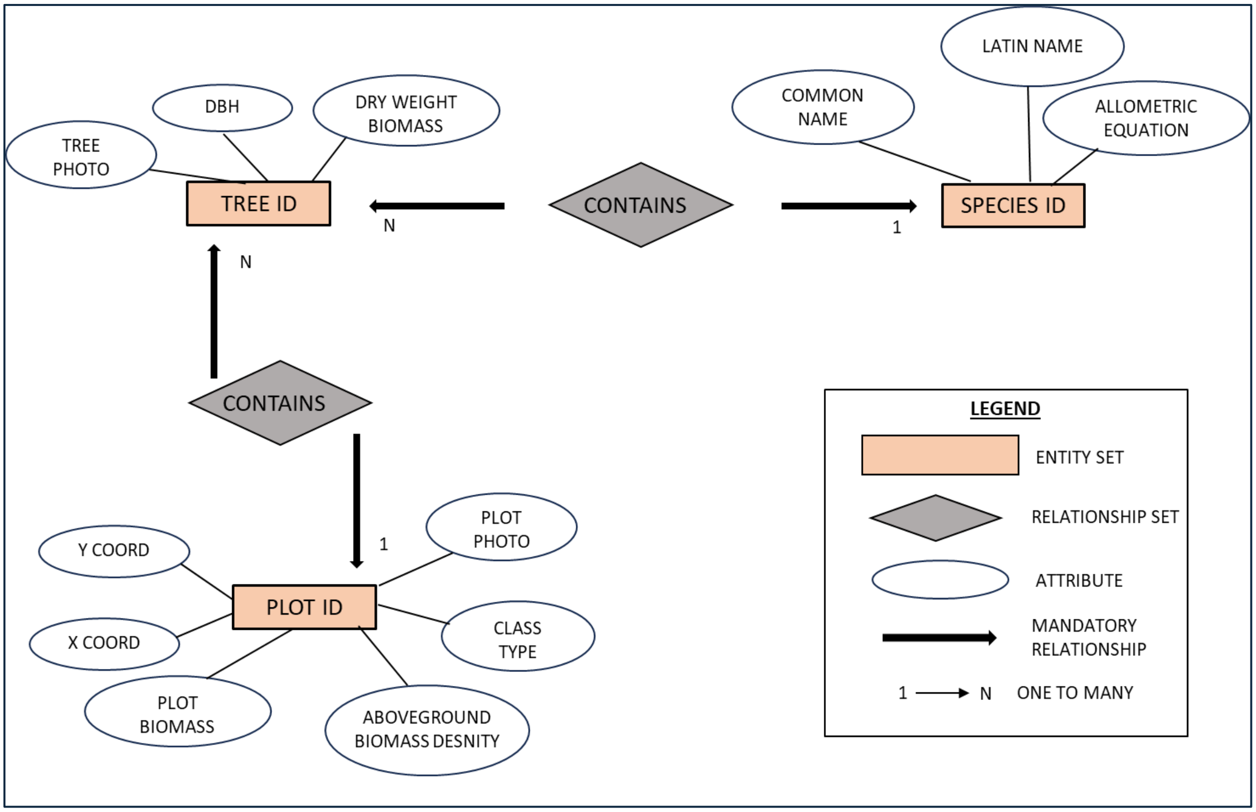
11. Appendix A: E-R model and data tables.

An entity-relationship model created using criteria from Chen (1976) so that redundancy is limited within the tables.



The tables derived from the E-R model. This was used as the formatting for data collection and will enable a future webmap to query this data.

Primary Key	Foreign Key

Plot ID	X Coord	Y Coord	Class Type	Plot Biomass	AGBD (kg/m2)	Plot Photo ID	Notes
Number(2)	Number(7,5)	Number(7,5)	Varchar2(10)	Number(6,3)	Number(6,3)	Number(4)	Varchar2(40)

Tree ID	Plot ID	Species ID	DBH(cm)	Tree Photo ID	Dry Weight Biomass
Number(2)	Number(2)	Number(2)	Number(4,2)	Number(4)	Number(6,3)

Species ID	Common Name	Latin Name	Allometric Equation	Equation Reference
Number(2)	Varchar2(20)	Varchar2(40)	Varchar2(40)	Varchar2(40)

12. Appendix B: Python code for error analysis.

```
import numpy as np
import matplotlib.pyplot as plt
from scipy.optimize import curve_fit
from scipy.stats import pearsonr

# Read the CSV file
data = np.genfromtxt('dataforpython.csv', delimiter=',', skip_header=1)

# Assign columns to variables
chm = data[:, 0] # Mean canopy height
agbd = data[:, 1] # Biomass

print(chm)
print(agbd)

# Define a linear model with intercept forced to 0
def linear_model(x, a):
return a * x

# Fit the model to the data
slope, _ = curve_fit(linear_model, chm, agbd)

# Calculate predicted values
predicted_agbd = linear_model(chm, slope[0])

# Calculate residuals
residuals = agbd - predicted_agbd

# Calculate standard error of the residuals
residual_std_error = np.sqrt(np.sum(residuals**2) / (len(chm) - 1))

# Calculate overall standard error
overall_std_error = residual_std_error / np.sqrt(len(chm))

# Calculate R-squared
ss_total = np.sum((agbd - np.mean(agbd))**2)
ss_residual = np.sum(residuals**2)

# Print the results
print("Line of best fit slope is", slope[0])
print("Overall standard error of the linear equation is",
overall_std_error)
print('Correlation is', pearsonr(chm, agbd))
```

```python
# Plot the data points
plt.scatter(chm, agbd)

# Plot the line of best fit
plt.plot(chm, predicted_agbd, color='orange', label='Line of best fit'

# Calculate and plot the boundaries of error
upper_bound = predicted_agbd + (overall_std_error*2)
lower_bound = predicted_agbd - (overall_std_error*2)
plt.plot(chm, upper_bound, color='blue', label='Upper Bound')
plt.plot(chm, lower_bound, color='green', label='Lower Bound')

# Add labels and title
plt.xlabel('Mean Canopy Height (m)')
plt.ylabel('Biomass (kg/m2)')
plt.legend()

# Show the plot
plt.show()
```

13. Appendix C: Calculations to estimate carbon savings from tram travel.

The City of Edinburgh Council does not provide information on the CO_2 savings made from trams, as a result of reduced car travel. A preliminary attempt to do so is made below:

CO_2 loss	**CO_2 savings**	**For CO_2 loss to be cancelled**
Carbon stock lost from the Roseburn path	**Carbon savings from reudced car use**	How many journeys would have to be taken
		by tram instead of car to cancel the loss of
From prior calculations:	Emissions for modes of transport	carbon stock from Roseburn?
	(from Transport Scotland, 2022):	
Carbon (C) stock = 734,683kg		If assuming a car journey of 6km:
	Petrol cars: 174gCO_2 per passenger km	*Petrol: 2,696,287/0.876*
To convert to CO_2 equivalent:	*Diesel cars: 168gCO_2 per passenger km*	*Petrol: 3,077,953*
	Light rail and tram: 28gCO_2 per passenger km	
*CO_2 = C*3.67 (from e.g. Kauffman et al.,*		*Diesel: 2,696,287/0.840*
2012; Omar et al., 2016)	Emissions savings by switching to tram:	*Diesel: 3,209,865*
*CO_2 = 734683*3.67*		
CO_2 = 2,696,287kg	*Petrol car > tram: 146gCO_2 per passenger km*	**Key finding**: Over 3 million 6km journeys would have to be taken by tram instead of by a petrol or diesel-fulled car to counteract the loss of carbon stock from the Roseburn path
	Diesel car > tram: 140gCO_2 per passenger km	
	Emissions savings for a 6km journey:	
	Petrol car > tram: 876gCO_2 (0.876kg)	
	Diesel car > tram: 840gCO_2 (0.840kg)	