Forestry Carbon Accounting

J. Zou [1,5], K. Byrne[2], N. Farrelly[1], I. Short[1], DS. Rathore [1], R. Irwin[1], M. Ryan[3], S. Green[4], K. Richards[5], F. Moore[6], J. Redmond[6], T. Houlihan[1]

[1] *Forestry Department, Teagasc, Athenry,*
[2] *Department of Biological Sciences, UL, Limerick,*
[3] *Rural Economy & Development Centre, Teagasc, Athenry,*
[4] *Agribusiness and Spatial Analysis Department, REDP, Teagasc,*
[5] *Climate Centre, Teagasc,* [6] *Forest Sector Development, Department of Agriculture, Food and the Marine, Wexford*

1. Introduction

Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide (CO_2). This process is critical for mitigating climate change by reducing the concentration of CO_2, a major greenhouse gas (GHG), in the atmosphere. Forests play a very significant role in carbon sequestration. Trees absorb CO_2 from the atmosphere, convert it into organic matter through photosynthesis, and store it in their biomass (trunks, branches, leaves, and roots). Dead organic matter, such as deadwood, leaves and branches, decomposes and contributes to soil organic carbon. CO_2 is released through autotrophic and heterotrophic respiration.

Ireland has committed to reducing GHG emissions and enhancing carbon sequestration through a range of measures in the agricultural, land use, land use change and forestry sectors. The Climate Action Plan 2024 identifies enhanced delivery of afforestation, sustainable forest management and increased use of harvested wood products (HWP) as key measures in meeting the objectives. Ireland's National Forestry Strategy targets a major expansion of climate resilient and healthy forests to 18% of total land area. This paper aims to provide an overview of current knowledge and practices related to forestry carbon sequestration in Ireland, highlight the measurement techniques used and carbon accounting efforts, and discusses future research needs. The objective is to inform policy and industry stakeholders about the importance of measuring and increasing carbon sequestration through forestry.

2. Current Knowledge of Forestry Carbon Sequestration in Ireland

Forests store carbon in five primary pools on site: aboveground biomass, belowground biomass, litter, deadwood, and soil carbon. The amount of carbon stored in any one pool changes over time. An important and often overlooked carbon pool is wood products. Most of the carbon is retained when the harvested tree becomes a durable wood product (furniture, flooring, etc.). Ireland's National Inventory Report (EPA, 2024) indicates that the average carbon sequestration by forest land in Ireland between 1990 and 2022 was 2.45 Mt CO_2-eq per year. The average rate of sequestration by HWP was 0.83 Mt CO_2-eq per year. The Teagasc MACC Analysis to 2030 describes options for consideration aimed at increasing climate change mitigation contributions from forestry within the LULUCF sector. These include afforestation rates of 8,000 hectares per year; forest management by adjustment of the age of rotation on 21% to 31% of the area of commercial conifer forests on suitable sites avoiding deforestation and agroforestry creation. These four measures combined could deliver about 1.32 Mt CO_2-eq per year in 2030 (Lanigan et al., 2023).

Historical Planting in Ireland

Historically, Ireland has experienced various phases of afforestation, notably expanding forest cover from 1.5% in 1920 to 11.6% in 2022, with public planting dominant until the mid-1990s, and private planting significantly increasing from the early 1990s (DAFM, 2022). A key challenge is to enhance the capacity of our forests to be an effective carbon store, with due consideration to other future demands on our forests. Irelands Forest Strategy sets out the overriding objective to urgently expand the national forest estate on both public and private land in a manner that will deliver lasting benefits for climate change, biodiversity, water quality, wood production, economic development, employment and quality of life. Eligible planting sites for afforestation (based on soil type and site fertility) under Forestry Programme 2023-2027 are set out in the Land Types for Afforestation publication (DAFM, 2023). These include mineral soil, organo-mineral soil with peat depths of less than or equal to 30 cm or suitable modified fen and cutaway raised bogs. Environmental considerations incorporated into the planting approval process to safeguard the environment will have an impact on land availability for afforestation.

Carbon Measurement in Irish Forestry

Ireland employs several methods to measure forest carbon stocks including remote sensing, ground-based monitoring, and inventory modelling. Ground-based methods involve direct measurement of tree dimensions (e.g., diameter, height) and soil sampling, with new technologies like eddy covariance measurements being used in recent years. Remote sensing techniques utilize advanced satellite and aerial imaging to analyse forest cover, biomass, and changes over time to quantify carbon stocks. Inventory modelling employs sophisticated computer models that integrate remote sensing data, field data, and other inputs to project forest carbon dynamics at national and regional scales. As new measurement techniques become available and existing techniques are improved and refined, increasingly accurate estimates and more comprehensive assessment of carbon fluxes in forests can be achieved.

Carbon Sequestration for New Forestry Types

The Afforestation Scheme 2023-2027 (DAFM 2023) supports the creation of a wide range of forests with varying objectives. Landowners can plant a range of different forest types on the same holding depending on the management objectives chosen for the site. Each forest type will have specific carbon sequestration rates, reflecting factors such as tree species/species mixes, soil types, planting patterns, future management approaches and harvest products. Teagasc, in conjunction with DAFM and Forest Environmental Research and Services (FERS) Limited have developed an online Forest Carbon Tool. The tool uses the same modelling framework (CFS-CBM) as used in the national GHG inventory and for submissions to the EU. The tool provides indicative data for potential carbon sequestration associated with new forest enterprises which will shortly include current options under the DAFM Forestry Programme. It also provides indicative sequestration data for specific tree species/species groups. The Forest Carbon Tool takes user-defined descriptive information on the forest and combines it with existing growth models to estimate potential carbon storage over the lifetime of the forest.

There are two normalised values used to compare forests with different species, rotations ages and silvicultural management regimes: The average CO_2 cumulative removals/emissions is the CAP, which is a measure of the once-off maximum potential CO_2 sequestration. The average annual CO_2 sequestration rate over time until steady state is reached. This is a measure of the normalised rate of sequestration over successive rotations and allow comparison between silvicultural regimes with different rotation ages. Generally, forests with a high normalised sequestration rates will reach the CAP sooner than forests lower normalised sequestration rates. For example, afforestation with slow growing oak results in a higher CAP than Sitka spruce. However, Oak takes longer to reach the CAP because the normalised sequestration rate is lower than that of Sitka spruce. Figure 1 shows indicative carbon sequestration ranges and average CAP values derived from the Forest Carbon Tool (expressed in tonnes of CO_2 equivalents) for four different forest types (note the values for FT8 excludes emissions from livestock).

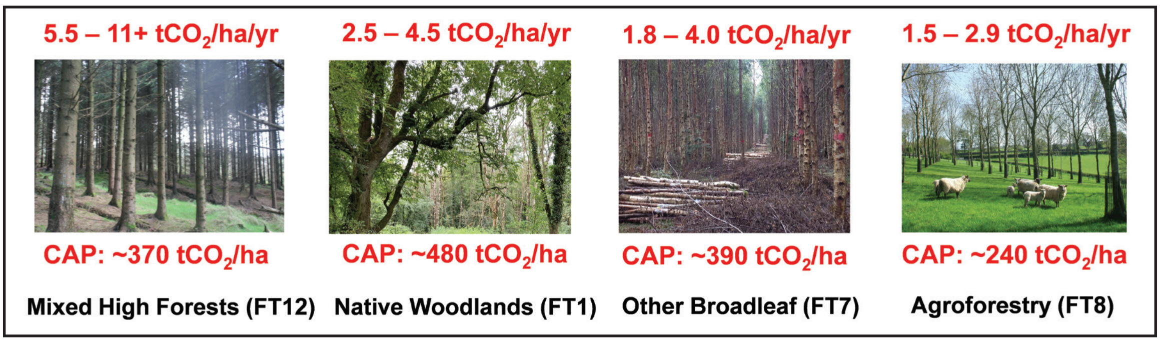

Figure 1: Carbon sequestration ranges and average CAP values for four forest types under the new afforestation scheme.

- **Mixed High Forests (FT12):** These forests are composed primarily of fast-growing conifer species with a 20% mixture of broadleaf species, resulting in high carbon sequestration rates. This type is designed to optimize both timber production and carbon storage. CAP time 60-100 years.
- **Native Woodlands (FT1):** These forests consist of species native to Ireland, providing significant biodiversity benefits and moderate carbon sequestration rates, but store carbon over long period of time. Native woodlands play a crucial role in conserving Ireland's native flora and fauna and enhancing ecosystem services. CAP time 100 years.
- **Other Broadleaf (FT7):** This category includes fast-growing broadleaf species such as birch, alder, and sycamore. These species are chosen for their ability to rapidly establish and grow, timber, contributing to moderate carbon sequestration and offering diverse ecosystem benefits, including improved soil health and enhanced habitat for various wildlife species. CAP time 150-160 years.
- **Agroforestry (FT8):** This system combines agriculture and forestry, offering benefits of both systems. Agroforestry practices can improve soil fertility, enhance biodiversity, and provide additional income streams for farmers while sequestering carbon. By integrating trees with crops or livestock, they enhance land use efficiency and resilience against climate change. CAP time 120-150 years.

Forestry Inventory and Recent Changes

Ireland maintains a comprehensive forestry inventory to monitor carbon stocks. The DAFM National Forest Inventory (NFI) collects data on forest area, tree species composition, age structure, health, and carbon stock. Notably, 38% of forests are on deep peats (>40cm depth). Recent forest carbon inventory reporting incorporate a significantly adjusted emission factor for forested peat soils. Research in 2021 indicated that emissions from drained forest peat soils are in the order of 1.68 t C/ha per year, nearly three times the previously-used emission factor (Jovani-Sancho et al., 2021). This change in emission factors has significantly impacted forest carbon accounting, with forestland sequestration reduced by about 50% (EPA, 2022).

Ireland's forests are transitioning to a source of emissions, and emissions reductions for this sector are set to become increasingly challenging, due to a number of combined factors including the decline in recent afforestation rates, continued emissions from organic soils, a projected increase in the level of harvest, deforestation and a reduction in landscape level sequestration potential due to age class structural shifts. Research work to further refine and validate emission factors on varying forest types and peat types is required and ongoing to strengthen knowledge and insights in this key area of forest sequestration accounting.

Higher timber yield is achieved on better forest site conditions, which largely determine the productivity and growth rates, ultimately influencing the carbon stocks in forests. Specific management practices, such as, ensuring optimum fertility status and appropriate thinning, can help optimise the carbon sequestration potential of forests. For example, selective thinning improves forest health and productivity by reducing competition for resources among trees, thereby enhancing the growth of the remaining trees. The continued inflow of wood from the harvest of successive rotations into the HWP avoids emissions by substituting energy-intensive products with wood and by replacing fossil fuel with bioenergy. Compared to unmanaged forests, high-production forests optimized for long-term HWP can potentially store double the amount of carbon at 100 years (FERS 2024).

3. Implications and Future Research Needs

Understanding and addressing social barriers to forestry acceptability is crucial. Engaging with communities, improving public perception, and providing incentives to landowners can promote afforestation. Outreach and education programs can highlight the benefits of forestry for carbon sequestration, biodiversity, and local economies. Collaborative approaches that involve stakeholders in the planning and implementation of afforestation projects can increase their acceptance and success. Enhancing the carbon sequestration capacity of Ireland's forest resource is essential to helping achieve climate targets. A multi-faceted approach encompassing forest creation, appropriate management practices, and the utilisation of long-lived harvested wood products is paramount. However, to effectively implement such strategies, increased understanding of forest carbon dynamics is imperative.

One area requiring significant attention is the effects of different forest management practices on carbon sequestration. Currently, the impact of practices such as forest thinning, clear-cutting, deforestation for habitat restoration, adjusted rotations, second rotation dynamics and continuous cover forestry approaches, and on carbon dynamics remains incompletely understood. Research initiatives should prioritise assessing these practices to determine their efficacy in enhancing carbon sequestration while maintaining ecosystem integrity. In addition to management practices, improved quantification of emissions and mitigation measures for forestry on organic soils is crucial. Refining emissions data for varying species on a range of organic soils, which are significant carbon pools prone to GHG emissions when disturbed, is imperative. Collaborative efforts between researchers and forest stakeholders are essential to further enhance knowledge on emission factors and thereby inform policy decisions aimed at mitigating emissions from organic soil disturbances. Moreover, understanding species-specific carbon sequestration dynamics is vital for optimising carbon storage potential. Detailed studies on the carbon sequestration rates of different tree species and their interactions with soil carbon dynamics are needed.

Lastly, assessing the potential impacts of natural disturbances and climate change on forest carbon sequestration is another area that merits attention. Given the uncertain future climate scenarios, evaluating the vulnerability of forest ecosystems to climate change-induced stressors such as drought, wildfire, and pest outbreaks is essential. Collaborative research efforts should focus on developing adaptive management strategies that enhance forest resilience and mitigate the adverse effects of climate change on carbon dynamics. Through concerted research endeavours, Ireland can develop holistic approaches to optimize forest carbon sequestration and optimize the huge potential of our valuable forest resource, including climate change mitigation capacity.

References

EPA (2024). Ireland's National Inventory Report 2024: Greenhouse gas emissions 1990-2022.

EPA (2022). Ireland's National Inventory Report 2022: Greenhouse gas emissions 1990-2020.

DAFM (2022). Ireland's National Forest Inventory 2022.

DAFM (2023). Land Types for Afforestation: Soil & Fertility. Working Document v.24Aug23.

FERS (2024). Forest carbon basic facts. https://www.fers.ie/forest-carbon-basic-facts/

Jovani-Sancho et al. 2021. Global Change Biology 27, pp. 3681-3698.

Lanigan et al. 2023. MACC 2023: An Updated Analysis of the Greenhouse Gas Abatement Potential of the Irish Agriculture and Land-Use Sectors between 2021 and 2030. Teagasc, 353pp.