Carbon Sequestration Potential of Indigenous Woody Vegetation on New Zealand Farmland and its Offsetting Ability for Carbon Footprints

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Executive Summary

Following the New Zealand Government's announcement to include agriculture into the ETS by 2025, He Waka Eke Noa has proposed two primary initiatives to measure and manage carbon emissions in the agriculture sector at the processor and/or farm level. For farmers to measure and manage their carbon footprints there must be a robust system in place to calculate not only their carbon dioxide emissions, but also their carbon dioxide sequestration potential. This research report will focus on answering the question of; what is the carbon sequestration potential of indigenous woody vegetation on New Zealand farmland and how can it be used to more accurately model on-farm carbon footprints?

Key findings

- The opportunity for indigenous carbon sequestration on New Zealand farmland is significant, with approximately 2,000,000 hectares of indigenous forest and shrubland existing.
- The carbon sequestration potential of indigenous woody vegetation is largely understudied. This was particularly evident in the lack of research completed on the carbon sequestration potential of indigenous forest and shrubland that is typical of New Zealand farmland; naturally regenerating, and restorative, mixed species compositions.
- Current ETS policy does not provide measures for landowners to accurately model the carbon sequestration of indigenous woody vegetation typically found on farm. This is specifically for landowners wanting to enter forest land less than 100ha which under policy they must use the MPI carbon look-up tables to calculate.
- Current ETS policy limits the actual on-farm carbon sequestration occurring within indigenous woody vegetation with its 'forest land definition'. It has been noted that feasibly, the only factor in the 'forest land definition' that could be changed would be the requirement to have trees that are 5m or more in height.

Recommendations

- Agriculture industry to prioritise extensive, nationwide research on understanding the carbon sequestration rates of indigenous woody vegetation, particularly of mixed species composition indigenous regeneration and restoration forest and shrubland on farmland.

- Agriculture industry to use this research to develop a robust model of indigenous carbon look-up tables that captures the common categories of woody vegetation on farmland. It may be that this is species specific for the large, more studied conifers, but it should also accommodate mixed species forest and shrubland scenarios typical of indigenous regenerating and restoration on farmland. This should also include a category for key indigenous scenarios growing below 5m in height, such as matagouri, *Coprosma, Hebe,* and riparian plantings. The current MPI look-up tables should be kept and used for calculating the sequestration of manuka and kanuka only.

- MPI's ETS policy of 'forest land definition' should be changed to allow indigenous forest and shrubland species less than 5m in height to be included. This may be that it is provided as a special case to the agriculture industry.

- Once robust carbon look-up tables have been developed, MPI's ETS policy which states that forests equal to or over 100ha should have its threshold area increased (e.g. to 500ha) before Field Measurement Assessment (FMA) is required, or one step further, have FMA as optional.

Table 1 compares the existing policy implemented and most studied carbon sequestration rates of indigenous woody vegetation applicable to New Zealand farmland.

Table 1: Carbon sequestration rates as total and mean average increments and their respective sequestration periods for ETS and non-ETS eligible indigenous woody vegetation; (1: MPI, 2017), (2: Beets et al, 2009), (3: Kimberley, Bergin, & Beets, 2014), (4: Case & Ryan, 2020), and (5: Burrows & Easdale, 2018).

Species/category	Total C (t CO2/ha)	MAI (t CO2/ha/yr)	Years of Sequestration (yrs)
1: Native MPI look-up tables	325.0	6.5	50
2: MAF native natural study	736.0	9.2	80
3: Kauri (plantation)	1,165.0	14.5	80
3: Totara (plantation)	929.0	11.2	80
3: Rimu (plantation)	712.0	8.9	80
3: Puriri (plantation)	631.0	9.0	70
3: Beech (plantation)	670.0	16.75	40
4: Matagouri	94.9	3.16	30
4: Coprosma	124.0	4.13	30
4:*Dracophyllum*, mountain celery pine, olearia, *Hebe* scrub	88.2	2.94	30
5: Riparian proxy	105.0	3.5	30

1 Introduction

Will climate change policy derail the New Zealand agriculture industry, or can New Zealand agriculture remain a leader in its field even under greenhouse gas reduction policies? New Zealand farmers and landowners hold over 40% of New Zealand's total carbon stocks (including both above and below ground carbon). Out of the 10,000,000-hectare estate for sheep and beef farmland in New Zealand, approximately 2,000,000 hectares of it is indigenous woody vegetation, equating to a total of 20% of the area. Out of this 20% of vegetative area, 8.2% comprised of indigenous forest, 5.5% as manuka/kanuka, 3.3% exotic forests, and 1.7% indigenous shrubland (Case & Ryan, 2020).

The Emissions Trading Scheme (ETS) is currently the only mechanism in New Zealand which recognises and verifies a landowner's forest to sequester and store carbon and be compensated for this process in return for carbon credits. Recent studies show that in 2018, 300,000 hectares of forest land is registered in the ETS, with only 25,000 hectares of that being indigenous (Tuahine, 2018). With the latter figure being applied to the current 2,000,000 hectares of indigenous woody vegetation, it appears there is a subjective limitation in relation to the recognition of the carbon being sequestered and stored by much of the indigenous vegetation present on New Zealand farmland. The common perception in New Zealand is that indigenous forest land provides limited carbon sequestration opportunities, mostly due to the interpretation that indigenous carbon sequestration rates are slow. However, emerging research on carbon sequestration rates and case studies of indigenous forestland entering the ETS are continually demonstrating the extraordinary opportunity present for indigenous forest land.

Indigenous forests are complex ecological systems and there is currently a significant lack of proficient research on the carbon sequestration rates of New Zealand's indigenous forest species where it can be applied to the array of vegetative models occurring on New Zealand farmland. At times this has resulted in severely diminished opportunities for farmers and landowners to enter the ETS, or more importantly, for them to have the ability to accurately model the carbon sequestration of indigenous forest land if the agriculture industry were to enter the ETS.

Following the New Zealand Government's announcement to include agriculture into the ETS by 2025, an industry non-Government organisation called He Waka Eke Noa has proposed two primary initiatives to measure and manage carbon emissions in the agriculture sector at the processor and/or farm level. For farmers to measure and manage their carbon footprints there must be a robust system in place to calculate not only their carbon dioxide equivalent emissions, but also their carbon dioxide sequestration potential.

This research report will focus on answering the question of; what is the carbon sequestration potential of indigenous woody vegetation on New Zealand farmland and how can it be used to more accurately model on-farm carbon footprints?

The hypothesis for this report states; due to the lack of research on carbon sequestration for indigenous woody vegetation on New Zealand farmland and the existing policy to enter forestry into the ETS, there are currently significant and subjective limitations to accurately modelling agricultural carbon footprints at the farm level.

2 Project Scope and Objectives

The scope of the carbon sequestration potential for farmland in New Zealand has been set for indigenous forest and shrubland only. As described above, the scale at which indigenous woody vegetation on farmland is significant. Extensive studies have already been completed on the likes of the carbon sequestration of *Pinus radiata* among other common exotic tree species.

It is important to define what is meant by the term 'woody vegetation'. A woody plant is a plant that produces wood as its structural tissue and thus has a hard stem. In cold climates, woody plants further survive winter or dry season above ground, as opposite to herbaceous plants that die back to the ground until spring. Woody vegetation means perennial trees and shrubs having stiff stems and bark. Woody vegetation does not include grasses, herbs, or annual plants (The Spruce, 2017).

Indigenous forest species in New Zealand are largely evergreen species that hold four major physiognomic elements; beech (*Nothofagus*), broadleaved angiosperms, kauri (*Agathis australis*), and conifers (predominantly podocarps) (Allen et al, 2013). Case and Ryan (2020) conclude that manuka and kanuka are within the species varieties of the genus *Leptospermum* for manuka and *Kunzea* for kanuka and are shrubland. Other indigenous shrubland comprised of smaller woody plant species common but not limited such as matagouri (*Discaria toumatou*), *Coprosma varieties*, Ribbonwood (*Plagianthus* divaricatus), small-leaved kowhai (*Sophora microphylla*), grass tree (*Dracophyllum traversii)*, mountain celery pine (*Phyllocladus alpinus*), lancewood (*Pseudopanax crassifolius*), *Hebe,* and leatherwood (*Olearia colensoi*).

The desired objectives of this research project are as follows:

- Provide a review of published sources regarding indigenous woody vegetation carbon sequestration.
- Summarise the current researched literature on the carbon sequestration potential of indigenous woody vegetation and understand how it can be applied to farming models.
- Analyse and understand the current ETS policy in relation to how it affects landowners with indigenous woody vegetation to determine whether it's fit for purpose on farmland.
- Complete a farm case study analysis which calculates the farm's carbon footprint and assesses it against indigenous carbon sequestration models applicable of the research.
- Evaluate the results and compile a list of recommendations to industry and ETS policy makers for greater outcomes.

3 Methodology

3.1 Literature Review

The method of approach was to complete a literature review of the available scientific documentation on the carbon sequestration potential of New Zealand indigenous vegetation. This information is used for the formulation of the New Zealand ETS policy which is the only verified pathway for carbon sequestration recognition for forestry. The purpose was to analyse and review the current research and theories on the topic to understand the fundamental views that exist and to critically evaluate and discuss those existing views in relation to the hypothesis.

The research undertaken in this report utilises a combination of qualitative and quantitative measures to calculate, analyse, conclude, and define a set of key recommendations to industry if the resulting research agrees with the hypothesis. Indigenous woody vegetation has been the selective study sample due to its significance and presence on farmland in New Zealand, but also because of the complimentary biodiversity benefits that are rendered from the encouragement of indigenous forestland establishment.

3.2 Farm Case Study Analysis

A case study model of a farm system in New Zealand that holds potential to have indigenous woody vegetation, Willesden Farm on Banks Peninsula, Canterbury, was completed on behalf of this report. Concluding theories from the literature review were applied to the modelling scenario which entail differing carbon sequestration rates external of the existing ETS policy.

The Beef and Lamb NZ (B+LNZ) carbon calculator has been used to calculate the farm's carbon footprint for the year of 2020-2021 using stock reconciliation data, fertiliser use, and other carbon sequestration inputs for the calculator. Existing Post-1989 *Pinus radiata* forest areas were also entered to eliminate these from the assessment.

The carbon forestry opportunities for the farm have been identified by assessing all the potential forest land's ability to meet MPI's 'forest land' definition. MPI's 'forest land definition' is a forest that:

- Is at least 1 hectare.
- Has the potential to reach an average canopy width of 30 meters.
- Has the potential to reach a canopy cover of at least 30%.
- Trees must be species that can grow to at least 5 meters in height.
- Was not classed as "forest land" as per above in 1989 or earlier (Post-1989).

Using aerial imagery between 1980-1989 and 1995-1999, Pre-1990 areas have been marked on GIS mapping. These areas were confirmed as being Pre-1990 through field assessment, scouting the areas on foot and surveying them with a drone.

Using a combination of historic imagery and current imagery, a preliminary assessment of the new forested areas was able to be determined as to whether it had potential as Post-1989 forest land.

Ground truthing, aerial drone surveying and an extensive mapping assessment of forest land definition provided the basis of the assessment to confirm Post-1989 eligibility. Forest land definition of potential Post-1989 areas was measured on QGIS software; 30% canopy cover, 1ha size, 30m average width, 5m tree height, and 15m mapping rule to determine eligibility. Tape measures were also used to measure mature tree species that were in doubt of reaching the 5m mark (e.g. manuka and other smaller podocarp varieties). Indigenous shrubland areas that would not reach 5m were also identified (e.g. matagouri and *Coprosma*).

The average age of all indigenous forest and shrubland areas was determined by weighted average age of each forest area as determined by MPI (2017). For example, a forest that met forest land definition as of 1990 and is continuously growing, showing new seedling regeneration in 2021, would have an average age of 16-years as some trees would be around 31 years of age and others 1 year of age. It was determined that all forest areas had an average age of 16 years at the start of the mandatory emissions return period (MERP) which runs from 2018-2022. Therefore, the starting date for forest sequestration is 2018 which aligns with ETS policy.

4 Literature Review

The scientific publications reviewed conclude that the research measures undertaken on the carbon sequestration rates of indigenous forest land in New Zealand is limited. This is however in exception to the data sets obtained for some key indigenous tree species grown in plantations as well as one study that obtained the carbon inventories for naturally occurring forestlands and shrublands. This is even more particularly so for the vast landscapes of indigenous woody vegetation occurring on farmland in all its variation. There is strong evidence to suggest that for forests under 100ha, the New Zealand ETS policy provides a model of carbon sequestration that is not accurate at capturing the diverse and dynamic nature of indigenous forest and shrubland occurring in New Zealand and that it provides only a simplification of a complex system.

Critical analysis of multiple sources of literature has drawn focus to three key themes which have emerged repeatedly in this literature:

- The carbon sequestration potential of indigenous woody vegetation on New Zealand farmland is largely understudied.
- Current ETS policy does not provide measures for landowners to accurately model the carbon sequestration of indigenous woody vegetation typically found on farm.
- ETS policy currently limits the recognition of actual on-farm carbon sequestration occurring within indigenous woody vegetation with its definition of ‘forest land definition’.

The literature review in this report will critically analyse and evaluate these three primary trends in the context of the report hypothesis.

4.1 1): The carbon sequestration potential of indigenous woody vegetation on New Zealand farmland is largely understudied.

As previously stated, indigenous vegetation has the scalability to act as one of the largest carbon pools for farmers and New Zealand, however, given the high variety of indigenous tree and shrub species present, only a relatively low number of occurrences has been studied for their carbon sequestration potential. Forest ecosystems in their natural form are highly diverse and rapidly changing due to an abundance of growing factors which make their measurement of carbon sequestration difficult to model.

Yarur Thys (2021) agrees that indigenous forests are complex biological systems with a range of different species present and that the lack of detailed studies makes it difficult to understand how much carbon is being sequestered. Their study of quantifying carbon sequestered by native restoration plantings on Quail Island in Canterbury found that there was a lack of proficient studies that addressed the carbon content of indigenous restoration sites in New Zealand. Yarur Thys (2021) used actual sampling of vegetation to model the carbon sequestration of their restoration sites, however, they had no suitable carbon sequestration rates relevant to evaluate and compare their data with. One finding of the project confirmed the need to involve a national scale data collection of indigenous restoration sites to establish a sensible model for carbon sequestration calculations of mixed indigenous species restoration.

Similarly, Bergin et al (2021) agree that there are remarkably limited measures of carbon sequestration that have been made on indigenous forests in New Zealand, however, they further state that new research from Tanes Tree Trust has recently produced a carbon calculator for a planted native database. This database is based on a comprehensive survey completed in 2010 throughout New Zealand over several decades, however, it is currently unavailable, and it is noted that this is of ‘planted’ natives and would therefore be most applicable to restoration sites and possibly not naturally regenerating sites.

Kimberley, Bergin, & Beets (2014), from Tanes Tree Trust and Scion, provided one of the most informative data bases for the carbon sequestration rates of indigenous tree and shrubland species in New Zealand. Their research has provided fundamental carbon sequestration data for key indigenous tree species of conifers, beeches, and hardwoods within monocultural plantations. Data has been obtained for indigenous forest land species, specifically for kauri, totara, rimu, puriri, black beech, red beech, and puriri, and shrubland, however, except for the shrubland, the data has been measured from managed tree stands which therefore leaves the question of its applicability for multi species indigenous regeneration and restoration sites common of farmland in New Zealand.

One study, completed by the Ministry for the Environment (MFE) during 2002-2007, has compiled inventory of carbon stocks stored within New Zealand natural forests (Beets et al, 2009). The same method of assessing carbon sequestration used by Kimberley, Bergin, & Beets (2014) has been used in this study, except measurement occurred on naturally existing indigenous forestland, not plantation forestry. The result of this study provided a high-level carbon inventory of indigenous forest land for larger forest species varieties and shrubland that was varied in its measured rates (Beets et al, 2009). The result was summarised as average figures for ‘forest plots’ and ‘shrubland plots’ (Beets et al, 2009).

In the case of smaller woody vegetation varieties outside of the larger podocarps, conifers, and beech, such as shrubland species or species found within riparian plantings, similarities in research are evident when trying to find sequestration rates applicable to indigenous woody vegetation found on farmland. Kimberley, Bergin, & Beet’s (2014) measured planted indigenous shrublands that were highly stocked, although it stated that their methodology did not attempt to distinguish between species. Later, they stated that most shrubland restoration sites in New Zealand consisted of a mix of kanuka, manuka, *Hebe* species, *Coprosma* species, *Pittosporum* species, akeake (*Dodondea viscosa*), and whauwhaupaku (*Psedudopanax arboreus*). Similarly, the study from MFE during 2002 which was cited in Beets et al (2009) also provided an average carbon data set derived from measuring indigenous shrubland carbon plots naturally occurring, however no details were given on species composition.

In the case of riparian plantings, Burrows & Easdale (2018) in their comprehensive literature review of non-ETS compliant land, state that there are no known quantitative data sets for carbon sequestration for planted riparian strips in New Zealand, with the only data for riparian shrublands being dominated by mostly gorse, broom, grass, and mixed shrublands. A typical mix for riparian plantings would include woody vegetation species such as karamu, koromiko, manuka, cabbage tree, five-finger, kohuhu, kowhai, lemonwood, lacebark, and ribbonwood (Horizons Regional Council, 2014), therefore, current surrogates available are likely inaccurate. Burrows & Easdale (2018) conclude with a key finding that their proxy data should be treated with caution when used for modelling riparian carbon sequestration. Additional findings further state that to understand the carbon sequestration potential of shrubland and riparian plantings it requires focused research for a range of environments that account for specific stand structure, age, environmental conditions, and species mixes.

Lastly, to understand the carbon cycle of an indigenous forest accurately, Nabuurs’s (2007) report for The Intergovernmental Panel on Climate Change (IPCC) suggests forest carbon should be estimated for five carbon pools: above ground biomass, below ground biomass, dead wood, litter, and soil organic matter. All the studies referenced in this report only calculate carbon above and/or below ground and do not include the later three defined by Nabuurs's (2007), however, the MPI carbon look-up tables include the calculation of carbon in the stems, branches, leaves and roots, and in the coarse woody debris and fine litter on the forest floor (MPI, 2017), but not soil organic matter.

Although there is research that provides an understanding of the carbon sequestration measures for key indigenous forestland species in New Zealand, there is a clear deficiency in research on the carbon sequestration potential of the types of indigenous woody vegetation typically found on farmland. Although there is an emerging data set for the carbon inventory of singular indigenous forest land species, it remains mostly unclear whether these would be suitable applications to model diverse regenerating and restorative indigenous woody vegetation. This is confirmed by Yarur Thys (2021), Burrows & Easdale (2018), and Bergin et al (2021) in their literature, indicating that such studies were largely unconducted.

4.2 2): Current ETS policy does not provide measures for landowners to accurately model the carbon sequestration of indigenous woody vegetation typically found on farm.

For landowners wanting to submit a claim for Post-1989 forestry and enter the ETS, current policy requires the carbon sequestration measures to be completed by one of two methods: The MPI carbon look-up tables or the Field Measurement Approach (FMA). The MPI carbon-look up tables must be used for landowners entering the ETS with less than 100ha of forest land and the FMA is used for forest land equal to or over 100ha.

The FMA provides landowners with a carbon sequestration measuring method that uses real time measurement of tree biomass. Therefore, this method is largely considered robust in its quantification due to actual modelling (Carver & Kerr, 2017).

The MPI carbon look-up tables provide the landowner with a tabulated dataset for indigenous forest land which calculates the tonnes of carbon sequestered per hectare annually. As written by MPI (2017) in their carbon look-up tables documentation, the tabulated values for Post-1989 indigenous forest land were formulated from the measurement of regenerating indigenous shrublands, more specifically, manuka and kanuka. Their justification for supplying only one table for landowners submitting indigenous forest land areas was that this shrubland type accounts for 70% of the total regenerating indigenous area in New Zealand. This is listed as a single forest category for all indigenous forest land submitted (see **Appendix 1**) and it does not allow for variation in growth due to differences in species or regionally orientated climatic conditions, unlike *Pinus radiata*, which has its own category with regional discretion.

To give quantified context to this, the MPI carbon look-up tables for indigenous forest land currently provide a mean annual increment (MAI) of 6.5 tCO2/ha/yr or a total of 325 tCO2/ha over a 50-year period (MPI, 2017). In comparison, *Pinus radiata* on the look-up tables is regionally discrete, with a MAI ranging from 21 to 27 tCO2/ha/yr or a total range of 1,028 to 1,313 tCO2/ha (MPI, 2017).

Firstly, some studies agreed that the MPI carbon look-up tables provided an accurate data set for modelling regenerating kanuka and/or manuka only. For example, Bergin et al (2021) state in their preliminary summary report of a yet to be published study, that they clearly demonstrate that planted and managed native forests exceed the MPI carbon look-up table rate of 6.5 tCO2/ha/yr by significant margins and that it is clear the look up tables need to be adjusted to reflect this situation. This study was conducted on forest areas ranging from naturally regenerating native scrub through to planted native forest stands. They concluded that the MPI look-up tables are only accurate for regenerating kanuka/manuka shrubland (6.5t CO2/ha/yr mean annual increment, or 325 tCO2/ha, over 50 years).

Carver& Kerr's (2017) agreed in their research report of facilitating native offsets from native forests, stating that their forestry panel interviewees agreed that results from the look-up tables are relatively consistent with those from the FMA in a regenerating indigenous scenario. However, many felt the look-up tables could be improved and that there was concern about its applicability for more mature native forest land.

Contrastingly, Trotter et al's (2005) study confirmed that, depending on site conditions, regenerating manuka and kanuka could expect to achieve an average carbon accumulation rate between 1.9-2.5 tCO2/ha/y, or 76-100 tCO2/ha, over a 40-year period. This was below half of the values expressed on the MPI carbon look-up tables.

Beyond kanuka and manuka regeneration, research illustrates that it is evident that the look-up tables are an unfit model for the complexity of indigenous forest land present for landowners in New Zealand. Carver & Kerr (2017) stated in their report that discrepancies exist between the growth rates of native plantation forest land species and those found in the native look up tables. The research was referring to Kimberley, Bergin, & Beets (2014) report on native plantation forestry which found that native plantation forestry will sequester 30-60% less carbon than implied by the look up tables over the first 20 years but after 40 years will exceed it by 10-100%.

Kimberley, Bergin, & Beets (2014) completed a study that used both tree measurements and associated models for predicting carbon over time for a range of New Zealand native tree species and shrubland covered area plantations.

Figure 1 below provides a good illustration of their study, showing the total average carbon sequestration rates of all measured native plantation sites exceeding the total carbon sequestration rate currently used in the MPI look-up tables (325 tCO2/ha).

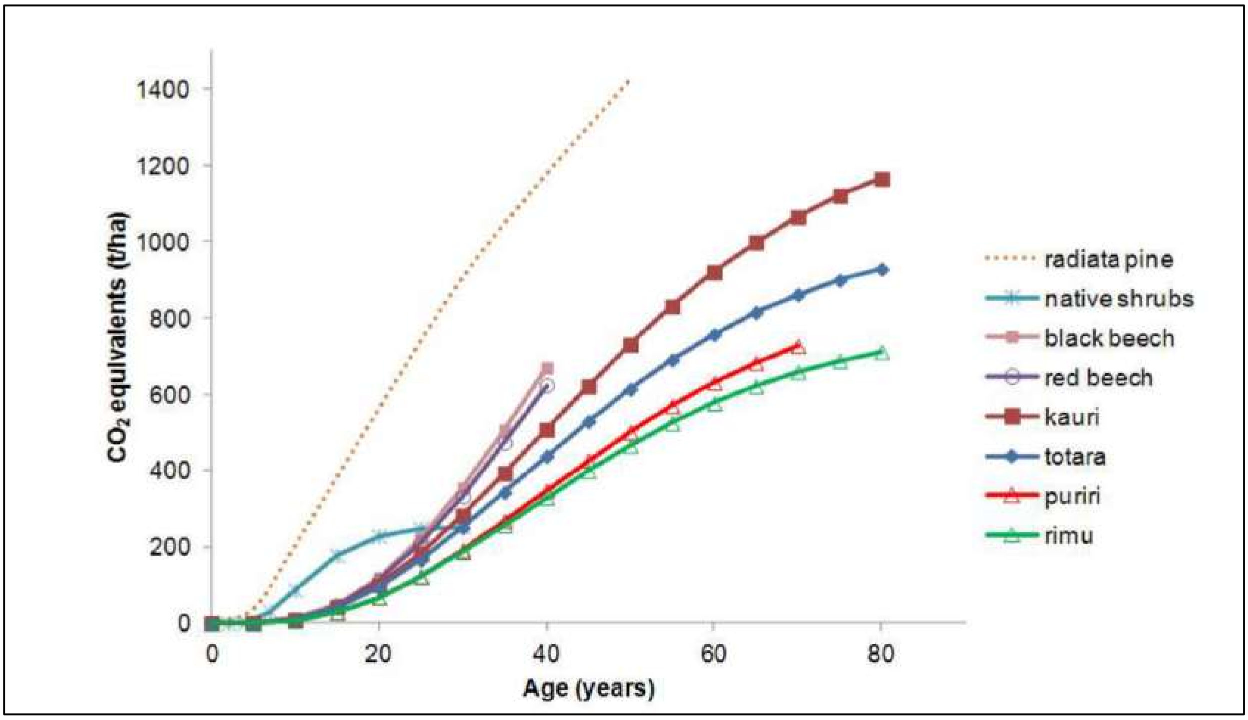

Figure 1: Predicted carbon sequestration rates on average sites for key native tree species, mixed shrublands, and radiata pine (Kimberley, Bergin, & Beets, 2014).

It also provides evidence that the currently 50-year period of carbon sequestration on the MPI carbon look-up tables is inadequate considering that indigenous trees like totara, kauri, and rimu had more like 80 years of carbon sequestration, 70 years for puriri, 40 years for beeches, and 30 years for mixed shrub plantings.

Additional to the study focused on native plantation forests, the research completed by the Ministry for the Environment (MFE) during 2002-2007 provided an inventory of carbon stocks stored within New Zealand natural forests (Beets et al, 2009). To summarise the data obtained, carbon storage for 'indigenous forestland' averaged 736 t/ha with most plots ranging from 400 to 1200 tCO2/ha, over 80 years (Kimberley, Bergin, & Beets, 2014).The wide range in distribution of carbon stored in above and below ground forest biomass found in this inventory reflects the diversity in successional stage, stand structure, forest type, and sites that are found in a natural forest (Kimberley, Bergin, & Beets, 2014). Comparably to Kimberley, Bergin, & Beets (2014) study on native plantation forests, the total tonnes of carbon sequestered are far greater than the MPI carbon-look up tables and more aligned with this study.

Similarly, Yarur Thys (2021) found that in measured diverse native restoration sites, carbon sequestration was higher on the MPI look-up tables until year 30. After 30 years the look up tables show a lag in carbon sequestration until age 50 whereas the carbon dioxide equivalent amount of their study showed that by 54 to 59 years the carbon sequestration is far higher. Yarur Thys (2021) measured the carbon sequestration of mixed indigenous woody vegetative restoration sites (podocarps, conifers, angiosperms, and shrubland).

Finally, Burrows & Easdale (2018) agreed that the look up tables were incorrect for the diversity of New Zealand's indigenous woody vegetation, however, they had different reasoning. Their report found that if the look up tables derived carbon sequestration rate (e.g. 6.5t CO2e/ha at 50 years of age) was applied to all indigenous vegetation typically found on sheep and beef farmland in New Zealand that the result would be an over estimation of total sequestered carbon as it would assume that all indigenous woody vegetation was of early regenerating kanuka and manuka rather than forests in a mature state.

Overall, it can be argued that the carbon sequestration measurement tool implemented by ETS policy for native forest owners with under 100ha is mostly inaccurate for any forest land outside of manuka or kanuka forest regeneration. Outside of manuka and kanuka the research shows that the long-term total tonnes of carbon being sequestered, the mean annual incremental carbon sequestered and the period of sequestration, is severely diminished on the MPI look-up tables compared to what is potentially happening on farm. As discussed, typical forest varieties of indigenous woody vegetation that are ETS eligible and found on New Zealand farms expands to additional types than just manuka and kanuka; beech, broadleaved angiosperms, conifers, and other shrubland. Evidentially, having a look-up table that only accommodates a regenerating bi-species scenario means that significant areas of forest and shrubland occurring on farmland are either not captured, poorly calculated, or in some cases, over calculated. Although the MPI look-up tables may provide an immediate model for early stage regenerating or restoration forest land it does not capture a long-term average model for the diverse indigenous woody vegetation found on New Zealand farmland (Case & Ryan, 2020).

4.3 3): ETS policy currently limits the recognition of actual on-farm carbon sequestration occurring within indigenous woody vegetation with its definition of 'forest land definition'.

Currently MPI state that a forest can be registered in the ETS as Post-1989 forest land if it meets their 'forest land definition'.

MPI's 'forest land definition' is a forest that:

- 1: Is at least 1 hectare.
- 2: Has the potential to reach an average canopy width of 30 meters.
- 3: Has the potential to reach a canopy cover of at least 30%.
- 4: Trees must be species that can grow to at least 5 meters in height.
- 5: Was not classed as "forest land" as per above in 1989 or earlier.

An investigation into the carbon sequestration potential of indigenous woody vegetation outside this forest land definition has been undertaken.

MPI will only accept Post-1989 forest land where they assess the submitted area to meet their 'forest land definition'. As a result, farmland in New Zealand that contains areas of indigenous woody vegetation that are commonly found outside of this forest land definition will not be recognised for its carbon sequestration.

Although there are woody vegetative areas smaller than 1ha, carbon sequestration calculations nationwide are calculated on a per hectare basis, therefore it would be unfeasible for this ruling factor to change to maintain stability in calculating sequestration rates.

The 30m average width rule was brought in to rule out the potential for farmer liability with the clearance of Pre-1990 shelter belts of exotics and this cannot change due to liability occurrences.

The 30% canopy cover rule will need to be kept as this provides a system which allows for calculating the diversity in canopy cover associated with varying tree species. This means stems per hectare can vary across forest areas dependant on the tree species present.

The minimum 5m tree height rule, however, could possibly be changed without further carbon accounting implications. This rule reduction will also likely have the greatest effect on capturing the actual carbon sequestration potential on farmland due to the vast areas of low growing woody vegetation occurring.

Lastly, the areas classed as forest land before 1989 (Pre-1990 forest land) are left out of the investigation. Under the Kyoto protocol, New Zealand chose not to account for Pre-1990 emissions during the first commitment period. We can only account for carbon stocks from activities existing after 1990 and from the first period of 2008-2012. If Pre-1990 forest land was to be included, then so would emissions from that period, therefore this is an unchangeable piece of policy for our ETS.

Even if mature forests existing before 1990 could be entered into the ETS, the opportunity for additional carbon sequestration outside of the already stored carbon within these forests is probably insignificant. Shugart (1984) agrees that this is because, on average, at large scales, new growth by existing trees in an old growth forest is approximately matched by mortality of old stems, fallen branches, and deadwood decomposition. There has been a considerable research effort of the last few decades in New Zealand to quantify this net change in carbon sequestration of mature forests, completed by Croome et al (2002) which has been proven to be a difficult process on a large scale. Burrows & Easdale (2018) conclude that in a given situation this carbon balance might be slightly positive or slightly negative depending on many abiotic or biotic variables. This was further substantiated by Paul, Kimberley & Beets (2021) where they similarly agreed by stating that the New Zealand indigenous forestlands are in balance and neither a carbon source nor a carbon sink. The argument to this would be the research presented in **Figure 1** which states that for certain species like totara and kauri they may still be sequestering as Pre-1990 forests due to their extended sequestration period.

Focusing on the possible changeable rule, the minimum 5m tree height rule, the two fundamental categories of indigenous woody vegetation most common on New Zealand farmland that typically do not meet this are regenerating shrubland and planted riparian zones. As stated by Case & Ryan (2020), New Zealand has 340,000 hectares of indigenous shrubland exclusive of manuka and kanuka. This shrubland comprised of smaller woody plant species such as; matagouri (*Discaria toumatou*), *Coprosma* varieties, Ribbonwood (*Plagianthus divaricatus*), small-leaved kowhai (*Sophora microphylla*), grass tree (*Dracophyllum traversii*), mountain celery pine (*Phyllocladus alpinus*), lancewood (*Pseudopanax crassifolius), Hebe* varieties, and leatherwood (*Olearia colensoi*) (Case & Ryan, 2020). Almost all these shrubland species will not meet 5m in height and are therefore excluded from meeting forest land definition, even if they commonly meet all of the other ETS requirements.

Research completed by Kimberley, Bergin, & Beets (2014) studied the carbon sequestration rates of planted native shrubland. Although species were not determined, they noted that the study sites had likely compositions of; manuka, kanuka, *Pittasporum* species*, Coprosma* species, *Hebe* species, *Dodonea viscosa*, and *Psedopanax arboreus*. Aside from kanuka and manuka, all of the remaining shrubland varities will not meet 5m in height in most instances. Their study confirms that due to high stocking densitys in planted shrubland areas there are high levels of carbon sequestration over a short period of time, approximately 30 years. The mean annual increments for their study sites showed a mean annual average of 30 tCO2/ha/yr, or 300 tCO2/ha, over 30 years.

Accompanied to this was the MFE study completed during 2002-2007 which provided an inventory of carbon stocks stored within New Zealand natural shrublands (Beets et al, 2009). Although species were not defined, the average carbon stocks measured across measuring sites equated to 201 tCO2/ha, however, no sequestration period was given (Beets et al, 2009). It is estimated this was over 30 years, as stated by Kimberley, Bergin, & Beets (2014), totalling 10 tCO2/ha 6.7 tCO2/ha/ for 30 years.

A third study of the carbon sequestration potential of indigenous shrubland species under 5m height, developed by Case & Ryan (2020), provides a high level analysis of the potential carbon sequestartion using carbon density estimates.

Table 2 provides a summary of obtained carbon sequestration rates (Case & Ryan, 2020) for indigenous shrubland species typical of New Zealand farmland that will not meet 5m in height. No period of time for the sequestration rates has been given, therefore 30 years has been used as described as the shrubland sequestration period by Kimberley, Bergin, & Beets (2014). **Appendix 2** provides a detailed version of this analysis.

Table 2: Carbon sequestration rates as total and mean average increments for non-ETS eligible indigenous woody vegetation (Case & Ryan, 2020).

Shrubland species	Total C density (t CO2/ha)	MAI (t CO2/ha/yr)	Years of sequestration (yrs)
Matagouri	94.9	3.16	30
Coprosma	124.0	4.13	30
Dracophyllum, mountain celery pine, olearia, *Hebe* scrub	88.2	2.94	30

Table 2 shows that total carbon sequestration rates for common indigenous shrubland species that do not have the potential to meet 5m in height are not insignificant.

Riparian plantings present an opportunity for farmers nationwide to enter the ETS, however, most of these plantings do not meet forest land definition due to area (<1ha), width (<30m), and species (<5m height), even though they can be assumed to be sequestering biomass carbon. One of the largest implementers and providers of education to farmers on riparian plantings, Dairy NZ, recommend planting compositions of flaxes, grasses, sedges, rushes, shrubs, and trees (Dairy NZ, 2022). These are advised for species that can withstand aquatic environments and flooding. The length in permanent waterways located on agricultural and plantation forestry land in New Zealand is 348,000km (Dairgneault, Eppink, & Lee, 2016). At the current high rate of riparian plantings to protect freshwater ways there will also be the co-benefit to capture carbon.

One of the largest literature review studies of the carbon sequestration potential of non-ETS land, conducted by Burrows & Easdale (2018), states that although riparian strips in New Zealand are likely to be sequestering biomass carbon there is limited research to be able to quantify this. Their study estimated a surrogate value of 3.5 t CO/ha/yr, which was derived from mostly gorse, broom, grass, and mixed shrublands.

On critical analysis of the above, current ETS policy does limit the actual levels of carbon sequestration able to be recognised by farmland in New Zealand. In relation to feasibility of this being able to be amended, this is specifically for MPI's 'forest land defintion' policy which limits tree species that cannot grow to 5m in height. Given the high level of regenerating and restoration indigenous woody vegetation that fit into this category, this is likely a significant limitation for recognising actual carbon sequestration potential on farmland. However, it is also confirmed that other factors relating to 'forest land definition' that would be thought of as limiting indigenous forest land would be either unchangeable or value would be lost through changing them (e.g. 1ha in size, 30m width, 30% canopy cover, Pre-1990 forest land).

4.4 Summary Results

Table 3 has been compiled to summarise the carbon sequestration potential of ETS and non-ETS eligible land recognised in this literature review. Measures are summarised as the species or category and its respective total carbon sequestration rate and mean annual increment of carbon sequestration, over the sequestration period.

The purpose of **Table 3** is to compare the existing ETS policy implemented carbon sequestration rates against the more studied carbon sequestration rates of indigenous woody vegetation applicable to New Zealand farmland.

Table 3: Carbon sequestration rates as total and mean average increments and their respective sequestration periods for ETS and non-ETS eligible indigenous woody vegetation; (1: MPI, 2017), (2: Beets et al, 2009), (3: Kimberely, Bergin, & Beets, 2014), (4: Case & Ryan, 2020), and (5: Burrows & Easdale, 2018).

Species/category	Total C (t CO2/ha)	MAI (t CO2/ha/yr)	Years of Sequestration (yrs)
1: Native MPI look-up tables	325.0	6.5	50
2: MAF native natural study	736.0	9.2	80
3: Kauri (plantation)	1,165.0	14.5	80
3: Totara (plantation)	929.0	11.2	80
3: Rimu (plantation)	712.0	8.9	80
3: Puriri (plantation)	631.0	9.0	70
3: Beech (plantation)	670.0	16.75	40
4: Matagouri	94.9	3.16	30
4: Coprosma	124.0	4.13	30
4:*Dracophyllum*, mountain celery pine, olearia, *Hebe* scrub	88.2	2.94	30
5: Riparian proxy	105.0	3.5	30

Table 3 provides a quantitative comparison of the sequestration rates discussed in the literature review; native MPI look-up tables (MPI, 2017), the MAF native natural study (beets et a, 2009), the native plantation study with give tree species (Kimberley, Bergin, & Beets, 2014), the non-ETS eligible shrubland (Case & Ryan, 2020), and the riparian proxy (Burrows & Easdale, 2018).

Figure 3 below provides a further detailed analysis of **Table 3** showing the sequestration rates of each forest type. Using an illustrative perspective, it confirms the high level of variability in the carbon sequestration rates present for New Zealand indigenous woody vegetation given what is known about their rates. Further to this it demonstrates the level of inaccuracy the current ETS policy implements on indigenous forest land.

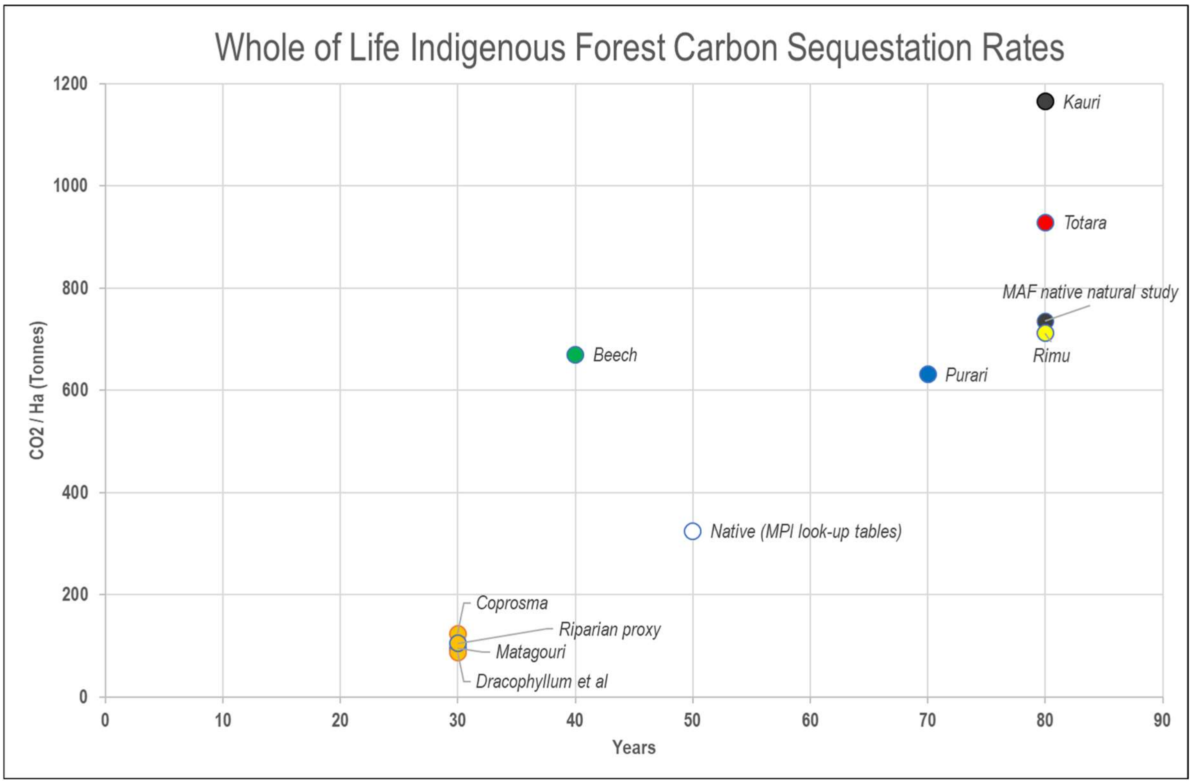

Figure 2: Carbon sequestration rates as total and mean average increments and their respective sequestration periods for ETS and non-ETS eligible indigenous woody vegetation; (1: MPI, 2017), (2: Beets et al, 2009), (3: Kimberley, Bergin, & Beets, 2014), (4: Case & Ryan, 2020), and (5: Burrows & Easdale, 2018).

5 Farm Case Study

A farm case study has been completed to look at the implications of the key outcomes from the literature review, how they relate to the hypothesis and how they will affect a real-life farming scenario in relation to carbon foot printing under intended climate change policy for agriculture.

The carbon footprint has been calculated for the subject farm where it is analysed against three carbon sequestration modelling scenarios:

1): **Current indigenous carbon sequestration rates** - modelled under current ETS policy using MPI carbon look-up tables and forest land definition only (MPI, 2017).

- 2): **Revised indigenous carbon sequestration rates** - modelled with MPI carbon look-up tables and additional carbon sequestration rates obtained by recent studies (Kimberley, Bergin, & Beets, 2014) and forest land definition.
- 3): **<5m non-eligible indigenous vegetation** – modelled with MPI carbon look-up tables, additional carbon sequestration rates obtained by recent studies (Beets et al, 2009) and (Kimberley, Bergin, & Beets, 2014) and with indigenous species below 5m in height (Case & Ryan, 2020).

Scenario 3 is cumulative with scenario 2 as this includes the indigenous forest land species that meet 'forest land definition' and also other recognised forest areas (matagouri and coprosma) that meet all forest land definition aspects except the 5m tree height.

5.1 Farm Background

The property area assessed is Willesden Farm, a 3,361ha property of extensively grazed sheep and beef hill country located on Banks Peninsula, Canterbury. The farm system runs an extensive flock of sheep and cattle consisting of 42,000 stock units and contains significant areas of regenerating and mature indigenous woody vegetation of forestland and shrubland species.

5.2 Gross Carbon Footprint

The Beef and Lamb NZ (B+LNZ) carbon calculator has been used to calculate a baseline farm carbon footprint for the year of 2020-2021 using stock reconciliation data, fertiliser use, and exotic carbon sequestration inputs. Existing Post-1989 *Pinus radiata* forest areas were entered to eliminate these areas from the assessment which focuses only on indigenous.

Table 4 below provides the current (2020-2021) carbon footprint for Willesden.

Table 4: Carbon footprint calculation for Willesden Farm, 2021.

Source	Total CO2e (tCO2/yr)
Livestock emissions	
Dairy cattle	1,957
Beef cattle	5,402
Sheep	7,648
Total	**15,007**
Fertiliser and lime	
Non-urea N	48
Urea with urease inhibitor	223
Total	**271**
Gross Total	**15,278**
Forestry Offsets	
Pinus radiata	1,217
Total	**1,217**
Net Total Carbon Footprint Per Year	**14,061**

As shown in **Table 4**, the gross annual carbon footprint for Willesden Farm is 14,061 tonnes of CO2.

5.3 Indigenous Woody Vegetation

The carbon assessment process has confirmed that there are number of indigenous woody vegetation species present on the property which are occurring as both ETS eligible (Post-1989) and non-ETS eligible forest land as determined by their assessment against MPI's 'forest land definition'.

Ground and drone assessment of indigenous woody vegetation areas existing Post-1989 confirmed there was a diverse range of naturally regenerating forest and shrubland species. Primarily these included kanuka (*Kunzea ericoides*) and totara (*Podocarpus laetus*), but also wineberry *(Aristotelia serrata),* broad-leaved cabbage tree (*Cordyline indivisa),* fuchsia *(Fuchsia excorticata),* whiteywood (*Melicytus ramiflorus),* and ribbonwood *(Plagianthus regius)*. Outside of 'forest land definition' due to not meeting the 5m height threshold were substantial areas of *Coprosma* varieties and matagouri (*Discaria toumatou*).

Figure 3 below provides a delineation of the indigenous woody vegetation areas on Willesden Farm. Pre-1990 mature forest areas have also been included.

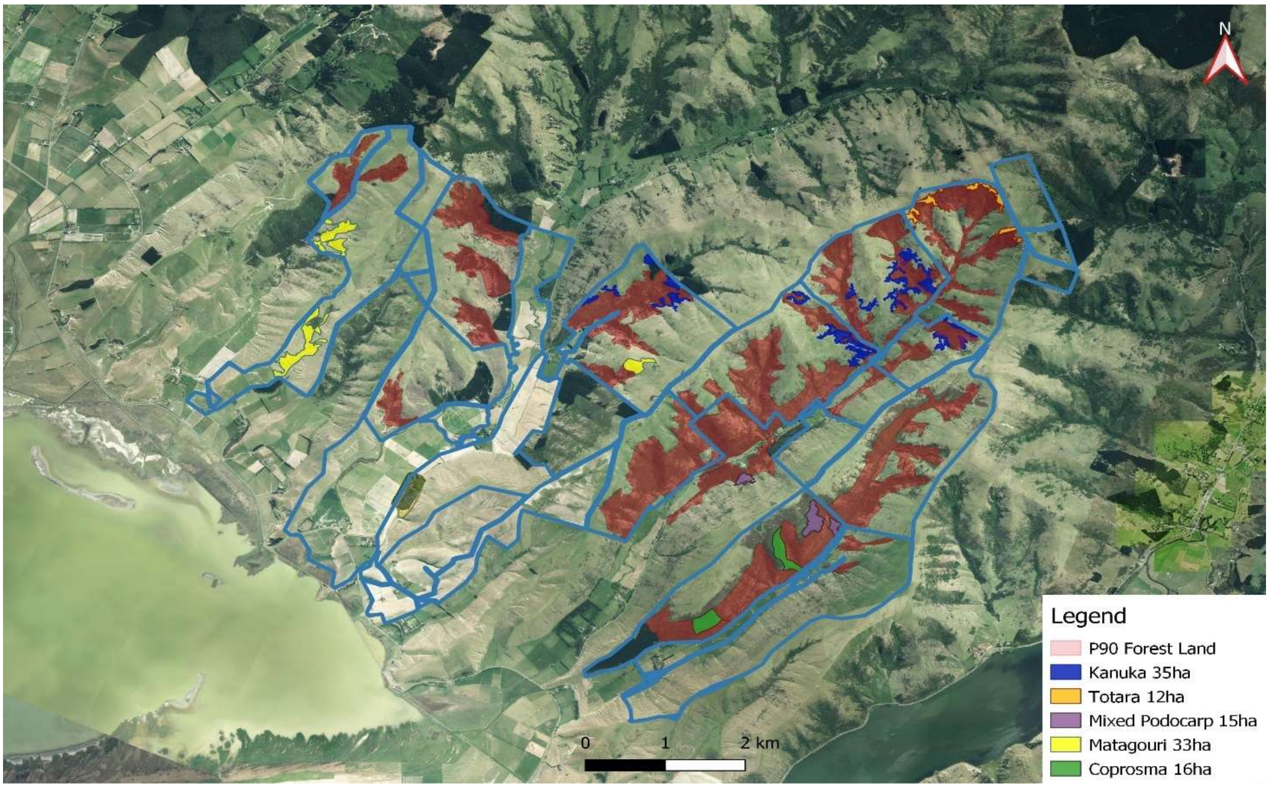

Figure 3: Indigenous woody vegetation species identified for the Willesden Farm, total area size (ha), and locations.

5.4 Carbon Sequestration Potential

Table 5: Carbon sequestration measures for Willesden Farm for each scenario): 1: Current indigenous carbon sequestration rates (MPI, 2017), 2): Revised indigenous carbon sequestration rates (MPI, 2017), (Kimberley, Bergin, & Beets, 2014), 3: <5m non-eligible indigenous vegetation (MPI, 2017) , (Kimberley, Bergin, & Beets, 2014) and (Case & Ryan, 2020).

Scenarios	Forest area (ha)	Sequestration period (yrs)	Remaining sequestration period (yrs)	Sequestration rate C/ha (t CO2/ha)	MAI (t CO2/ha/yr)	Actual Total sequestration (t CO2)	Actual MAI (t CO2/yr)
1): Current indigenous carbon sequestration rates							
Indigenous forest land	62	50	34	325	6.5	13,702	403
Total	**62**	N/A	N/A	N/A	N/A	**13,702**	**403**
2):Revised indigenous carbon sequestration rates							
Totara	12	80	64	929	11	8,602	134
Kanuka	35	50	34	325	6.5	7,735	228
Mixed Podocarp	15	50	34	325	6.5	3,315	98
Total	**62**	N/A	N/A	N/A	N/A	**19,652**	**459**
3):2 + <5m non-eligible indigenous vegetation							
Totara	12	80	64	929	11	8,602	134
Kanuka	35	50	34	325	6.5	7,735	228
Mixed Podocarp	15	50	34	325	6.5	3,315	98
Matagouri	33	30	14	94.9	3.2	1,460	104
Coprosma	16	30	14	124	4.1	925	66
Total	**111**					**22,037**	**630**

Table 5 provides a quantitative overview of each carbon sequestration scenario for Willesden Farm. From left to right, measures were recorded as the forest area identified (ha), the carbon sequestration period (yrs), the remaining sequestration period (yrs) in relation to the current age of the forest, the species or categories carbon sequestration rate per hectare (t CO2/ha), the mean annual increment of carbon sequestration for the species/category (t CO2/ha/yr), the actual tonnes of carbon sequestered by the forest in total (t CO2), and the mean annual increment of carbon sequestration for the species/category over the remaining forest period (t CO2/yr). These were modelled for each forest area at the estimated average age of 16 years as of 2018.

The first scenario (1) modelled the carbon sequestration potential for Willesden Farm recognised under the current ETS policy. This includes all of the indigenous forest land assessed as being Post-1989 forest land and its carbon sequestration totals being calculated using the MPI carbon look-up tables as one forest without species or category variation. A total of 62ha of Post-1989 indigenous forest land was identified. The forest was calculated to sequester 13,702 tonnes of carbon in total for the remaining 34 years, a mean annual average incremental sequestration of 403 tonnes of carbon per year.

The second scenario (2) modelled the carbon sequestration of the same identified Post-1989 indigenous forest land area, however, the total forest area was classified into categories that would align with revised indigenous carbons sequestration data available (Kimberley, Bergin, & Beets, 2014). In this case, 12ha was identified as totara, 25ha was kanuka, and 15ha was of mixed podocarp composition. The totara was modelled with Kimberley, Bergin, & Beets, (2014), the kanuka and mixed regenerating podocarp using the MPI carbon-look up tables. The result was that the same 62ha of Post-1989 forest land sequestered a total of 19,652 tonnes of carbon over the remaining 64 years, a mean annual incremental sequestration rate of 459 tonnes of carbon.

Lastly, the third scenario (3) was modelled using the existing figures of scenario 2, however, indigenous shrublands identified that would not meet 'forest land definition' only due to achieving species that would meet 5m in height, was also modelled. 33ha of matagouri and 16 of *Coprosma* areas were identified. Combining both the indigenous forest land rates from scenario 2 with the non-ETS eligible forest areas identified, a total of 111ha of indigenous woody vegetation was confirmed. This equated to a total on 22,037 tonnes of carbon being sequestered over the remaining 64 years, a mean annual incremental sequestration rate of 630 tonnes of carbon.

Table 6: Net difference of mean annual incremental carbon sequestration of each model for Willesden Farm.

Scenario	Actual MAI (t CO2/yr)	Net Difference of Actual MAI (t CO2/yr)
1): Current indigenous carbon sequestration rates	403	-
2):Revised indigenous carbon sequestration rates	459	+56
3):2 + <5m non-eligible indigenous vegetation	630	+227

Table 6 demonstrates that if scenario 2 were able to be applied to the existing ETS policy (1), then the mean annual carbon sequestration would increase by 56 tonnes of carbon annually. If a step further were taken and tree species under 5m were allowed to enter the ETS that still met the

remaining forest land definition rules, then a further 227 tonnes of mean annual carbon would be recognised for its sequestration on farm.

5.5 Net Carbon Footprint

The current primary sector climate action partnership, He Waka Eke Noa (HWEN), is a Government and industry partnership formed to equip farmers to measure, manage and reduce on-farm agricultural greenhouse gas emissions and adapt to climate change. Initiated in 2020, the five-year program has an end goal that all farms will have a written plan in place to measure and manage their greenhouse gas emissions. HWEN have confirmed two methods for managing the carbon liability by 2025; carbon liability at the farm gate, or at the processor levy. If measured at the farm gate, the Government has indicated they would allocate 95% of the carbon units to offset farming individual footprints, therefore the farmer would be liable for 5% of the total annual carbon footprint. If either of these approaches are not up taken, then agriculture will enter the ETS under the backstop approach where it will be liable for its entire carbon footprint annually.

This report will summarise the outlook for Willesden Farm on the carbon liability at the farm gate as recommended by HWEN.

Table 7 reports each scenario against the potential carbon liability policy recommended by HWEN.

Table 7: Net carbon footprint following carbon offsetting using each scenario when applied to intended HWEN policy options at the farm gate for Willesden Farm.

Scenario	Actual MAI (t CO2/yr)	HWEN 5% Carbon Liability at Farmgate (tCO2/yr) Before Offsetting	HWEN 5% Carbon Liability at Farmgate (tCO2/yr) After Offsetting
1): Current indigenous carbon sequestration rates	403	703.2	**-300.2**
2):Revised indigenous carbon sequestration rates	459	703.2	**-244.2**
3):2 + Non-ETS eligible indigenous vegetation	630	703.2	**-73.2**

Table 7 provides the result of how much carbon is being sequestered from indigenous woody vegetation under each scenario and how this affects the potential carbon liability policy that has been proposed by HWEN. Scenario 1 would mean Willesden would be required to pay for 300.2 tonnes of carbon per year after offsetting, and scenario 2, 244.2 tonnes of carbon per year, and Scenario 3 meant Willesden would only be liable for 73.2 tonnes of carbon each year.

6 Findings and Discussion

This research project has provided an analysis on better understanding the carbon sequestration opportunity of indigenous woody vegetation on farmland in New Zealand. By critically analysing literature on the topic, further high-level carbon sequestration data was able to be confirmed and applied to typical indigenous woody vegetative scenarios at the farm level, allowing a more accurate calculation method of carbon foot printing at the farm level. The key findings of this report are summarised below.

The results confirmed that the initial scope of opportunity for carbon sequestration of indigenous woody vegetation on New Zealand farmland is high due to quantity of area. Out of the 10,000,000-hectare estate for sheep and beef farmland in New Zealand, approximately 2,000,000 hectares of it is indigenous woody vegetation, equating to a total of 20% of the area. Out of this 20% of vegetative area, 8.2% comprised of indigenous forest, 5.5% as manuka/kanuka, 3.3% exotic forests, and 1.7% indigenous shrubland (Case & Ryan, 2020).

Secondly, the analysis supports the theory that the carbon sequestration potential of indigenous woody vegetation is largely understudied. This was particularly evident in the lack of research completed on the carbon sequestration potential of indigenous forest and shrubland that is typical of New Zealand farmland; naturally regenerating and restorative forest and shrubland of mixed species compositions. There were a small number of studies completed on mono-cultural planted indigenous forest land species, such as totara, kauri, rimu, puriri, and beech, as well as kanuka and manuka (MPI, 2017), (Bergin et al, 2021), (Trotter et al's, 2005), (Kimberley, Bergin, & Beets (2014), and (Beets et al, 2009). Indigenous shrubland in a naturally regenerating scenario was largely understudied, with only one study demonstrating average sequestration rates that were not species specific (Beets et al, 2009). Burrows & Easdale (2018) in their comprehensive literature review of non-ETS compliant land, state that there are no known quantitative data sets for carbon sequestration for planted riparian strips in New Zealand, with the only data for riparian shrublands being dominated by mostly gorse, broom, grass, and mixed shrublands. Additionally, when compared to the carbon sequestration expectation of the IPCC, it appears developing New Zealand studies have lacked three of the five fundamental elements for forest carbon modelling, being dead wood, litter, and soil organic matter (Nabuurs's, 2007).

Thirdly, the study suggests a correlation of evidence that current ETS policy does not provide measures for landowners to accurately model the carbon sequestration of indigenous woody vegetation typically found on farm. This is specifically for landowners wanting to enter forest land under 100ha which under current ETS policy they must use the MPI carbon look-up tables to calculate. Conclusively, it can be argued that overall, the carbon sequestration measurement tool implemented by ETS policy for native forest owners with under 100ha is mostly inaccurate for any forest land outside of manuka or kanuka forest regeneration. In most instances, research shows that the long-term total tonnes of carbon being sequestered, the mean annual incremental carbon sequestered and the period of sequestration, is diminished on the look-up tables compared to what is potentially happening on farm (Yarur Thys,2021), (Kimberley, Bergin, & Beets, 2014), (Carver & Kerr, 2017), (Burrows & Easdale, 2018) and (Bergin et al, 2021). Although the look-up tables may provide an immediate model for early stage regenerating or restoration forest land it does not capture a long-term average model for the diverse indigenous woody vegetation found on New Zealand farmland (Case & Ryan, 2020).

Fourthly, the results further indicate that current ETS policy limits the recognition of actual on-farm carbon sequestration occurring within indigenous woody vegetation due to its definition of forest land. It has been noted that feasibly, the only factor in 'forest land definition' that might be changed would be the requirement to have trees that can reach 5m in height. Given the high level of regenerating and restoration indigenous woody vegetation that fit into this category, this is a serious limitation for the reconition of actual carbon sequestration rates occuring on farmland that could be capitalised on (e.g. matagouri and *Coprosma* varities that are typical).

The last key finding was the outcome of applying these theories to the farm case study. The case study modelling produced quantitative results that evidentially suggest the current ETS policy and carbon measurement stratergy for indigenous forest land is inaccurate. Additionally, when the carbon sequestration figures were applied to the potential HWEN policy implemented on farmers by 2025, the outcome when considering the key research theories was that the farm case study would have a significantly greater chance at achieving carbon neutrality. This would provide a more accurate model of actual carbon sequestation when modelling a farms carbon footprint verses the current ETS policy implemented.

This report hypothesis states that due to the lack of research on carbon sequestration for indigenous vegetation on New Zealand farmland and the existing policy to enter forestry into the ETS, there are currently significant and subjective limitations to accurately modelling agricultural carbon footprints at the farm level. In line with the hypothesis, this study confirms that, fundamentally, there are limitations in how New Zealand farmers can be recognised for the carbon sequestration of indigenous woody vegetation. This is particularly due to the lack of proficient research in the carbon sequestration rates of vegetation typical of farmland and the recognition ability implemented by the ETS's 'forest land definition'. However, it has become evident there is a reason for the lack of research on indigenous scenarios, and that is the shear complexity of making measured assessments on the ever-changing nature of forest stands, particularly in mixed species stands.

The deficiency in the carbon sequestration rates within the MPI look-up tables was expected, however, seeing confirmed measures of significantly higher sequestration rates over a long period of time of some of the larger indigenous species was a surprise. This could also be said for the sequestration rates of indigenous vegetation typically found on farm within the species and varieties that grew less that 5m in height, such as matagouri and *Coprosma*. Once transposed into a quantitative analysis within the farm case study it was evident that there is a diminished ability for farmers to be able to accurately model their carbon footprints if they have indigenous woody vegetation growing on farm under current policy.

Overall, the results agree with emerging studies that indigenous forest and shrubland requires further research to provide more accurate carbon sequestration rate models.

There are several limitations that are present throughout the report with regards to the findings and results. Firstly, modeling the carbon sequestration potential of indigenous forest land in New Zealand is incredibly difficult in relation to comparing it against the botanical diversity and an ever-changing environment common in New Zealand. With regards to the farm case study, the carbon revised sequestration rates used were average figures that were in some cases applied to areas of mixed forest species composition (e.g. mixed podocarps). Additionally, modelling of matagouri and *Coprosma* in the farm case study were based off **Appendix 2**, however, the sources of these figures beyond the paper they were published in (Case & Ryan, 2020) was unknown. The sequestration period was also unknown.

Second to this, the MPI carbon look-up tables state that the calculation of carbon in the stems, branches, leaves, and roots, and in the coarse woody debris and fine litter on the forest floor (MPI 2017) whereas the other studies cited only included above and below ground carbon. The scale as to which this has affected sequestration rates is unknown, however, is likely to be relatively insignificant.

Another limitation was the outcome of the farm case study when applying the third forest scenario which took the total forest area to 111ha. This would mean this scenario under current ETS policy would require an FMA approach, however, this remains uncertain. Perhaps if indigenous woody vegetation below 5m height were to be brought in to the ETS it would have its own category. Although not discussed in the research, the FMA approach is a very time consuming and expensive process, approximately double the price for measurement of indigenous compared to exotic plantation forestry (Carver & Kerr, 2017). Therefore, establishing an approach that is look-up tables based and more accurate than the current would be a desired outcome for landowners.

7 Recommendations

As a result of the findings in this research the following actions are recommended.

- Agriculture industry to prioritise extensive, nationwide research on understanding the carbon sequestration rates of indigenous woody vegetation, particularly of mixed species composition indigenous regeneration and restoration forest and shrubland on farmland.

- Agriculture industry to use this research to develop a robust model of indigenous carbon look-up tables that captures the common categories of woody vegetation on farmland. It may be that this is species specific for the large, more studied conifers, but it should also accommodate mixed species forest and shrubland scenarios typical of indigenous regenerating and restoration on farmland. This should also include a category for key indigenous scenarios growing below 5m in height, such as matagouri, *Coprosma, Hebe,* and riparian plantings. The current MPI look-up tables should be kept and used for calculating the sequestration of manuka and kanuka only.

- MPI's ETS policy of 'forest land definition' should be changed to allow indigenous forest and shrubland species less than 5m in height to be included. This may be that it is provided as a special case to the agriculture industry only.

- Once robust carbon look-up tables have been developed, MPI's ETS policy which states that forests equal to or over 100ha should have its threshold area increased (e.g. to 500ha) before FMA is required, or one step further, have FMA as optional.

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9 Appendix

Appendix 1: MPI carbon look-up tables for Post-1989 forest land (MPI, 2017).

Table 2: Carbon stock per hectare for Douglas-fir, exotic softwoods, exotic hardwoods and indigenous forest (expressed as tonnes of carbon dioxide per hectare)

Age (yrs)	Douglas-fir	Exotic softwoods	Exotic hardwoods	Indigenous forest
0	0	0	0	0
1	0.1	0.2	0.1	0.6
2	0.1	1	3	1.2
3	0.4	3	13	2.5
4	1	12	34	4.6
5	2	26	63	7.8
6	4	45	98	12.1
7	7	63	137	17.5
8	20	77	176	24.0
9	33	87	214	31.6
10	50	95	251	40.2
11	69	106	286	49.8
12	90	118	320	60.3
13	113	132	351	71.5
14	138	147	381	83.3
15	165	163	409	95.5
16	193	180	435	108.1
17	222	197	459	120.8
18	253	214	483	133.6
19	268	232	505	146.3
20	286	249	526	158.7
21	307	266	546	170.9
22	331	283	565	182.6
23	355	299	584	193.9
24	382	315	601	204.7
25	409	330	618	215.0
26	436	344	633	224.6
27	445	359	648	233.7
28	468	373	661	242.2
29	493	387	674	250.1
30	518	400	685	257.5
31	545	414	696	264.3
32	572	427	706	270.6
33	597	440	714	276.3
34	625	452	722	281.6
35	650	465	729	286.5
36	679	477		290.9
37	704	489		295.0
38	730	501		298.7
39	730	512		302.0
40	751	524		305.1
41	772	536		307.8
42	794	547		310.4
43	815	559		312.6
44	836	570		314.7
45	857	582		316.5
46	878	593		318.2
47	898	605		319.7
48	918	617		321.1
49	938	629		322.3
50	957	641		323.4

Appendix 2: Relative areas of carbon density (tCha-1) for mapped indigenous woody vegetation (Case & Ryan, 2020).

Table A1. Relative areas and carbon density (tC ha^{-1}) estimates (±SD) for mapped indigenous (in grey) and exotic vegetation types on sheep and beef farmland. Where LUCAS plots spatially-coincided with an indigenous vegetation type, a mean above ground live biomass value was computed for that type from plot data; where there were no plots associated with a vegetation type, a mean carbon density value (±SD) was computed using data for the broader ecosystem type (e.g., CDF) and applied to that type. For LCDB-derived vegetation types (except for subalpine shrubland), carbon stock density values were taken from the published literature.

Vegetation type	Sheep and beef area (ha)	Mean C density (t ha-1)	SD C density (t ha-1)	No. LUCAS plots
MF7, Tawa, kamahi, podocarp forest	158,918	117.2	99.9	89
WF13, Tawa, kohekohe, rewarewa, hinau, podocarp forest	80,368	93.2	59.5	34
CDF3, Mountain beech forest	72,212	92.4	49.4	17
WF11, Kauri, podocarp, broadleaved forest	69,118	66.8	76.3	34
LCDB Sub Alpine Shrubland	60,684	48.6	61.1	30
MF21, Tawa, kamahi, rimu, northern rata, black beech forest	51,135	108.2	64.2	9
CLF10, Red beech, silver beech forest	39,072	228.2	129.9	101
CLF9, Red beech, podocarp forest	37,623	194.8	166.5	47
MF8, Kamahi, broadleaved, podocarp forest	28,990	205.5	207.5	26
WF3, Tawa, titoki, podocarp forest	25,088	150.3	63.4	0
WF14, Kamahi, tawa, podocarp, hard beech forest	23,468	119.0	90.2	9
MF22, Tawa, rimu, northern rata, beech forest	22,254	152.4	80.8	12
CLF3, Podocarp, ribbonwood, kowhai forest	20,793	157.1	72.1	1
MF3, Matai, totara, kahikatea, broadleaved forest	18,640	20.7	24.6	1.5
CLF11, Silver beech forest	16,179	199.5	101.5	11
MF1, Totara, titoki forest	15,231	137.8	92.9	0
MF2, Rimu, matai, hinau forest	15,187	79.8	137.2	6
WF9, Taraire, tawa, podocarp forest	14,350	45.2	25.7	5
MF5, Black beech forest	13,796	27.9	92.9	1
MF16, Rimu forest	13,491	224.9	108.4	2
TI2, Kanuka, Olearia scrub/treeland	10,969	124.0	124.1	0
WF12, Kauri, podocarp, broadleaved beech forest	8,270	36.5	40.2	2
MF20, Hard beech forest	7,837	178.9	144.4	22
CDF7, Mountain beech, silver beech, montane podocarp forest	6,776	109.0	74.3	4
MF17, Rimu, kamahi, tawheowheo forest	6,493	150.5	118.0	3
MF11, Rimu forest	5,795	163.9	51.4	3
CLF12, Silver beech, mountain beech forest	4,871	180.1	54.0	10
VS6, Matagouri, Coprosma propinqua, kōwhai scrub [Grey scrub]	4,734	94.9	0.8	0
VS3, Manuka, kanuka scrub	4,571	95.7	0.8	0
WF4, Pohutukawa, puriri, broadleaved forest [Coastal broadleaved forest]	4,171	4.2	5.9	2
WF7, Puriri forest	4,155	88.7	14.1	0
CDF4, Hall's totara, pahautea,kamahi forest	3,632	110.8	71.4	17
MF12, Rata, hard beech, kamahi forest	3,609	52.1	32.2	3
WF8, Kahikatea, pukatea forest	2,968	88.7	14.1	0

Appendix 2 continued.

MF10, Totara, matai, kahikatea forest	2,772	391.3	92.9	3
WF2, Totara, matai, ribbonwood forest	2,280	88.7	63.4	0
CLF7, Rimu, kamahi, beech forest	2,039	176.7	124.1	0
TI4, Coprosma, Olearia scrub [Grey scrub]	1,985	124.0	124.1	0
CDF2, Dracophyllum, mountain celery pine, Olearia, Hebe scrub [Subalpine scrub]	1,963	88.2	84.8	0
CDF6, Olearia, Pseudopanax, Dracophyllum scrub [Subalpine scrub]	1,304	40.8	42.3	11
WF17, Northern rata, mahoe, nikau forest	1,274	88.7	63.4	0
VS2, Kanuka scrub/forest	1,211	94.9	0.8	0
MF6, Kohekohe, tawa forest	1,173	115.0	92.9	1
CLF1, Hall's totara, mountain celery pine, broadleaf forest	1,172	176.7	124.1	0
WF1, Titoki, ngaio forest	1,099	88.7	90.3	0
MF13, Kahikatea, northern rata, kamahi forest	1,015	137.8	92.9	0
CLF5, Matai, Hall's totara, kamahi forest	981	17.4	124.1	1
MF24, Rimu, towai forest	771	79.3	51.0	2
TI1, Bog pine, mountain celery pine scrub/forest	767	124.0	124.1	0
CLF4, Kahikatea, totara, matai forest	683	176.7	124.1	1
CL3, Coprosma, Muehlenbeckia shrubland/herbfield/rockland	602	124.0	124.1	0
MF4, Kahikatea forest	569	137.8	92.9	0
CDF1, Pahautea, Hall's totara, mountain celery pine, broadleaf forest	440	88.2	84.8	0
MF14, Kahikatea, silver pine, kamahi forest	358	137.8	92.9	0
WF5, Totara, kanuka, broadleaved forest [Dune forest]	343	88.7	63.4	0
CL1, Pohutukawa treeland/flaxland/rockland	260	124.0	124.1	0
WF15, Matai, totara, northern rata, titoki forest	130	88.7	63.4	0
MF25, Kauri, towai, rata, montane podocarp forest	102	137.8	110.4	0
CLF8, Silver beech, kamahi, southern rata forest	69	259.6	124.1	1
WF10, Kauri forest	69	194.4	63.4	2
CL2, Ngaio,taupata treeland/herbfield/rockland	56	124.0	124.1	0
WF16, Matai, northern rata, broadleaved forest	55	88.7	63.4	0
WF6, Totara, matai, broadleaved forest [Dune Forest]	50	88.7	81.2	0
VS5, Broadleaved species scrub/forest	15	94.1	0.8	0
TI3, Monoao scrub/lichenfield	12	124.0	124.1	0
TI5, Bog pine, mountain celery pine, silver pine scrub/forest	12	124.0	124.1	0
MF18-2, Silver pine, mountain beech, pink pine low forest	4	137.8	92.9	0
UM2, Conifer, beech, manuka forest/scrub, rockland	0	223.3	5.1	2
LCDB - Manuka and/or Kanuka	556,530	69.0	32.7	
LCDB - Exotic Forest	310,088	98.1	47.1	
LCDB - Gorse and/or Broom	103,994	14.9	3.3	
LCDB - Matagouri or Grey Scrub	86,992	13.0	0.7	
LCDB Sub Alpine Shrubland	60,684	61.1	48.6	30
LCDB - Mixed Exotic Shrubland	34,980		19.1	
LCDB - Deciduous Hardwoods	34,679	160.0	19.4	
Overall mean/total area (ha)	2,089,030	120.6		

Appendix 3: B + L Willesden carbon footprint and greenhouse gas calculation for the year ending 2021.

Greenhouse Gas Emissions Calculation for Willesden Farm

Farm emissions			Kilograms of greenhouse gases		
Source		kg CO_2-e	kg of CO_2	kg of CH_4	kg of N_2O
Livestock emissions	Dairy cattle (incl. grazing dairy)	1,957,514		60,618	1,483
	Beef cattle	5,402,804		167,309	4,094
	Sheep	7,648,471		261,938	3,691
	Deer	0		0	0
Fertiliser and lime use	Non-urea nitrogen fertiliser	48,330			162
	Urea without urease inhibitor	0	0		0
	Urea with urease inhibitor	223,583	73,333		504
	Limestone	0	0		
	Dolomite	0	0		
	Total kg	15,280,702	73,333	489,866	9,935
	Tonnes CO_2-e		Tonnes of greenhouse gases		
	CO_2	73	Tonnes of CO_2	Tonnes of CH_4	Tonnes of N_2O
	CH_4 (tonnes CH_4 x 25)	12,247	73	490	10
	N_2O (tonnes N_2O x 298)	2,961			
	Tonnes (A)	15,281			
	Tonnes / total ha	2.83			

Appendix 3 continued.

Deforestation emissions		
Source		kg CO_2-e
Exotic forest	Harvest and deforestation	0
Indigenous forest	Natural forest deforestation	0
Shrubland	Mature shrubland loss	0
	Total kg	0
	Tonnes (B)	0

Vegetation offsets		
Source		kg CO_2-e
Exotic forest	Growth (p.a. for 28 years)	1,217,052
Indigenous forest	Regenerating natural forest (p.a. for 100+ years) and tall natural forest	0
Shrubland	All shrubland	0
	Total kg	1,217,052
	Tonnes (C)	1,217

Estimated net CO_2 emissions (t CO_2-e)* = A + B - C	14,064
Estimated net CO_2 emissions / hectare (t CO_2-e)*	3

* Global Warning Potentials (GWPs) used are those from the IPCC, 2007, Fourth Assessment Report.