A Comparison Study Examining the Impacts of Carbon Forestry Integration Within New Zealand Sheep and Beef Farms Upon Economic and Environmental Performance

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Abstract

In the face of a changing climate, New Zealand has committed to reducing its greenhouse gas emissions. Emissions from New Zealand pastoral agriculture form a large proportion of the nation's total greenhouse gas emissions, and therefore, significant reductions must be made by this sector. Carbon forestry has been identified by multiple groups as a means of achieving these reductions from pastoral farmland. However, without adequate information regarding the economic and environmental impacts of integrating carbon forestry into sheep and beef farms, it is likely that adoption rates by farmers will be low.

Therefore, this study is a comparison study that evaluates two sheep and beef case study farms within the Hawke's Bay Region to compare and contrast the impacts of integrating carbon forestry onto marginal pastoral land. Several modelling software systems were used to model base scenarios for each farm, with mitigation scenarios incorporating carbon forestry then modelled to report changes in economic and environmental performance of the case study farms.

It was found that the economic and environmental impacts of carbon forestry integration are dependent upon the relative performance of the pastoral farming enterprise and type of carbon forestry undertaken on marginal pastoral land. Factors such as physical productivity, pastoral management practices, forestry management practices, and size of area of afforestation were some of the determining factors.

Whilst the environmental impacts of carbon forestry integration do vary depending on several factors, and between farms, it can be concluded from this research that integration of carbon forestry will reduce gross greenhouse gas emissions (9.0% to 66.1%) and net greenhouse gas emissions (51.4% to 322.5%), as well as nitrogen root zone loss (9.4% to 56.0%) and phosphorus root zone loss (8.6% to 51.7%), from sheep and beef farms when integrated upon marginal pastoral land. However, the economic impacts of carbon forestry are far more subject to farm heterogeneity, and therefore, to understand the impacts of carbon forestry integration upon economic performance an in-depth analysis of the property needs to be undertaken.

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Abbreviations

CAA	Carbon accounting area
CH_4	Methane
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent
DBH	Diameter at breast height
DCF	Discounted cash flow
DM	Dry matter
DMI	Dry matter intake
ETS	Emissions Trading Scheme
FTE	Full-time equivalent
GDP	Gross domestic product
H_2O	Water vapour
Ha	Hectares
LMU	Land management unit
LUC	Land use capability
MAI	Mean annual increment
masl	metres above sea level
ME	Metabolisable energy
N	Nitrogen
N_2O	Nitrous oxide
NO_3^-	Nitrate
NPV	Net present value
NSA	Net stocked area
NZU	New Zealand Unit
P	Phosphorus
PPA	Potentially plantable area
QGIS	Quantum Geographic Information System
Selection ratio	Ratio of planted trees to final crop trees
sph	Stems per ha
SU	Stock unit

Key Definitions

Afforestation Integration Level	The categorical level of integration in terms of area of carbon forestry within the case study (preferred, total, permanent)
Afforestation Scenario	A specific afforestation type integrated at a specific level within the case farm
Afforestation Type	The carbon forestry species adopted, accounting for the regime adopted
Discounted Cash Flow	A method that is used to assess the value of an investment by considering future revenue and expenditure of the investment
Farm/farmed Ha	Including all land that is used for pastoral production within the property boundary of a farm
Farmlet	Farmax equivalent of an LMU
Full-time Equivalent	A unit indicating an employed person's workload. One full-time equivalent is equal to one full-time employee
Internal Rate of Return	The discount rate that will result in an NPV of zero
Land Management Unit	Areas of similar natural resources and productive capacity
Management Block	Overseer equivalent of an LMU
Marginal Pastoral Land	Land that has been classified as LUC Class VI, VII, or VIII.
Net Present Value	The sum of all revenue minus the sum of all expenditure over a specified investment period for an investment, discounted at an appropriate rate
Net Stocked Area	The area of land upon which the desired forest species in planted
Potentially Plantable Area	Includes the NSA of desired forest species, roads, skid sites, and unplantable areas such as boundary, waterway and powerline buffers, and other non-plantable areas
Stock Unit	A method of estimating livestock numbers for varying species and age classes based on feed demands
Total ha	Including all land within the property boundary of a farm

Chapter One: Introduction

Background

Issues of a Changing Climate

The natural greenhouse effect, which is partly caused by greenhouse gases absorbing infrared light, is the process responsible for the warming of both the earth's lower atmosphere and surface (Le Treut, et al., 2007; Pinares-Patino, et al., 2009). Solar radiation passes through the earth's atmosphere largely unimpeded and is absorbed by the earth's surface (Anderson, et al., 2016), although, some of the incoming solar radiation is reflected by clouds and the earth's surface (Le Treut, et al., 2007). The warmed earth's surface emits infrared heat radiation at long wavelengths, as opposed to the short-wavelength solar radiation, and is intercepted by greenhouse gases (Anderson, et al., 2016; Snyder, et al., 2009). The greenhouse gases absorb and redirect infra-red light, some of it back towards earth, which causes further warming of the earth's lower atmosphere and surface (Snyder, et al. 2009). Evidence of this correlation was reported by Trenberth et al. (2007) and Pachauri et al. (2014), who stated that higher concentrations of greenhouse gases in the atmosphere coincided with an increase in global mean surface temperature of 0.85°C from 1880 to 2012.

Therefore, the earth's temperature is linked to the amount of greenhouse gases in the atmosphere, with water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) being the most abundant greenhouse gases (Latake, et al., 2015). Atmospheric concentrations of greenhouse gases, notably; CH_4, CO_2, and N_2O, have increased since the pre-industrial era (Pachauri, et al., 2014; Reay & Grace, 2007). It is stated by Hirsch et al. (2006), Denman et al. (2007), Le Treut et al. (2007), and Latake et al. (2015) that these increases are strongly attributed to human activities, which include the burning of fossil fuels, increased agricultural production, and destruction of forests.

There are numerous flow-on effects from increased global temperatures, which are a result of higher concentrations of greenhouse gases in the earth's atmosphere. Bindoff et al. (2007) and Pachauri et al. (2014) both indicate there has been an increased uptake of CO_2 by the ocean, which has caused increases in ocean temperature and acidity, as well as rises in mean global sea level. The increase in global sea level, due to both thermal expansion of water and melting of ice sheets and glaciers (Latake, et al., 2015), will force the migration of human, animal and plant species alike, thereby disrupting biological and economic systems (Bindoff, et al., 2007; Hennessy, et al., 2007; Pachauri, et al., 2014). Furthermore, increased global temperatures are thought to cause changes in precipitation patterns and increase the frequency and intensity of climatic extremes (Hennessy, et al., 2007) and increase ocean acidification, which will limit the ocean's function as a carbon sink (Reay & Grace, 2007). Increased temperatures will also allow diseases that are currently limited to tropical areas to spread (Pachauri, et al., 2014).

As evidenced above, greenhouse gas concentrations in the earth's lower atmosphere have been shown, and are predicted, to have a significant impact upon many of the earth's climatic and ecological cycles. Equations applied by Anderson et al. (2016) show that a doubling of CO_2 concentrations in the earth's atmosphere would cause an increase in temperature of approximately 1.6 °C. Pachauri et al. (2014) predict that the global average surface temperature is likely to be 1.5 to 2.0 °C warmer by the end of the 21st century. Therefore, it is in the best interests of the global community to address the issue of increasing greenhouse gas concentrations within the earth's atmosphere.

Steps Taken to Address Greenhouse Gas Emissions

To address the issue of a changing climate, the New Zealand government signed the Kyoto Protocol (Trotter, et al., 2005), which is an international agreement that has set emissions reduction targets and limitations for Annex 1 countries (Ford-Roberston, et al., 1999; Kirschbaum, et al., 2012). The government also signed the Paris Agreement, which has the goal of limiting the increase in global temperature to between 1.5 to 2 °C above pre-industrial levels (Ministry for the Environment [MFE], 2019) by committing countries to their own national greenhouse gas reduction plans. These plans set out countries' strategies for addressing climate change, with reductions in greenhouse gas emissions being central to the strategies (Fernandez & Daigneault, 2016; Rogelj, et al., 2016). To meet the goals of international agreements, an emissions trading scheme (ETS) was established by the New Zealand Government and encompassed all those greenhouse gases identified within the Kyoto Protocol (Manley & Maclaren, 2012). To further address the issue of climate change, the current government has enacted The Climate Change Response (Zero Carbon) Amendment Bill, which stipulates how New Zealand will transition to a low-emissions economy (MFE, 2019). The Amendment Bill sets out several key targets for achieving the transition. Firstly, the reduction of all greenhouse gases, with the exception of biological methane, to net zero by 2050, and secondly, the reduction of biological methane to between 24 to 47% of 2017 levels by the year 2050, which includes an intermediary target reduction to 10% below 2017 levels (MFE, 2019).

Leining and Kerr (2018) state that the ETS was designed as an instrument that can be used to send price signals to consumers, producers, and investors to facilitate the reduction in greenhouse gas emissions. Emitters of greenhouse gases are liable to surrender emissions units for each tonne of emissions they emit. The theory is that producers who must purchase and surrender emissions units will pass the cost onto consumers, making high-emissions goods more expensive relative to low-emissions goods, and therefore, changing consumer, producer, and investor behaviour toward seeking low emissions production and consumption. This is vital for reducing New Zealand's gross emissions. Conversely, greenhouse gases can be sequestered, for which an emissions unit will be received for every tonne sequestered. This has the effect of reducing New Zealand's net emissions as greenhouse gases that are sequestered offset greenhouse gases that are emitted.

Agriculture in the Context of New Zealand's Emissions Profile

New Zealand's greenhouse gas emissions profile is unique to most other countries in the OECD due to the fact that agriculture contributes 48% of total emissions (MFE, 2021; Reisinger, et al., 2017), and therefore, New Zealand's strategy for reducing greenhouse gas emissions will rely heavily upon reducing emissions from this sector. Currently, the agriculture sector is responsible only for reporting biological emissions and is not liable to pay for them (Leining & Kerr, 2018). This is likely to change soon, as proposals are being made to include the agriculture sector within the ETS, making it accountable for its emissions (MFE, 2019). However, pastoral agriculture systems, particularly sheep and beef farms, are at a disadvantage when it comes to reducing on-farm emissions, with only modest reductions available through improved farm performance and altered farm management practices (Biological Emissions Reference Group, 2018; MFE, 2020; Reisinger, et al., 2017).

Utilising Land Use Change to Reduce Net Emissions

Land use change from pastoral agriculture to forestry has been identified as a mitigation strategy available to sheep and beef farmers that will allow them to make significant reductions in their emissions (Biological Emissions Reference Group, 2018; Reisinger, et al., 2017). Forests reduce greenhouse gas emissions by sequestering carbon whilst they grow by combining CO_2 from the atmosphere with H_2O and nutrients from the soil to form cellulose during the photosynthesis process (Adams & Turner, 2012). A change of land use from sheep and beef land to forestry has a low abatement cost compared to other options (MFE, 2020), so the

New Zealand Government intends to meet nearly half of its emissions targets by afforestation and reforestation (Trotter, et al., 2005). Not only is forestry a cost-effective tool for sequestering carbon and thereby reducing net emissions (Van Kooten, 2000), but it will also reduce gross emissions of CH_4 and N_2O (Ausseil & Dymond, 2010; Kirschbaum, et al., 2012), from New Zealand's single largest emitting sector. Plantinga and Wu (2003) state that other benefits of afforestation include increased stability of erosion-prone land, reduced nutrient loading in waterways, as well as increased provision of natural habitats.

Since the election of the current Labour Government, the price of a single New Zealand Unit (NZU), the unit of trade within the ETS, has risen from NZD $17.05 to NZD $44.95 on the spot market as at 6th July 2021 (OMF, 2021). An increase in the price of NZUs has a significant impact on the profitability of forestry (Manley & Maclaren, 2012) and will cause an increase in the economic feasibility of carbon forestry (Trotter, et al., 2005). The increased carbon price, coupled with the environmental benefits, makes carbon forestry an attractive alternative land use in New Zealand.

Importance of Agriculture and a Balanced Land Use

As outlined thus far, reducing greenhouse gas emissions to limit the modelled effects of climate change is important and must be addressed. However, the contribution of the sheep and beef sector, relative to the contribution of carbon forestry, to the New Zealand economy must be given consideration.

Exports of meat and wool were expected to reach NZD $10.2 billion in the year ending June 2020, contributing 21.9% of total agricultural exports, a 0.3% increase from the previous year (Ministry for Primary Industries [MPI], 2020). In the prior year, 2019, the agriculture sector contributed NZD $9.37 billion to the New Zealand economy, which was 4.05% of New Zealand's total gross domestic product (GDP) (Statistics New Zealand, 2019a). Furthermore, the sheep and beef sector alone employs a total of 20,600 people on farm (excluding downstream employment generated), which is 24.12% of all people employed in the agriculture sector, and 0.90% of New Zealand's labour force (Statistics New Zealand, 2019b). Not only is the sheep and beef sector a significant contributor to the New Zealand economy currently, but it is forecast that global demand for protein will increase by 57% from 2005 to 2050 (Kim, et al., 2019) due to factors such as population growth (Verge, et al., 2007), rising incomes, and urbanisation (Henchion, et al., 2017). Numerous strategies will have to be implemented to meet the growing demand, and animal protein will be one of the important avenues for meeting this demand, on account of the already established supply chains, existing consumer familiarity (Henchion, et al., 2019), and also because of agriculture’s entrenchment in society (Carter & Perry, 1987).

Two recent studies have been conducted to assess the economic benefits and relative productivity of forestry and sheep and beef farming. Fogan and Pollard (2020) utilised a multiplier analysis to estimate changes in GDP and employment resulting from within-sector expenditure, purchases made by that sector from other sectors, and income expenditure of the aforementioned sectors within the wider economy. Fogan and Pollard (2020) also used as a net present value (NPV) analysis (which is the sum of all revenue minus the sum of all expenditure over a specified investment period for an investment, discounted at an appropriate rate) to compare returns from forestry to returns from sheep and beef farming. In contrast, a second study comprised a case study analysis of the Wairoa District (Harrison & Bruce, 2019). Of three modelled scenarios being; sheep and beef farms integrated with plantation forestry, sheep and beef farms integrated with permanent carbon forestry, and sheep and beef farms with no forestry integration, Fogan and Pollard (2020) concluded that sheep and beef farms integrated with plantation forestry had the highest annual value-add, and highest annual total economic impact per 1,000 ha. More specific to one geographic area, the study conducted by Harrison and Bruce (2019) concluded that in the Wairoa District, sheep and beef farms generated 7.4 jobs per annum per 1,000 ha within the locality. This was compared with production forestry (harvest and carbon), which generated 5.1 jobs per annum per 1,000 ha, and carbon forestry (no harvest), which generated 0.6 jobs per annum per 1,000 ha (Harrison & Bruce, 2019).

Both studies highlighted a key difference between forestry and sheep and beef farming, being that annual returns are derived from sheep and beef farming and only periodic returns are derived from forestry (Fogan & Pollard, 2020; Harrison & Bruce, 2019). Therefore, without the consistency of employment and direct local expenditure between harvest years that sheep and beef farming provides, the wider economy will suffer as support businesses won’t have regular income and will likely cease to trade. The effects felt upon the economy will be even greater if only large-scale carbon forestry is adopted, as the economic benefits of carbon forestry are completely attributed to capital (Fogan & Pollard, 2020), with nearly no employment benefits created (Fogan & Pollard, 2020; Harrison & Bruce, 2019). Therefore, striking a balanced land use between the lower-profitability sheep and beef farming that provides annual returns, and the higher-returning forestry will benefit the economy in terms of GDP and employment.

Need for Awareness of Carbon Forestry Benefits

Most sheep, beef, and dairy farmers believe that the New Zealand agriculture sector should reduce its emissions (Biological Emissions Reference Group, 2018). However, Evison (2008) and Stewart et al. (2011) state that if farmers are unaware of the benefits of carbon forestry, or they lack confidence in their ability to implement mitigation options (Niles, et al., 2016), then adoption of climate mitigation strategies can be low. Furthermore, farmers are unlikely to implement a policy if they cannot see how it will help them achieve their economic, social, or environmental goals (Dominati, et al., 2019; Samarasinghe, et al., 2012). Therefore, for there to be successful integration of carbon forestry into New Zealand sheep and beef hill country farms, farmers need to be provided with evidence that it will benefit their system as a whole (Taylor & Harnett, 2020).

Problem Statement

The New Zealand government has committed to reducing the country's greenhouse gas emissions in accordance with intergovernmental agreements and is relying heavily upon a change in land use from sheep and beef pastoral agriculture to carbon forestry to meet its commitments. The high price of NZUs and environmental benefits of carbon forestry mean that it is a desirable alternative land use on some sheep and beef hill country. However, the sheep and beef industry is a vital economic and social component of New Zealand, so careful integration of forestry must be achieved to preserve the industry. The extent to which carbon forestry will be integrated into farming systems is dependent upon farmers' knowledge of greenhouse gas emissions, carbon forestry, and carbon forestry's economic and environmental benefits. Therefore, this comparative case study analysis aims to examine the economic and environmental impacts of carbon forestry integration on marginal land into sheep and beef farms in New Zealand.

Research Aim

The aim of this research is to examine the economic and environmental impacts of carbon forestry integration into sheep and beef farms in New Zealand on marginal pastoral land.

Research Question

What impact does the integration of carbon forestry on marginal pastoral land within New Zealand sheep and beef farms have on the economic and environmental performance of the overall farm business?

Research objectives

The secondary objectives of this research are outlined below:

1) Calculate the quantum of marginal pastoral land within each case study farm and investigate how farm heterogeneity impacts the quantum.
2) Model the economic and environmental performance of the pastoral farming base scenarios of the case study farms.
3) Estimate and compare the environmental benefits of carbon afforestation types.
4) Estimate and compare the economic feasibility of carbon afforestation types.
5) Compare the profitability of the carbon afforestation types against returns from pastoral farming on marginal pastoral land.
6) Demonstrate how farm heterogeneity alters the economic and environmental impacts of carbon forestry integration.
7) Investigate pursuing carbon neutrality of each case study farm with varying afforestation types.

Dissertation outline

Chapter one is the introduction to the research. This chapter has outlined the need for the research and has also set out the objectives of this research. Chapter two is the literature review. This chapter contains a review of literature of multiple topics, including marginal pastoral land, carbon forestry, economic comparison of sheep and beef farming to carbon forestry, and environmental benefits of carbon forestry. The impacts of carbon forestry integration, as well as the methodology used to assess these parameters, are also discussed in this chapter. Chapter three sets out the methods, materials, and assumptions adopted to undertake this research. Chapter four contains the results of the pastoral farming scenarios for both case studies. Economic and environmental performance of varying afforestation types are then presented. Lastly, the results of the economic and environmental impacts of integrating carbon forestry into New Zealand sheep and beef farms are presented. Chapter five is the discussion. In this chapter, the results presented in Chapter Four are discussed. Chapter six is the conclusion. In this final chapter, the conclusions of the research are outlined, with limitations and recommendations for further research discussed.

Chapter Two: Literature Review

Introduction

Carbon forestry can provide both economic and environmental benefits, particularly when established on marginal pastoral land. This review of literature will discuss what carbon forestry is, as well as several common types of carbon forestry found within New Zealand that are to be investigated within this research. Also to be discussed is the definition of marginal pastoral land and how farm heterogeneity influences the quantum of marginal pastoral land within different properties. The economic and environmental benefits of carbon forestry will be discussed, followed by a review of literature that examines the benefits of carbon forestry integration into New Zealand sheep and beef farms. Lastly, a review of methods used in existing research to investigate the economic and environmental benefits of carbon forestry integration will be conducted.

Marginal Pastoral Land

New Zealand has a total land mass equating to 26.8 million ha that is comprised of flat, hill, and mountainous landforms. Approximately 20% of New Zealand's surface resides above 1,000 metres above sea level (masl), and 40% is classified as steep land that resides below 1,000 masl, which is not suitable for arable production (Blaschke, et al., 1992). The rock types of New Zealand are predominantly of sedimentary origin and comprise sandstones and mudstones: the mountain ranges are predominantly greywacke, and the central plateau in the North Island is layered in thick ask (Wilkinson, 1999). New Zealand's rock types mean that natural erosion rates are typically high throughout the country (Wilkinson, 1999).

As outlined by Lynn et al. (2009), New Zealand's land has been classified into eight classes, each reflecting a varying degree of pasture productivity, known as Land Use Capability (LUC), with the higher the LUC number, the lower the general suitability for long-term sustainable production. This assessment is based on five physical factors: rock type, soil, slope angle, erosion type and severity, and vegetation cover. There are several further sub-classifications relating to the predominant limitation of that LUC, which are classified into erosion susceptibility, soil wetness, physical and chemical properties of soil, and climatic conditions. LUC Classes I to IV are the most versatile of the classes, being suited to the widest range of land uses, including cropping, viticulture, and horticulture, as well as pastoral farming and forestry. For these classes, contour ranges from flat (LUC Class I) to strongly rolling (LUC Class IV). LUC I is typically the least common class, being restricted to areas of deep, well-drained soils, whereas the other three classes are more common, with LUC Classes III and IV being found extensively throughout New Zealand. LUC Classes V to VII are not suitable for arable cropping like LUC Classes I to IV. However, they are suited to pastoral farming and forestry. LUC V is still high-productivity land but is physically constrained for arable use. Contour typically ranges from moderately steep slopes (LUC Class V) to very steep slopes (LUC Classes VI and VII). These classes are widely distributed throughout New Zealand and are most commonly physically limited by erosion susceptibility. LUC Class VIII has severe limitations that render is largely unsuitable for any means of production and largely comprises of mountainous land.

The LUC classification of land is based on physical, chemical and climatic constraints of land, as opposed to the economic viability of the enterprises that can be undertaken on the land (Lynn, et al., 2009). However, it is a logical assumption that land with significant limitations for pasture production would also be economically less productive. This assumption was demonstrated in a catchment analysis study, which found that within the catchment the lowest per ha economic returns were generated by LUC Class VI and VII land, and their removal from the productive area increased overall economic performance (Quinn, et al., 2007).

Van Kooten and Cornelis (2000) investigated afforestation of marginal pastoral land in Canada with poplars as a method of reducing CO_2 emissions. In determining what pastoral land should be defined as ‘marginal’, they proposed that the value of the land under its current agricultural activity should be considered. It was found that as the value of the agricultural activity increased, the quantum of marginal pastoral land decreased. Therefore, it can be stated that Van Kooten and Cornelis (2000) defined what land was ‘marginal’ based on the economic returns able to be derived from it. Other definitions of marginal pastoral land have been provided by Trotter et al. (2005), who defined it as land that is “environmentally marginal for long-term agriculture” (p. 866) and that also has “an erosion risk rating of medium to extreme under pastoral farming” (p. 867). Furthermore, Reisinger et al. (2017) define marginal land as the “less productive pasture areas” (p. 47).

The definition of marginal pastoral land is key to providing context to this research. Within this research document, marginal pastoral land will be defined as “land that has been classified as LUC Class VI, VII, or VIII.” These three classes have been chosen to define marginal apastoral land as they all have moderate to severe physical limitations for pasture production, with LUC Classes I to V being suited to pasture production with none to slight limitations (Lynn, et al., 2009). The adoption of this definition also allows for an objective assessment of the quantum of marginal pastoral land within each case study farm, as existing datasets can be used to identify LUC Class VI, VII, and VII land.

Heterogeneity of Sheep and Beef Farms in New Zealand

New Zealand has a cool, subtropical climate. Coupled with a wide range in altitude, slope, latitudinal band, and complex geological processes, New Zealand's hill country is invariably diverse in its physical characteristics (McIvor, Hedderley, et al., 2011).

According to Basher et al. (2000), the North Island of New Zealand has a total land area of 6.3 million ha, with 45% of this comprising soft rock terrain that is located to the south-east and west of the island. The central plateau makes up a further 23% of the North Island, comprising volcanic ash with loess-mantled contour. Hard rock hill country is situated on the periphery of the North Island's axial ranges and constitutes 14.5% of the island's land mass. In contrast, the hill country that has been formed on strongly weathered igneous and sedimentary rocks is found in Northland and the Coromandel Peninsula and makes up 13.6% of the island's land mass. As a result of the North Island's formation upon soft rock, it is at much higher risk of erosion than the South Island, which is formed predominantly on hard rock.

Heterogeneity in New Zealand's landform is highlighted further by the LUC system. Lynn et al. (2009) state that not only are there variations within both the North and South Islands in the quantum of land within each classification, but there are also variations between the islands. Approximately 6.6 million ha (24.9%) of New Zealand is classified as highly productive land suitable for arable cropping, with 48.6% residing in the North Island. There are a further 13.3 million ha (50.3%) classified as suitable for pastoral agriculture, with 51.9% of this area situated in the North Island. Lastly, there are 5.8 million ha (21.8 %) of land that is not suitable for either agricultural or forestry production, with a vast majority of 82.5% of this being situated in the South Island.

From 1840 to 1970 there was a significant influx of European settlers into New Zealand, and subsequently, large areas of land were cleared for grazing and settled during this period (MacLeod & Moller, 2006). Although further settlement occurred from this initial period through to the early 20th century, land settlement was markedly increased for a short period of time after both World Wars through legislation to provide farms for returned servicemen (Ward, 1961). It was not until 1969 that the first edition of the 'Land Use Capability Survey Handbook: A New Zealand handbook for the classification of land' was published (Lynn, et al., 2009), with the definition of 'marginal pastoral land' within this research being based upon the classification system in the handbook. As the LUC Classification system was first published after the vast majority of land settlement in New Zealand had occurred, no consideration could have been given to the quantum of marginal pastoral land, as defined by this research, within each sheep and beef property. Therefore, it is likely that farms will be heterogenous is nature, regarding the quantum of marginal pastoral land, as the tool used for classifying marginal pastoral land used within this research document was not in existence during early settlement. Changes in land ownership after original settlement are also likely to have given rise to heterogeneity among farms in terms of the quantum of marginal pastoral land. As many farms consist of more than one parcel of land, one or more parcels contained within a farm can be easily sold whilst still maintaining the balance farm (Moran, 1997). Therefore, if any consideration had been given to the quantum of marginal pastoral land within each farm at the time of original settlement, the on sale of certain parcels of the farm would cause a shift in this quantum.

Environmental Issues Caused by Pastoral Agriculture in Hill Country

The arrival of Māori and then European settlers saw significant areas of indigenous forests cleared for agricultural and horticultural production (Blaschke, et al., 1992; Douglas, Wall, et al., 2013), with indigenous vegetation once covering the majority of land that is now farmed in New Zealand (Norton, et al., 2020). Prior to settlement by Europeans, the majority of New Zealand (66%) was covered in forest and scrublands (Wilkinson, 1999). Recent studies conclude that New Zealand has lost nearly 75% of its indigenous vegetation (Ewers, et al., 2006), as well as over 90% of its wetlands (Ausseil, et al., 2011). Land clearance for agricultural production has been a large factor in deforestation of indigenous vegetation, but ironically, sheep and beef farms now account for a significant proportion of remaining indigenous cover, retaining 2.8 million ha (or 25%) of total indigenous cover (Norton & Pannell, 2018). Therefore, one of the largest offending sectors for contribution to indigenous vegetation clearance, now plays a key role in its preservation. A dominant trend in agricultural systems globally is to intensively farm the most productive land, resulting in a highly modified landscape, which is undesirable as a range of landscapes are required to support different species (Austin & Smith, 1989). Therefore, to ensure heterogeneity, indigenous cover should be maintained on a range of landscapes, from low to high productivity (Fischer, et al., 2006). However, more recent indigenous cover clearance has come to include more marginal pastoral land, primarily for the growing of exotic forestry. From 1996/97 to 2001/02 exotic plantation forestry was a significant cause of indigenous cover clearance in New Zealand (Walker, et al., 2006).

Deforestation of Indigenous Vegetation

The conversion of indigenous forests to grassland by Māori and Europeans exposed the highly erodible soils of New Zealand's hill country, and exacerbated by poor management practices and high intensity rainfall events, the rate of erosion of hill soils increased rapidly (Wilkinson, 1999). Subsequently, the grazing of livestock has caused significant landscape management issues (Blaschke, et al., 1992). Erosion is an issue predominantly because it reduces soil productivity and degrades water quality (Basher, et al., 2008). Furthermore, erosion can cause significant financial losses, which are particularly severe during rainstorm events such as the 2011 event that struck Hawke's Bay. McIvor et al. (2015) surveyed 60 farmers who were impacted by the storm and found that over half of the farms lost more than 400 head of livestock at an average total cost of $495,000 to the farming business. In addition to these losses were costs associated with destocking (average cost per farm of $94,600), recovery costs (ranging from $20,100 to $64,000 per farm), and damage to farm infrastructure from slippage, silt, forest debris, and water (average cost per farm of $84,250) (McIvor, et al., 2015). Long-term productivity losses from erosion have been estimated at 0.2% per annum (Trustrum & Hawley, 1986), which could cause pastoral hill country farming to become uneconomic within several generations.

Biodiversity Loss as a Result of Deforestation

Inextricably linked to deforestation is loss of biodiversity. Agriculture has indirectly caused a significant reduction in New Zealand's biodiversity through deforestation, with an estimated 14 million ha (71%) of indigenous forest having been cleared (Ewers, et al., 2006). Extensive deforestation has significantly reduced biodiversity of New Zealand's forests (Gardner, et al., 2009) and been a major factor in the extinction of approximately 40% of New Zealand's land bird species in the post-colonialization era (Atkinson, 1989). Brown's study examining extinction of indigenous fauna (as cited in Dominati et al., 2019), reported that over 70 species have become extinct. In addition to this, Brown (as cited in Dominati et al., 2019) also states that a significant portion of bird species and plant species, as well a large majority of indigenous lizard and freshwater fish species, are either threatened or near extinction. There is a perception that highly modified and depleted ecosystems are not important to ensure biodiversity, however, most of New Zealand's threatened species of flora and fauna exist only in these environments (Walker, et al., 2006). Therefore, the preservation of these highly modified and depleted ecosystems, along with pristine environments, is crucial in ensuring continued biodiversity (Walker, et al., 2006).

Nutrient Loss from Pastoral Agriculture

The introduction and continuation of pastoral agriculture in New Zealand has resulted in increased concentrations of nitrogen (N) and phosphorus (P) in waterways (Dodd, et al., 2016). Evidence of this relationship was discussed by Quinn and Stroud (2002), who found that within hill-land catchments in the Waikato Region, streams found within agriculture systems had higher concentrations of both nutrients and sediment, as well as poorer water visual clarity than streams that flowed through native forest. When in their dissolved inorganic forms, N and P, encourage growth of periphyton and macrophytes in waterways (Davies-Colley & Wilcock, 2004), as they are immediately available for uptake. Excessive amounts of N and P in waterways can cause increased plant and algal growth that can reduce fish populations, reduce human enjoyment of waterways, and also create health risks in animals and humans (Cameron, et al., 2013; Davies-Colley & Wilcock, 2004).

In the New Zealand context, N is predominantly added to soils under pastoral farming systems through biological fixation by legumes, with small contributions also made from the application of nitrogenous fertiliser (Ball, 1969). In pastoral farming systems the main source of Nitrate (NO_3^-) leaching is from livestock urine patches, especially those deposited during grazing events that occur over the period from summer through to early winter (Di & Cameron, 2002). The high concentrations of N in these urine patches can result in surplus NO_3^- still residing in the soil when the drainage season commences, which results in leaching from the root zone and eventually into groundwater and waterways (Betteridge, et al., 2017; Cameron, et al., 2013; Dominati, et al., 2019).

P is largely introduced to New Zealand soils via fertiliser applications (Parfitt, Baisden, et al., 2008) and rock weathering (Lenton, 2001). Enrichment of waterways with P can occur through direct applications fertiliser and manure (McDowell, et al., 2005). However, the majority of P enrichment is from sediment that is lost from land through surface runoff (Gillingham & Thorrold, 2000; McDowell, et al., 2001). Sediment loss is considered to be the main environmental issue realted to hill country (Dodd, et al., 2016), espceically in the North Island as soils are formed on soft rock types (Basher, et al., 2008). P losses are strongly linked with sediment loss (Parfitt, Dymond, et al., 2008) because P is mostly held in top soils and does not easily leach. Therefore, given the high rates of sediment loss from hill country, the accompanying P losses are of concern (Dodd, et al., 2016). Losses of P to waterways are greater when soil concentrations of P are higher (McDowell, et al., 2001). Therefore, pastoral areas with higher historic phosphate fertiliser use and/or stocking rates tend to leach greater quantities of P. Higher concentrations are often the result of untargeted applications of fertiliser with high P percentages that have been applied to increase pasture growth (Craighead, 2004).

Greenhouse Gas Emissions from Pastoral Agriculture

As previously discussed within this document, greenhouse gas concentrations in the earth's lower atmosphere have been shown, and are predicted, to have a significant impact upon many of the earth's climatic and ecological cycles. Furthermore, New Zealand's greenhouse gas emissions profile is unique to most other countries in the OECD because agriculture contributes 48% of total emissions (MFE, 2021; Reisinger, et al., 2017). Therefore, New Zealand's strategy for reducing greenhouse gas emissions will rely heavily upon reducing emissions from this sector.

Land use change from indigenous vegetation to pastoral agriculture has been a significant historic source of anthropogenic CO_2 emissions (Johnson, et al., 2007). However, with significant deforestation of New Zealand's native vegetation already having occurred, CO_2 emissions related to agricultural production nowadays are insignificant (Reisinger, et al., 2017), and are primarily sourced from off-farm processes. As a result, the majority of New Zealand agriculture's' contribution to total greenhouse gas emissions in terms of carbon dioxide equivalent (CO_2-e) now comes from biological CH_4 and N_2O gases (Reisinger, et al., 2017). There are additional, smaller, contributions from CO_2 as well (Johnson, et al., 2007).

Biological CH_4 emissions from agriculture originate from methanogenic bacteria that live in anaerobic soils and in the rumen of sheep and cattle, with the main source of CH_4 emissions from within agriculture systems being enteric fermentation and manure management (Johnson, et al., 2007). Therefore, changes to agricultural systems in the form of reduced stock numbers (Reisinger, et al., 2017) and changing feed types (Journeaux, et al., 2020) result in lower biological CH_4 emissions. The majority of N_2O emissions arise from microbial processes in soils, being nitrification (aerobic oxidation of ammonia to nitrate) and denitrification (anaerobic conversion of nitrate to N_2 gas) (Monteny, et al., 2006). Nitrogenous fertiliser is the predominant driver of increased N_2O emissions (Johnson, et al., 2007; Monteny, et al., 2006) from agricultural systems, so mitigation strategies that reduce the reliance upon nitrogenous fertilisers will cause a decrease in biological N_2O emissions. Nowadays, CO_2 emissions are primarily related to the consumption of fossil fuels during transport of livestock, chemicals and fertilisers, as well as the production of chemicals, fertilisers and other equipment (Houghton, et al., 1983). Therefore, greater reductions in total greenhouse gas emissions from agricultural systems can be achieved by focusing on reducing biological CH_4 and N_2O emissions (Journeaux, et al., 2020; Reisinger, et al., 2017). Reductions in CO_2 emissions tend to be a by-product of mitigation strategies aiming to reduce CH_4 and N_2O emissions.

Intensification of Pastoral Land

In New Zealand, the historic unsuitability of some land uses to the land type they were undertaken on, coupled with little regard given to the impacts of pastoral farming upon surrounding environments, has created numerous environmental issues that now need rectifying (Dominati, et al., 2019). Subsequent intensification of agricultural land through increased inputs, irrigation, and smaller-sized paddocks (MacLeod & Moller, 2006) has had wide-reaching negative impacts on water quality, including decreased stream flow, heavier nutrient loading of waterways and water bodies, as well as eutrophication of wetlands (Foote, et al., 2015). Inorganic fertilisers have replaced organic manures as a means of increasing the intensity of agricultural land (Chalmers, et al., 1990). However, inorganic fertilisers are applied to the soil in a more heavily concentrated manner, and subsequently, cause pollution of streams (van Roon & Knight, 2004). Some New Zealand soils have a limited ability to retain N and P, and environments that receive pollutants from production landscapes have the same limited ability to absorb these nutrients (Dominati, et al., 2019). This was demonstrated by Power et al. (2002), who concluded that the intensification of sheep and beef land, either through higher stocking density supported by increased fertiliser inputs, or through optimising pasture utilisation, lead to higher rates of N leaching from farms by up to 44% in one of the modelled catchments. Higher stocking densities also cause increases in biological CH_4 emissions from enteric fermentation (Reisinger, et al., 2017: Journeaux, et al., 2020), and increased application of nitrogenous fertilisers has led to increases in N_2O emissions (Gregorich, et al., 2005).

From the outlined literature, it can be seen that the introduction of pastoral farming to the New Zealand landscape, coupled with the subsequent and ongoing intensification of farming practices, has had wide-reaching impacts on New Zealand's environmental landscapes and its indigenous flora and fauna. Of particular interest to this research are N and P losses to groundwater and waterways, as well as greenhouse gas emissions to air.

Carbon Forestry

Carbon forestry has been defined by Funk (2009) as "any land use in which landowners receive economic benefits from carbon sequestration" (p. 14). This definition allows for the consideration of multiple revenue streams from carbon forestry, and these additional revenue streams, when bundled together, increase the overall economic benefits of carbon forestry. Mitchell et al. (2012) also have a very similar definition to the aforementioned study and provide the following as examples of carbon forestry activities: plantations established for wood production, permanent carbon 'sinks', biodiversity plantings, and plantings established to produce biomass for energy and fuel production. Therefore, by summarising definitions from available literature, it can generally be said that for a land use activity to be defined as 'carbon forestry', or for that activity to be described as the process of 'carbon farming', said activity must be able to generate income through CO_2 sequestration. The primary purpose of the land use does not have to be CO_2 sequestration for generating revenue (Mitchell, et al., 2012), but the ability to generate revenue through CO_2 sequestration is a requirement for the land use activity to be defined as carbon forestry.

In order for land to be capable of generating income through CO_2 sequestration in New Zealand, the land must be classified as Post-1989 eligible within the ETS, the trees species established upon that land must be deemed to be a forest species, and the afforested area must also meet the definition of a forest as specified in New Zealand Legislation (Climate Change Response Act 2002). The definitions of Post-1989 eligible land and forest land are summarised as follows:

> Post-1989 forest land means forest land that –
>
> i. was not forest land on 31 December 1989
> ii. land that was forest land on 31 December 1989 but was deforested in the period beginning on 1 January 1990 and ending on 31 December 2007 (Section Four, Climate Change Response Act 2002).

Forest land is defined as:

i. an area of land of at least one ha that has, or is likely to have, tree crown cover from forest species of more than 30% in each ha; but
ii. does not include a shelter belt of forest species, where the tree crown cover has, or is likely to have, an average width of less than 30 metres (Section Four, Climate Change Response Act 2002).

Moreover, a forest species “means a tree species capable of reaching at least 5 metres in height at maturity in the place where it is located but does not include tree species grown or managed primarily for the production of fruit or nut crops” (Section Four, Climate Change Response Act 2002).

The criteria set out by New Zealand Legislation means that not all land, not all tree species, and not all afforested areas are able to generate income directly related to CO_2 sequestration. As the creation of economic benefits though CO_2 sequestration is central to the definition of carbon forestry, it is critical that these criteria are met when assessing alternative land use options to pastoral farming.

The following sections will discuss traditional Pinus radiata plantation, space-planted poplars, and Mānuka/conifer-broadleaved native forests as to their relevance to New Zealand sheep and beef farms as carbon forests.

Traditional Pinus Radiata Plantation Forestry

Pinus radiata is a conifer tree that is native to coastal California and was introduced to New Zealand in the mid-1800s (Will, 1978). By the mid-1870s, widespread plantings of Pinus radiata in New Zealand for woodlots and shelterbelts were evidenced (Mead, 2013). Since the early introduction of Pinus radiata to New Zealand, plantings of it have become widespread throughout the country, with Pinus radiata now being the planted species within 90% of all plantation forests, which equates to a total of 1.53 million ha (MPI, 2019). The preference of Pinus radiata over other tree species for plantation purposes in New Zealand is because of the species’ many favourable characteristics.

Maclaran (1993) states that the timber properties of Pinus radiata make it suitable for a wide range of uses, which increases the species’ desirability to foresters. Being a softwood, Pinus radiata is made up of long fibres, is lightweight, and is straight-grained (Shmulsky & Jones, 2011). Pinus radiata typically matures around age 30, forming a medium density wood (Bayne, 2015) that comprises 20% heartwood and 80% sapwood (Maclaran, 1993), with the sapwood being only slightly less durable than the heartwood (Mead, 2013). The timber milled from Pinus radiata trees is generally free from defects, has a good strength-to-weight ratio, and good workability (Maclaran, 1993). On account of the above attributes, New Zealand-grown Pinus radiata is able to be used for structural timber in buildings, plywood and composite board, and even pulp for paper and cardboard production (Maclaran, 1993). Therefore, the majority of the tree is utilisable.

Pinus radiata is a fast-growing tree, exhibiting a mean annual increment (MAI) growth rate in New Zealand of 25 m^3/ha/year (MPI, 2016), which is very high compared to, for example, the slower growing, later maturing native Rimu forests situated in South Westland that have a measured MAI of between 1.45 to 3.43 m^3/ha/year (Franklin, 1972). The slow growth of native trees, coupled with increasing demand for, and decreasing supply of, timber due to land clearing for agricultural purposes, paved the way for the planting of a faster growing tree species (Mead, 2013). The comparably fast growth rate of Pinus radiata means that it is more successful at sequestering large amounts of CO_2 in a short time, as compared to the slower-growing native species. As per the default Look-up table for Pinus radiata in the Hawke's Bay/Southern North Island Region, the average annual sequestration of CO_2 by Pinus radiata over a 50-year period is 26.4 t CO_2/ha/year and peaks at 38 t CO_2/ha/year in year 17, compared to indigenous forest, which averages annual sequestration of 6.3 t CO_2/ha/year, and peaks at 12.8 t CO_2/ha/year in year 18 (MPI, 2017).

The ability for Pinus radiata to adapt to a variety of differing sites has also encouraged its widespread adoption by plantation foresters (Watt, et al., 2008). Historically, Pinus radiata has been established within New Zealand on poor sites deemed unsuitable for agricultural production (Will, 1978). However, for optimal growth, Pinus radiata should be established in localities with a temperate climate and relatively dry summers (Mead, 2013). Table 1 outlines the optimal growing conditions for Pinus radiata, along with minimum and maximum extremes the species can tolerate and still grow.

Table 1: Growing Conditions for Pinus Radiata in New Zealand

Condition	Min.	Max.	Optimal
Annual Rainfall (mm)	500	1,000	600 - 750
Temperature (°C)	- 10	30	12 - 15
Altitude (masl)	0	1,000	200

Note. Adapted from Mead. 2013.

Whilst Pinus radiata has been recorded growing outside the optimal ranges specified within Table 1, productivity is lower than when grown within optimal conditions. Although sub-optimal, Pinus radiata is also able to grow on sites with low fertility and poor drainage characteristics (Will, 1978).

Pinus radiata trees are typically established at 600 to 1,000 stems per ha (sph) and are thinned to a final crop stocking of between 300 to 350 sph (Mead, 2013). In an un-pruned forest, there is typically a thinning event between ages 10 to 12 years old to the final crop stocking. Conversely, in a pruned forest, there are typically three pruning events up to heights of 2.6m, 4.2m and a final height of 6.4m at five, eight and ten years of age, respectively. Two thinning events then occur between age eight to ten years old and 12 to 14 years old (Mead, 2013; West, 1996). Trees are pruned to maximise the volume of recoverable knot-free wood, and to minimise the defect core (West, 1996), which is advantageous as timber that is knot-free and has a small defect core is more valuable because it is stronger (Shmulsky & Jones, 2011). Whereas, thinning is undertaken to increase the growth rates of the remaining trees, whether they be pruned or un-pruned (Shmulsky & Jones, 2011; West, 1996).

Recent statistics suggest that only 47% of Pinus radiata tree crop in New Zealand has been, or is intended to be, pruned, which is a continuance of the recent trend to leave Pinus radiata trees unpruned (Forest Owners Association, 2019). This trend has resulted from a smaller price differential between pruned and unpruned logs (Forest Owners Association, 2019), and increasing cost of pruning, which is incurred early in the investment period (M. Morice, personal communication, October 8, 2020). These two factors combined have meant that it is becoming less economically advantageous to prune. Furthermore, as NZU prices increase, the desire to grow bigger trees that sequester more CO_2 becomes more of an influencing factor upon silviculture practices. The pruning of trees reduces their growth for a short period (West, 1996), so is not desirable where volume maximisation is the main objective.

Poplar agroforestry

Poplars are a deciduous hardwood tree species that grow in temperate climates (Ball, et al., 2005). They were introduced to New Zealand in the 1840s and were extensively planted throughout the country in the 1960s and 1970s with government funding (Wilkinson, 1999), and have traditionally been used in pastoral systems as a way of controlling erosion on hill country (Douglas, et al., 2001).

The space planting of poplars allows for the growth of trees in the presence of grazing animals (McIvor, Douglas, et al., 2011); does not significantly reduce pasture growth; reduces the risk and extent of erosion (Schwarz, et al., 2016; Wilkinson, 1999); provides fodder, shelter and shade; produces timber, and sequesters CO_2 (Ball, et al., 2005). Therefore, poplars are a suitable tree species for afforestation in circumstances where permanent retirement of land from pastoral agriculture is not desired. This form of afforestation is known as agroforestry, which is a term commonly used to describe trees that are planted with wide spacing (Douglas, Wall, et al., 2013) on the same land that is used for pastoral production and can be for either economic or environmental purposes (Nature, et al., 1995). Given the desire for farmers to continue farming their land, agroforestry will play a key role in sustainable management of hill country in New Zealand (Blaschke, et al., 1992).

As per the definition of a carbon forest, space-planted poplars must be able to generate revenue through CO_2 sequestration, meaning in New Zealand plantings must be able to be registered within the ETS. However, upon land that is to be planted with poplars, there is also the requirement of soil conservation through reduced erosion, and continued livestock grazing.

For the space-planted poplars to be defined as a forest within the ETS, the following criteria must be met:

i. plantings must be at least one ha in size; and
ii. plantings must have a tree crown cover of forest species of more than 30% in each ha; and
iii. plantings need to have an average width of tree crown cover of at least 30 m (Section Four, Climate Change Response Act 2002).

Another consideration is that the ETS mapping standard allows for a 15 m gap between tree canopy edges (MPI, 2018a), which in a traditionally stocked forest, allows for the smoothing of carbon accounting area (CAA) boundaries, which is a defined area of registered post-1989 forest. However, for the application of space-planted poplars, it means that the canopy edges of the individual trees cannot have a distance between them of greater than 15 m. Of the above listed constraints, the crucial ones are that there must be a tree crown cover of forest species of more than 30% in each ha, and there must not be a gap between tree dripline of greater than 15 m. Of these two constraints, it has been calculated within this research that the requirement for tree cover is more restrictive than the 15 m gap requirement.

Soils that are reinforced by roots have a greater ability to maintain their formation and strength than soils with no root reinforcement (Douglas, McIvor, et al., 2013; McIvor, et al., 2008). Soils are stabilised by roots because they provide reinforcement through their strength, creation of surface friction between the root and soil particles, and their ability to bond with the soil (Bischetti, et al., 2005). Trees planted for erosion control have an advantage over pasture at reducing erosion as they can bind the soil at greater depths, reduce the severity of rainfall events upon soil runoff, and transfer water out of the soil profile at greater soil depths through evapotranspiration (McIvor, Douglas, et al., 2011). Poplars reduce erosion and stabilise hill sides through development of an extensive root system. Annual root growth downslope of the stem has been recorded as being similar, in metres, to the annual increase in tree height above ground (Wilkinson, 1999). However, poplars are not effective at reducing erosion until lateral and vertical development of roots is sufficient, which occurs by year five (Douglas, Wall, et al., 2013).

Research shows that in order for space-planted poplars to be effective in reducing soil erosion, they should be established at a rate of between 40 and 100 sph, equating to 15 x 15 m and 10 x 10 m planting spacing, respectively (Plant and Food Research, 2011; Wilkinson, 1992). However, on more erosion prone land, a higher density is recommended. The recommended density for poplar trees aged nine to 11 years to ensure adequate soil stabilisation through root growth and adequate pasture yields is 160 sph, equating to a planting spacing of 8 x 8 m (Horizons Regional Council, 2014; McIvor & Douglas, 2012). More intensive planting at the time of establishment followed by thinning as the trees grow will allow for the rapid stabilisation of hillsides whilst having minimal impact on pasture yields (Horizons Regional Council, 2014; National Poplar and Willow Users Group, 2007). Where poplars are correctly planted and maintained to suit the type of erosion to be mitigated against, they can reduce the amount of soil erosion close to levels that are observed on stable hillsides within five to ten years of establishment (Hicks, 1992; McIvor, Douglas, et al., 2011), with reductions in soil erosion remaining largely static from year ten onwards (Parminter, et al., 2001).

Poplar trees are typically established from un-rooted poles that are two to three metres in height when planted (Wilkinson, 1999), or from bare-rooted poplar poles, which are typically smaller and hence further from maturity at planting, which means that livestock need to be excluded from the planted areas for longer periods (National Poplar and Willow Users Group, 2007). Poplar poles can be protected using either sleeves or netting, which prevent browsing from livestock and allow for the continuation of livestock grazing when the poles are establishing (Douglas, Wall, et al., 2013; Wilkinson, 1999). However, cattle should be excluded from areas with poles for at least two to three years as they can rub on the poles, either breaking them or loosening the soil around their base (McIvor, Douglas, et al., 2011). Pruning should be undertaken as soon as a dominant leader has emerged, which is typically within the second or third year (Plant and Food Research, 2011). Form pruning has the advantages of decreased shading of pasture at the base of the tree; lifting the height of the tree's foliage, which decreases shading and stock camping; creating trees that are more tolerant to wind; and avoiding tree splitting when branches grow against one another (Horizons Regional Council, 2014). The first prune undertaken should be to reduce the poplar to a single, dominant leader, with subsequent pruning events at years five and nine to achieve a final pruned height of six metres. At maturity i.e., when the tree has attained a greater than 30 cm diameter at breast height (dbh), and assuming the root system has extended out beyond 10 m, poplar stands can then be thinned to a stocking rate of 30 to 60 sph, which is dense enough to ensure stabilisation of the soil (McIvor & Douglas, 2012; McIvor, Douglas, et al., 2011). Poplars should not be thinned until they have reached a size greater than 30cm dbh (Plant and Food Research, 2011).

The requirement for stabilisation of the hill side comes from needing to reduce soil losses because of erosion, which is a particular problem within pastoral hill country farms (Jones & McIvor, 2016). Soil erosion reduces land productivity directly though loss of topsoil, and indirectly through reductions in pasture growth because of lost topsoil (Blaschke, et al., 1992). Studies have shown that eroded hill country, after an erosion event, is unlikely to reach greater than 70 to 80% of pasture production of neighbouring un-eroded soils, and it will take 20 to 40 years to return to these levels (Blaschke, et al., 1992; Lambert, et al., 1984; Schwarz, et al., 2016). A further study showed that pasture yields on new earthflows were 23% of that on neighbouring un-eroded slopes, and pasture yields on old but still active earthflows were 60% of un-eroded neighbouring sites, which is partly due to reduced water holding capacity (Miller, et al., 1996). Reductions in pasture production caused by erosion are not as easy to predict or manage long term as those caused by increasing canopy cover of planted poplars (Wall, et al., 2006).

Afforestation with Indigenous Species

Mānuka Plantation

As has already been outlined, the arrival of Māori and European settlers has been a causal factor of significant clearance of indigenous vegetation and destruction of wetlands (Ausseil, et al., 2011; Blaschke, et al., 1992; Douglas, Wall, et al., 2013; Ewers, et al., 2006; Norton, et al., 2020; Wilkinson, 1999;). Two options for indigenous afforestation have been investigated within this research, and consequently, the review of relevant literature has been restricted. This research has investigated afforestation with Mānuka and conifer-broadleaved species.

At present, there are approximately 720,000 ha within the North Island of New Zealand that are classified as Mānuka/Kānuka (Boffa Miskell Limited, 2017). Mānuka is an important species for reforestation as it is a pioneer species, being one of the first to establish on bare ground (Brock, et al., 2018). It grows rapidly to form a scrub layer that then begins to thin itself, allowing for the emergence of successional species (Boffa Miskell Limited, 2017), which have been shown to take double the time to achieve canopy closure as Mānuka that was established on a similar site (Bergin, 2011). Mānuka stands provide numerous environmental benefits, including increased CO_2 stocks, and positive influences of waterway health. However, Mānuka has increasingly been recognised for its honey and oil, which has unique antibacterial properties (Marden, et al., 2020).

Boffa Miskell Limited (2017) state that hydrogen peroxide is the lead antibacterial component in honey, but it is readily degraded, meaning honey's beneficial properties are unreliable. Honey made from Mānuka nectar has been found to retain its antibacterial properties even after hydrogen peroxide has been degraded. This is due to a chemical, methylglyoxal (MGO) being present in Mānuka honey, which is created from dihydroxyacetone (DHA), a component of Mānuka nectar. Consequently, Mānuka honey is renowned for its health and medicinal benefits due to a component found in Mānuka nectar that isn't found in other honey-producing plants (Boffa Miskell Limited, 2017; Douglas, 2019; Marden, et al., 2020). Higher DHA levels result in higher MGO levels, and subsequently greater health and medicinal benefits. Therefore, the aim is to maximise DHA content through selecting high quality Mānuka cultivars and ensuring the main source of nectar is Mānuka shrubs (Boffa Miskell Limited, 2017). For Mānuka plantations to be of significant enough size for

Mānuka to be the dominant source of nectar, Douglas (2019) estimates that a minimum plantation size of 100 ha is required.

Mānuka honey production is highly variable, with annual yields ranging from 15 to 52 kg/hive/season, and yields also varying regionally throughout New Zealand, ranging from 15 to 16 kg/hive/season in Eastern Bay of Plenty, to up to 60 kg/hive/season in Whanganui (Boffa Miskell Limited, 2017). As Mānuka can grow successfully in a wide range of conditions, commonly to between four to eight metres in height (Boffa Miskell Limited, 2017), it is able to generate revenue via the ETS from CO_2 sequestration. CO_2 sequestration of Mānuka plantations is comparatively insignificant compared to those returns derived from other forestry species (MPI, 2017). However, revenue generated through the ETS from Mānuka plantations can still provide suitable returns, especially on large scales (Douglas, 2019). This stable, annual cash flow becomes more vital in years when honey production is low.

Typically, Mānuka stands planted for the purpose of Mānuka honey production are established at a density of less than 1,111 sph, as flower development is suppressed when planted at higher densities, and canopy closure is attained earlier (Marden, et al., 2020). Bergin (2011) outlines the establishment and management practices of Mānuka plantations. For both low and high-density plantings (two to four metre and 1 to 1.5 m plant spacings, respectively), livestock should be excluded in the first year after a hard grazing of pasture. Establishment sites should then be sprayed, and planting should commence two weeks after spraying has been completed. Several inspections should also be carried out to identify areas for replanting, especially on more exposed sites. In low-density stands, weed control is important and should be ongoing for the next decade. In contrast, high-density stands should achieve canopy closure within several years, eliminating the need for ongoing weed control.

Conifer-broadleaved Forests

New Zealand has two general forest types: conifer-broadleaved forests and beech (*Nothofagus* species) forests (Cockayne, 1926; Kerr & Stewart, 2013). Conifer-broadleaved forests have a diverse range of trees and other plants, resulting in a complex ecosystem. This is because the variety of species is heavily influenced by altitude and latitude, as well as disturbance (Kerr & Stewart, 2013). Therefore, conifer-broadleaved forests comprise a range of conifer genera, notably, Kauri, Rimu, Tōtara, Kahikatea, Pāhautea, as well as a range of broadleaved genera, notably, Mānuka, Kānuka, Pōhutukawa, and Pokaka (Cockayne, 1926).

Generally, beech forests contain a less diverse range of trees and other plants than conifer-broadleaved forests, which is due to them being found in areas with cooler, wetter climates, and poorer quality soils (Cockayne, 1926; Kerr & Stewart, 2013). Beech forests are characterised by the presence of Black Beech, Red Beech, Silver Beech, and Hard Beech (Cockayne, 1926).

Preservation of biodiversity and conservation are the primary management objectives of publicly and privately held native forests. This has resulted in Governmental policy change over the past 40 years, which has been primarily responsible for a decline in native timber harvest volumes from 700,000 m^3 per annum in 1985, to only 40,000 m^3 per annum in 2005 (Kerr & Stewart, 2013). Timber production from New Zealand's native forests is currently limited to 1.4 million ha (21.5% of total native forests) situated on privately owned land. However, approved management plans only exist, and timber production is currently only undertaken on, 120,000 ha (1.8% of total native forest area) of privately owned land (Kerr & Stewart, 2013). Private owners of native forest can harvest timber, provided harvest is undertaken in accordance with an approved management plan, which requires certain conditions to be met depending on the type of forest (Te Uru Rakau, 2019). Harvesting of beech forest is typically limited to areas of less than 0.1 ha, trees of various size must be harvested, greater than 10% of total basal area is allowed to be harvested over a ten-year period (Te Uru Rakau, 2019). Whereas harvest of conifer-broadleaved forests can only be done five mature trees at a time, any thinning must remove a range of tree diameters, and a maximum of 5% of total basal area is permitted to be harvested within a five-year period (Te Uru Rakau, 2019). These guidelines prescribe how sustainable management of native forests is to be achieved, which allows for harvest of trees, however, if native trees are planted with the aim of producing merchantable sawlogs, silvicultural practices will be required to prevent multiple leaders and large branching (Bergin, 2011).

Davis' study of establishing indigenous forest on erosion-prone grassland (as cited in Bergin, 2011) concluded that native trees can either be established at a close planting density to achieve quicker canopy closure, typically within two to three years, or can be planted at lower densities to allow for ongoing monitoring and weed control in the long term, with canopy closure achieved within ten years. A stand of native trees planted at high density will typically have 5,000 sph, equating to a plant spacing of less than 1.5 m. The denser plantings will encourage trees to grow tall, straight stems. Plantings should be managed in accordance with Bergin (2011) as outlined in the previous section for Mānuka plantations. However, competition within the native tree stand will increase once canopy closure has been realised, so a thin will be required 10 to 20 years after planting (Bergin & Kimberley, 2003).

Environmental Impacts of Carbon Forestry

The three species of carbon forestry (Pinus radiata plantation, space-planted poplars, and Mānuka/conifer-broadleaved native forests) that are central to this study have numerous environmental impacts. These impacts include sequestration of CO_2 (Douglas, 2019; Marden, et al., 2020) and improvements in the health and quality of waterbodies and waterways (Marden, et al., 2020; Quinn & Stroud, 2002), which are the two key environmental impacts focused on in this study. Furthermore, benefits such as maintaining and enhancing biodiversity (Moller, et al., 2008; Quinn & Stroud, 2002; Walker, et al., 2006), control of soil erosion (Manderson, et al., 2007; Schwarz, et al., 2016), among various other impacts (Ball, et al., 2005; Dominati, et al., 2019; Maseyk, et al., 2019), are also provided by carbon forestry.

The following sections of the literature review discuss studies that have aimed to estimate the environmental benefits afforded by Pinus radiata plantations, space-planted poplars, and Mānuka/conifer-broadleaved native carbon forests.

Reduction in Gross Greenhouse Gas Emissions

Afforestation can reduce greenhouse gas emissions directly through CO_2 sequestration and indirectly through reducing the area of pastoral agricultural land. Although pastoral land does sequester CO_2 in its soil, it is hard to calculate, and it also is not provided for within the ETS (Journeaux & Kingi, 2020). This means that pastoral land cannot be utilised to sequester CO_2 as carbon forestry can in New Zealand.

Indirect reductions in gross greenhouse gas emissions through reducing the area of pastoral land, and subsequently reducing livestock numbers, have been proven by several studies to be modest. Ausseil and Dymond (2010), who studied the impacts of afforesting 32,000 ha of erosion-prone land (totalling 5% of the catchment) within the Manawatū catchment, estimated only a 1% reduction in gross CH_4 and N_2O emissions was likely to be observed. Similarly, Journeaux et al. (2020) reported only an approximate 1 to 2% decrease in gross greenhouse gas emissions on two sheep and beef farms within their study when 2 to 3% of the total farm area was afforested. The reductions in gross emissions are low as the afforestation is targeted as the less productive pastoral agricultural areas, which typically have lower stocking rates and smaller fertiliser inputs.

Furthermore, the benefits of gross emissions reductions do not vary between forestry species as reductions relate to the livestock enterprise that was replaced, not with the sequestration capability of the forestry species (Ausseil & Dymond, 2010).

In contrast, differences in CO_2 sequestration rates between forestry species do exist, which is predominantly due to growth rates of the various trees. Indigenous shrub species such as Mānuka and Kānuka have been shown to grow twice as fast as Tōtara (indigenous conifer) (Bergin, 2011), and Rimu (indigenous conifer) has been shown to be slower growing than Pinus radiata (Pizzirani, et al., 2019). More specifically, varied CO_2 sequestration rates were indicated in the study by Ausseil and Dymond (2010), who demonstrated that Pinus radiata forests reduced net greenhouse gas emissions of the catchment by 5.2%, compared to only 2% when shrubland species were planted. Even when harvest of the Pinus radiata plantation at year 28 was modelled, which resulted in a drop in carbon stocks, the Pinus radiata plantation had still sequestered twice the amount of CO_2 than the indigenous Mānuka/Kānuka shrubland had over a 50-year period (Ausseil & Dymond, 2010). Varying CO_2 sequestration rates are further evidenced by MPI (2017), who provide default Look-up tables for forests less than 100 ha in size. Pinus radiata has the greatest CO_2 sequestration potential of the three forestry species mentioned within this study, sequestering a total of 1,345 t CO_2/ha by age 50 in the Hawke's Bay/Southern North Island Region, which equates to an average annual sequestration rate of 26.4 t CO_2/ha/year. In contrast, indigenous vegetation (Mānuka/conifer-broadleaved forests) will have sequestered only 323.4 t CO_2/ha, equating to 6.3 t CO_2/ha/year over the same 50-year period. Poplars are categorised within the ETS as exotic hardwoods, with the Look-up tables only having sequestration data available to the end of year 35, at which point a total of 729 t CO_2/ha has been sequestered, equating to 20.3 t CO_2/ha/year. However, these rates do not reflect space-planted poplars, which are established at much lower densities than those assumed in the default Look-up tables (McIvor, Douglas, et al., 2011). There has been comparatively minimal research conducted on the CO_2 sequestration of space-planted poplars. However, Guevara-Escobar et al. (2002) found that space-planted poplars hold 26% more carbon than adjacent pasture-only systems, which is held within the poplar trees, and also calculated CO_2 sequestration rate of space-planted poplars (at a density of 37 sph) over a 30-year timeframe to be 2 t CO2-e/ha/year, which is significantly lower than those derived from the default Look-up tables (MPI, 2017).

Improvements of Health and Quality of Waterbodies and Waterways

Streams found to be flowing through vegetative cover tend to have lower concentrations of both nutrients and sediment, as well as superior water visual clarity than streams that flow through pastoral land (Quinn & Stroud, 2002), and therefore, the restoration of vegetative cover is the most commonly used method of improving waterway quality (Manderson, et al., 2007). Tree species have a greater ability to reduce leaching of N than pastures through not only uptake, but also by changing chemical, physical, and microbial soil properties (Franklin, et al., 2016). Trees have fast growth rates, large biomass production and deep roots, which means they are more effective at up taking N from the soil compared to pastures (Rockwood, et al., 2004).

Plantinga and Wu (2003) evaluated the co-benefits of reducing the externalities from agriculture in Wisconsin, America. They observed only small reductions in N leaching, which is reflective of CO_2 sequestration programs tending to result in the afforestation of agricultural land that is farmed less intensively than other agricultural land. These results were corroborated by Ausseil and Dymond (2010), who reported that N and P loss only reduced by 1.5% in the afforestation scenario when erosion-prone land was afforested in the Manawatū catchment. There was no difference in nutrient loss within this study between Pinus radiata and indigenous vegetation.

There have been several studies that have modelled impacts of carbon forestry integration into pastoral farming systems within New Zealand upon N and P loss – these will be discussed later in the literature review, within the ‘Impact of Carbon Forestry Integration into Sheep and Beef Farms’ section.

Other Environmental Impacts

Plantinga and Wu (2003) found that afforestation of 3.08 million acres (equivalent to 25% of agricultural land in Wisconsin) resulted in significant reductions in erosion of up to 28%, which is similar to the results of Ausseil and Dymond (2010), who found that sediment loss was reduced by 38% when 32,000 ha of erosion-prone land (5% of the catchment) in the Manawatū catchment was afforested with Pinus radiata. Space-planted poplars have also been shown to be effective at reducing soil erosion, with research showing that at a planting spacing of 10 m x 10 m (100 sph), by years 14 to 17, reductions in pasture yields as a result of erosion have been reduced by up to 70%. In contrast, under poplars planted at a spacing of 20 m x 20 m (25 sph), by years 14 to 17, losses were reduced by only 13.8% (McIvor, Douglas, et al., 2011). Therefore, poplars planted at closer spacings reduce erosion to a greater extent than lower densities. A further study by Hicks (1992) found that mature broadleaved species, including poplars, planted at 70 sph (12 m spacing) on hill country caused a 50 to 80% reduction in area subject to shallow landslides, as compared to unplanted slopes. Douglas and McIvor et al. (2013) investigated the reduction in landslide occurrence after rainfall events and concluded that space-planted trees on hills can reduce the percentage of area within a 10 m radius of the tree that bears a scar from landslides from 7.9 to 0.4%, which is a 95% reduction from sites with no trees planted. Bergin et al. (1995) demonstrated that closed canopied indigenous stands of Mānuka can reduce landslide incidence during significant storm events by approximately 65% as compared to incidence on adjacent pastoral slopes, increasing to 90% lower incidence 20 years after such a storm event.

The maintenance and creation of indigenous cover is also a useful strategy for maintaining biodiversity. Larger areas of indigenous cover support a greater variety of species than smaller areas (Daily, 1997), and greater biodiversity can be further enhanced by ensuring there is variety and complexity to indigenous cover (MacArthur & MacArthur, 1961). Integration of indigenous cover within agricultural systems in one form or another is vital to maintaining/enhancing biodiversity. Although indigenous cover is preferred, some exotic vegetation species will aid biodiversity (Moller, et al., 2008), as the lack of indigenous cover in many places throughout New Zealand means that exotic tree species play an important role in providing ecosystem services (Maseyk, et al., 2019). However, different tree species have differing levels of biodiversity enhancement. It was found by Ausseil and Dymond (2010) that exotic Pinus radiata plantation and indigenous Mānuka/Kānuka shrubland did not equally provide benefits to biodiversity. Pinus radiata afforestation increased the biodiversity indicator in the Manawatū catchment by 1.5%, whereas Mānuka/Kānuka shrubland provided an increase of 2.6%. A further study, conducted by Blackwell et al. (2005), found in a South Island study of 36 sheep and beef farms that there were more abundant numbers of native and introduced land birds on farms with greater areas of native vegetation and scrub, as well as vegetation in riparian areas. Conversely, introduced species and open country birds were more abundant on farms that had greater areas of open paddocks, exotic hedges, and shelterbelts. Consequently, restoration and preservation of forest cover (particularly indigenous cover) is vital to the survival of native bird species (Moller, et al., 2008). Forbes et al. (2019) studied the potential of using permanent Pinus radiata plantations as a nurse crop for indigenous forest species in the Kaingaroa forest in the Central North Island and found that permanent Pinus radiata stands can provide a suitable habitat for indigenous plant species that is superior to pastoral landscapes. However, results are best when there is a nearby indigenous seed source (Forbes, et al., 2019).

Summary of Environmental Impacts

The reviewed literature indicates that afforestation of land for CO_2 mitigation typically occurs on marginal pastoral hill country, which means the reductions in gross greenhouse emissions, and N and P loss are comparatively lower than reductions that would be achieved if more-intensively farmed land was afforested. Therefore, if gross greenhouse emissions and nutrient loss are to be reduced significantly, marginal pastoral land is the least suitable class of land to achieve this. Furthermore, it is evidenced by the literature that the environmental benefits provided for by Pinus radiata plantation, space-planted poplars, and Mānuka/conifer-broadleaved native forests are not equal, particularly in terms of CO_2 sequestration potential. A study conducted by Funk et al. (2014) concluded that for carbon farming to be a viable alternative land use, its ecological benefits must be able to be monetised, but Plantinga and Wu (2003) and Ausseil and Dymond (2010) struggled to monetise the value of reduced N and P loss. It is likely that the benefit of reducing nutrient loss may not come from direct sources, but from indirect sources such as the allowance for intensification of remaining pastoral land, or simply the continuance of farming in regions where nutrient loss restrictions are imposed.

Economic Impacts of Carbon Forestry

As stated previously, the ability of a forest species to generate income through CO_2 sequestration is fundamental to the ‘carbon forestry’ definition adopted within this research. However, the definition of ‘carbon forestry’ adopted within this research also allows for the incorporation of other revenue streams. This section will discuss the various revenue streams available for Pinus radiata plantation, space-planted poplars, and Mānuka/conifer-broadleaved native forests. As revenue from CO_2 sequestration is inextricably linked to the sequestration rates of the forestry species, this avenue of income will not be discussed here, as variances in CO_2 sequestration rates have already been discussed.

Timber Harvest Revenue

Pinus radiata grows at a much faster rate than indigenous species, so is the preferred forestry species for producing merchantable timber (Ausseil & Dymond, 2010), however, indigenous forests can provide merchantable timber that is of considerable value (Pizzirani, et al., 2019).

Pizzirani et al. (2019) modelled three afforestation scenarios within a New Zealand catchment on the East Coast of the North Island, being: intensively managed Pinus radiata, indigenous Rimu managed on a continuous-cover model, and intensive Mānuka plantation for producing essential oils. The Pinus radiata forestry model was a typical production model, assuming harvest, whereas the Rimu scenario comprised a continuous-cover technique, which sees 20% of the total standing volume harvested at age 80, with this being repeated every ten years until the originally planted stand has been entirely harvested. As both the Pinus radiata and Rimu scenarios included harvest, a timber price was input. An average log prices across all log grades for Pinus Radiata of \$94 per m^3, compared to a log price of \$358 per m^3 for the Rimu, were adopted. Timber sourced from Rimu fetches a higher price than that sourced from Pinus radiata due to its relative scarcity, and its desirable characteristics for use in furniture, joinery, and panelling. The Mānuka scenario was designed around the harvest of the Mānuka plant for extraction of essential oils. Therefore, it was planted on flat land to accommodate mechanical harvest and was planted at a high planting density to maximise biomass production. To allow for a comparison of feasibility of the three scenarios, a discounted cash flow (DCF) was used to generate an NPV. To ensure that a similar investment period was used over which to compare the three scenarios, one 120-year rotation of Rimu was compared against eight rotations of Mānuka (15-year rotation) and four rotations of Pinus radiata (28-year rotation). Both the Pinus radiata and Rimu scenarios returned negative NPVs, irrespective of the discount rate. As a higher opportunity cost was input into the flat land option as opposed to the steep land option (\$1,040 per annum vs \$208 per annum), the NPV results were worse for both Pinus radiata and Rimu on flat land than steep land. The Pinus radiata became profitable when a discount rate of 6% or lower was used, and the stumpage value was greater than \$100 per m^3. In contrast, the Rimu scenario did not become profitable until discount rates as low as 2% were used, and stumpage values of \$650 per m^3 in year 80 were adopted. The Mānuka scenario is highly sensitive to price, with a price of \$300 per kg of oil causing the scenario to be unprofitable irrespective of discount rate. It is important to note all three scenarios excluded potential benefits from CO_2 sequestration. As CO_2 sequestration has the potential to significantly alter the profitability of some forestry types, the research has not analysed the full suite of benefits afforded by carbon forestry, and therefore, there is an opportunity to include the revenue from CO_2 sequestration to better assess the relative profitability of forestry.

A significant limitation to the widespread adoption of planting native tree species is the prohibitive cost. Davis' study of establishing indigenous forest on erosion-prone grassland (as cited in Bergin, 2011) estimated the costs of establishment of a medium-density planting of Rimu at 4,444 sph at $35,000 per ha, which is similar to Bergin and Gea (2007), who estimated the cost at $30,000 per ha for plantings at the same density. For higher density plantings of native trees of 10,000 sph, Bergin and Gea (2007) estimated that costs can increase to $60,000 per ha. In contrast, the same study estimated significantly lower per ha costs of $5,500 per ha for lower density plantings at 625 sph.

Other Revenue

Poplars that are space planted to just meet the minimum requirement of the ETS to have crown cover of at least 30% will reduce pasture yields by approximately 7 to 11% beneath pruned and unpruned trees, respectively, when the trees have foliage on them (McIvor & Douglas, 2012). This means that livestock grazing is still provided for as a revenue stream where poplars are space-planted. Further research conducted at two sites, Lawrence and Pohangina, with trees planted at 10 to 20 m spacing (100 to 25 sph) and 15 to 25 m spacing (44 to 16 sph) and that were between eight and 15 years old, recorded the impacts of shading upon pasture growth (Douglas, et al., 2001). On the Lawrence site, pasture production was significantly reduced as compared to open pasture, with a 20 to 34% reduction recorded, in contrast, only a 7 to 14% reduction in pasture production was recorded at the Pohangina site (Douglas, et al., 2001). Some of these differences in reduced pasture growth are attributable to soil water content, site fertility, and tree diameter and height (Douglas, et al., 2001). These results are further corroborated by Gilchrist et al. (1993) who found that poplars that were spaced 20 m apart, and were 16 years of age, had a negligible impact on pasture production. In contrast, a study showed that underneath a mature, untended poplar canopy comprising of 25% crown cover, pasture yields were reduced to 77% of the unplanted pasture yields, compared to a 50% and 75% canopy covers reducing pasture yields to 60% and 48% of the unplanted pasture yields (Wall, et al., 2006). It is apparent that tending and canopy closure have significant impacts on the pasture production underneath. However, the mitigation of soil erosion needs to be taken into consideration when looking at the reduction in pasture yields through planting of poplars. Reductions in pasture yields as a result of erosion are often a lot more severe, and more permanent (Wall, et al., 2006). A lack of control and maintenance of canopy cover of poplar trees leads to significantly poorer pasture production, but measures that can be taken to control canopy cover often have impacts on tree-root development and soil-water interactions, which reduce the effectiveness of poplars at mitigating erosion (Wall, et al., 2006). However, if left untended, poplars can grow in excess of 60 cm dbh and cause significant shading of pasture underneath, as well as become a physical hazard to livestock and humans as branches break and fall (Douglas, Wall, et al., 2013; McIvor, Douglas, et al., 2011).

Forestry Revenue vs Pastoral Revenue

The aforementioned studies of carbon forestry have given an outline of how Pinus radiata plantation, Mānuka, and conifer-broadleaved native forests compare to one another on an economic basis, as well as alluding to the potential for preserved pastoral income when space-planted poplars are afforested. In addition to these studies, there have been several studies of how profitability of carbon forestry compares to profitability of pastoral farming. These studies provide further insight into economic comparison and will be discussed in this section.

Trotter et al. (2005) and Funk et al. (2014) investigated the effects of afforestation of pastoral land by indigenous shrubland species. Both studies investigated the potential size of the CO_2 sink that could be created by afforestation/reforestation of indigenous shrubland species. However, Trotter et al. (2005) conducted their analysis on a national scale, whereas, Funk et al. (2014) limited their analysis to the Gisborne District in the North Island. The size of the potential CO_2 sinks were estimated by comparing the profitability of pastoral agriculture and carbon forestry, with it being assumed that if the gross margin from carbon forestry exceeded the gross margin from livestock grazing, the land would be afforested (Funk, et al., 2014; Trotter, et al., 2005). It was not within the scope of these studies to assess the impacts of other benefits of carbon forestry on the size of the CO_2 sink, however, the co-benefits of carbon forestry must be considered. To compare the profitability of carbon forestry and livestock grazing, the calculated gross margins for carbon forestry and livestock grazing were discounted to provide an NPV of each land use, with spatial datasets used to extrapolate these gross margins to a larger scale (Funk, et al., 2014; Trotter, et al., 2005). Both studies used similar methodology, which is appropriate when estimating the effects of carbon forestry on such a large scale. However, the reliance upon spatial datasets that were not mapped to a farm scale (1:50,000 and 1:125,000), means that farm heterogeneity has not been properly accounted for. As sheep and beef farms are typically heterogenous in nature, the lack of farm-level analysis means that the results reported by Trotter et al. (2005)

and Funk et al. (2014) are not able to be applied at a farm level. Trotter et al. (2005) limited their assessment of economic returns to between the Gisborne and East Cape areas of the North Island, which is very similar to the area analysed by Funk et al. (2014). A long-run average sequestration rate of 1.2 t CO_2/ha/year was estimated over a 100-year period, and a livestock gross margin for the marginal land was assessed at $16/ha (Trotter, et al., 2005). This analysis means that at a NZU price of $12/t CO_2, carbon farming of indigenous shrubland species would be more profitable than pastoral agriculture on marginal hill country, and at a carbon price of $19/t CO_2, the NZU sale revenue from indigenous shrubland would be very comparable to livestock gross margins on approximately 120,000 ha of land within the upper East Coast Region (Trotter, et al., 2005). These results are very similar to those reported by Funk et al. (2014), who over a 70-year period, and a carbon price of $15/t CO_2 assessed an annual carbon income of $167/ha/year. At this conservative NZU price, and a livestock gross margin of $20 per stock unit (SU), it was estimated that 98,339 ha would be afforested. This result is similar to Trotter et al. (2005), however, Funk et al. (2014) also considered the impact of additional revenue from carbon forestry.

When additional income of Mānuka honey and conservation programmes were added to the carbon revenue, assuming the same carbon price, the area of conversion would increase to 277,692 ha (Funk, et al., 2014). The conclusion of Funk et al. (2014) that revenue from Mānuka honey made afforestation with indigenous shrubs more profitable than pastoral farming was corroborated by Douglas (2019) who, as part of a wider study, compared the returns from Mānuka planted for honey production against returns from dairy, and sheep and beef farming. Four Mānuka options were investigated: plantation Mānuka (excluding establishment costs) on a 30% or 50% honey revenue share with the landowner, and plantation Mānuka (including establishment costs) on a 30% or 50% honey revenue share with the landowner. Data from Beef + Lamb NZ was used to estimate comparable returns from sheep and beef pastoral farming. Farm 'Class 9 – All Classes – All New Zealand' was used as the benchmark for sheep and beef farming profitability, which comprises a mixture of farms from all classes, and therefore, represents a sort of 'average profitability' of sheep and beef farming. This study concluded that the plantation Mānuka (excluding establishment costs) with 50% of honey revenue returned to the landowner has a higher average per ha return ($509/ha) and NPV ($3,465/ha) over a 20-year investment period, compared to sheep and beef farming, which was shown to have an average per ha return of $208/ha and an NPV $2,042/ha. The remaining three options, with lower revenue shares returning to the landowner, and inclusion of establishment costs, all had inferior average per ha returns and per ha NPVs compared to sheep and beef pastoral farming. The poorest performer was plantation Mānuka (including establishment costs) with 30% of honey revenue returned to the landowner, which had an average return of \$141/ha/year, and an NPV of -\$837/ha.

Therefore, Funk et al. (2014) can be said to have conducted a more in-depth analysis that more accurately reflects potential land use changes in the region than Trotter et al. (2005). Without considering additional revenues from carbon forestry, Trotter et al. (2005) have underestimated the amount of land on which carbon forestry would generate higher gross margins than livestock grazing. A shortcoming of both studies is that neither study included costs associated with the afforestation/reforestation of marginal pastoral land. It was stated that these costs were omitted from analyses, but could include fencing, and weed and pest control (Funk, et al., 2014; Trotter, et al., 2005). The omission of these costs has likely caused an overestimation of the area of land that would be converted under different scenarios, which is evidenced by Douglas (2019) who found that when establishment costs of plantation Mānuka were incorporated into analyses, the profitability of plantation Mānuka fell below that of sheep and beef pastoral farming. However, Douglas (2019) did not include any revenue from CO_2 sequestration, which would improve profitability. This proposed research intends to include establishment costs, as they will be comparatively easier to estimate at farm level than a regional level, as well as revenue from both Mānuka honey production and CO_2 sequestration – the two main income sources of plantation Mānuka.

The incentives for planting poplars for erosion control are marginal, because while environmental sustainability is important, the planting of trees must also be economically sustainable if a landowner is expected to invest (Parminter, et al., 2001). Three scenarios were analysed by Parminter et al. (2001) on a cost-benefit basis, with consideration given to erosion rates, planting densities, timber revenue, lost dry matter production, repair costs from erosion events, and the time value of money. It was found that shading by the tree canopies caused greater reductions in dry matter production than those from losses to soil erosion (Parminter, et al., 2001), which corroborates research conducted by Wall et al. (2006) but is in contradiction to research conducted by Miller et al. (1996), McIvor and Douglas et al. (2011), and Douglas et al. (2001). However, it must be noted that both age and tending history have a significant bearing upon shading of pasture (Douglas, McIvor, et al., 2013; McIvor, Douglas, et al., 2011), so it is crucial to specify such assumptions in research as they are key to intepreting results regarding profitability of pastoral farming under space-planted poplars.

Parminter et al. (2001) found that the reductions in shading of pasture compared to protection against soil erosion resulted in decreased profitabiltiy compared to sheep and beef pastoral farmimg, but when the revenue from tree harvest was incorporated into the analysis, the NPV of some scenarios became positive. For the base scenario, which assumed low erosion and excluded fodder values, the NPV ranged from -$87 at a 5% discount rate when harvest was incorporated, to -$1,501 at a 5% discount rate when no harvest was incorporated. Internal rate of return (IRR), which is the discount rate that will result in an NPV of zero, ranged from 3.6 to 4.6% for planting rates of 50 and 100 sph, respectively, when harvest was assumed. Under a more favourable scenario, where erosion rates and repair costs were high, and fodder values were included, the NPV ranged from $209 at a 5% discount rate assuming harvest, to -$1,205 at a 5% discount rate assuming no harvest. IRR ranged from 5.5 to 5.9% for planting rates of 50 and 100 sph, respectively, when harvest was assumed. This research provides valuable insight in the profitability of space-planting poplars for erosion control and finds that the activity has very marginal economic benefits to the farmer. However, this cost-benefit analysis has not taken into consideration the value of CO_2 sequestration, which was not a possibility at the time of the study. The inclusion of revenue from CO_2 sequestration is likely to have a significant influence on the feasibility of space planting poplars. Therefore, there is scope to build on previous research.

Although wider impacts upon the economy are not within the scope of this research, Fogan and Pollard (2020) compared the economic effects of forestry to those of sheep and beef pastoral farming at a national scale. A multiplier analysis was used to estimate changes in GDP and employment resulting from within-sector expenditure, purchases made by that sector from other sectors, and income expenditure of these sectors within the wider economy. A three-step modelling approach was used to conduct the analysis. Firstly, Beef + Lamb New Zealand, the Forest Owners Association, and Statistics New Zealand were used to establish sales and/or revenue data for the sectors. Secondly, economic multipliers, based on data from Statistics New Zealand's 2015 Input-Output tables, were applied to the sales and/or revenues to estimate value-added and full-time equivalent (FTE) impacts, which is a unit indicating an employed person's workload. Lastly, to allow for a national comparison between sheep and beef farming and forestry, the value-added and FTE impacts were scaled to a per 1,000 ha level. On a per ha basis, forestry was found to create more value-added than both the sheep and beef pastoral farming and carbon farming industries, annually creating $4.6 million of value-add and 38 FTE per 1,000 ha, compared to $1.7 million of value-added and 17 FTE per 1,000 ha created by the sheep and beef pastoral farming industry, and $0.8 million of value-added and 1 FTE per 1,000 ha created by the carbon forestry industry. Annual value-add per 1,000 ha of permanent carbon forestry was highest for Pinus radiata, with exotic hardwoods and indigenous forest both having lower impacts, which is due to the lower total CO_2 sequestration compared to Pinus radiata. There was a broad spectrum of land types included in the total area for both forestry and sheep and beef, but particularly sheep and beef pastoral farming within the modelling. Consequently, there is a wider variation of productivity levels included for sheep and beef pastoral farming as compared to forestry, including land in some areas such as the Otago High Country, which is not suitable for forestry production. Therefore, this study does not allow for a direct comparison of specified forestry land to specified sheep and beef pastoral farming land. The benefit of the approach to be adopted within this research is that direct comparison between forestry and sheep and beef pastoral farming returns will be provided for, because specified areas will be focused upon in each of the case study farms. Fogan and Pollard (2020) also found that plantation Pinus radiata forestry (assumed harvest with no carbon revenue) and permanent carbon forestry (assumed no harvest but include carbon revenue) were shown to have similar long-term returns, but permanent carbon forestry has significantly lower economic impacts than both plantation forestry and sheep and beef farming. It was also found that returns generated from permanent carbon forestry were nearly completely attributed to capital, with nearly no employment benefits created. Permanent carbon forestry had a higher NPV than production forestry on account of lower establishment costs, fewer costs early in the investment period, and more regular revenue from sale of NZUs compared to the less-frequent harvest revenue of production forestry.

A further investigation was conducted by Fogan and Pollard (2020), who utilised the multiplier analysis to compare the economic returns of sheep and beef farms integrated with plantation forestry, sheep and beef farms integrated with permanent carbon forestry, and sheep and beef farms with no forestry integration. It was concluded that sheep and beef farms integrated with plantation forestry had the highest annual value-added, and highest annual total economic impact, per 1,000 ha. It was assumed that when forestry was integrated into sheep and beef farming systems, it was done so on the least productive 10% of farmland. It was also assumed that sheep and beef production did not decrease, as some farmland is more suited to forestry than sheep and beef farming, intensification of higher-producing land occurs, and there are increases in animal survival and welfare. This part of the study undertaken by Fogan and Pollard (2020) corroborates the results of Trotter et al. (2005), Funk et al. (2014), and Douglas (2019) who all found that economic returns from carbon forestry can be greater than those from sheep and beef pastoral farming. However, much like Trotter et al. (2005), Funk et al. (2014), and Douglas (2019), the results from Fogan and Pollard (2020) are not representative of any particular unit of land. They provide very useful information at a high level, however, this level is often too high to be of use to any particular sheep and beef farmer.

Summary of Economic Impacts

Sheep and beef pastoral farmers are reluctant to make land use changes that benefit the environment if it is not also economically advantageous (Journeaux, et al., 2020), and therefore, carbon forestry being more profitable than sheep and beef pastoral farming is paramount to ensuring integration into sheep and beef farms. Numerous studies have calculated the profitability of carbon forestry, with several of those providing a comparison with sheep and beef pastoral farming. These studies have evaluated a range of forestry species, silvicultural practices, localities, revenue streams, as well as utilised varying assumptions and methodologies. As a result, it is difficult to draw direct comparison between studies and conclude definitively if carbon forestry is more profitable than sheep and beef pastoral farming. However, the studies have provided insight and guidance into the important considerations to be made within this study, such as the inclusion of CO_2 sequestration as a revenue source alongside other sources, the incorporation of establishment cost of carbon forestry, and the investment period over which carbon forestry should be evaluated.

Impact of Carbon Forestry Integration into Sheep and Beef Farms

Thus far, the literature review has discussed research that independently assessed either the environmental or the economic impacts of carbon forestry in a standalone fashion. In this section, literature that has analysed both the environmental and economic impacts of carbon forestry integration into sheep and beef farms will be reviewed.

Quinn et al. (2007), Vibart et al. (2011), Reisinger et al. (2017), Dominati et al. (2019), and Journeaux et al. (2020) all investigated the effects of forestry integration into sheep and beef farming systems. Quinn et al. (2007) conducted a participatory workshop approach to allow for examination of the economic and environmental performance of a hill country farm in the Whatawhata Catchment. Dominati et al. (2020)

adopted similar methodology, using a case study analysis of a sheep and beef farm near Tirau, Waikato, and applied the ecosystem approach to optimise the farm system so the impacts upon the receiving environments were minimised. Furthermore, Journeaux et al. (2020) undertook a research project with the aim of providing advice to the Māori pastoral sector on mitigation options for reducing greenhouse gas emissions, including impacts upon farm profitability. This study involved a wider network of 29 farms and the intensive modelling of four (two dairy and two sheep and beef) of the farms. A suite of mitigation scenarios were modelled for the four case study farms, with each farm being subject to differing mitigation strategies, with the various modelling scenarios for each farm intended to mitigate against losses specific to that farm (Journeaux, et al., 2020). The approaches adopted in these studies contrasted those of Vibart et al. (2011) and Reisinger et al. (2017), who both used several modelled farm scenarios to simulate the effects of forestry integration, among other mitigation options. Model farms were used within the analyses, which were created as 'average' farms for specific regions throughout New Zealand (Reisinger, et al., 2017; Vibart, et al., 2011). Appropriate statistics sourced from Dairy NZ Statistics as well as Beef + Lamb NZ Economic Survey data (Reisinger, et al., 2017; Vibart, et al., 2011) were used to guide the formulation of model farms, with expert opinion then relied upon to finesse the systems and ensure the model farms were balanced in Farmax's 'long-term' state.

The approaches used by Quinn et al. (2007) and Dominati et al. (2019) allowed for a more in-depth analysis of a single case, with both pieces of research focussing on the economic and environmental impacts of forestry integration. However, this prevented a wider analysis of how farm heterogeneity impacts upon the economic and environmental benefits of carbon forestry, which was achieved by Vibart et al. (2011), Reisinger et al. (2017), and Journeaux et al. (2020).

Quinn et al. (2007) implemented several land use management changes to a farm in the Whatawhata catchment, including afforestation of 153 ha of the farm (51.7% of total farm area) using Pinus radiata, intensification of remaining pastoral land, and improved indigenous forest management. Significant improvements in water quality were observed in a relatively short time frame, with water samples taken from several catchment outlet weirs showing reductions in sedimentation of 76%, P loading reductions of 62%, and N loading reductions of 33% (Quinn, et al., 2007). In contrast to Quinn et al. (2007), Dominati et al. (2019) used a new farm optimisation model, AgInform, developed by AgResearch and Deer Industry NZ, which has the ability to account for heterogeneity between different land management units (LMUs), which are areas of similar natural resources and productive capacity (Rendel, et al., 2015). Within the study, there were three modelled scenarios: scenario one reflected the status quo farming system with no changes; scenario two kept the same effective grazing area as scenario one but was optimised, with the identification of a sixth LMU that cattle could not be grazed on at certain times of the year; and in scenario three the newly identified LMU 6 was retired and established in native Mānuka. Dominati et al. (2019) found that planting 42 ha of Mānuka on LMU 6 land, decreased average N loss by 6% from scenario two, and P losses by 14%. The reductions in nutrient loading of waterways reported by Quinn et al. (2007) are much higher than those modelled by Plantinga and Wu (2003), Ausseil and Dymond (2010), and Dominati et al. (2019), which is likely due to such a large portion of the property being afforested in comparison to other studies. Journeaux et al. (2020) stated that for afforestation mitigation options investigated, per ha losses of N and P did not fall, and no reporting was made on changes in total farm loss.

Furthermore, Dominati et al. (2019) estimated that gross greenhouse gas emissions dropped by 4.8% as a result of afforesting 42 ha (9% of total property) of land, which resulted in reduced livestock and fertiliser inputs. This result is greater than those calculated by Journeaux et al. (2020), who reported an approximate 1% decrease in gross greenhouse gas emissions for the first case study Marotiri farm when 50 ha (2% of total area) of land were afforested with either Pinus radiata, Lusitanica, or Mānuka being the afforested species, as well as on the second case study Oromahoe farm, where two afforestation options were investigated on 30 ha (3% of total area) of marginal land, with either Pinus radiata of Mānuka, with both forestry scenarios reducing gross greenhouse gas emissions by approximately 2%. The percentage of afforested land within the total property is an indicator of how much gross emissions will reduce by, which is evidenced by 9% of the case study farm used in the Dominati et al. (2019) study being afforested and providing for the greatest reduction in gross greenhouse gas emissions. Conversely, the first case study modelled by Journeaux et al. (2020) has the smallest percentage of land afforested and reported the smallest decrease in gross greenhouse gas emissions. However, when the CO_2 sequestration potential of the afforested tree species is taken into consideration, the net greenhouse gas emissions reduce by a larger margin. For example, the sequestration by the Mānuka planting as outlined by Dominati et al. (2019) offset 11% of total greenhouse gas emissions from the farm. This result is corroborated by Journeaux et al. (2020) who reported that planting the 50 ha of the first case study in Pinus radiata reduced net greenhouse gas emissions by 100%, compared to a 53% reduction and 27%

reduction when Lusitanica and Mānuka, respectively, were the forest species planted (Journeaux, et al., 2020). Furthermore, planting 30 ha of the second case study in Pinus radiata reduced net greenhouse gas emissions by 39%, compared to a 27% reduction when Mānuka was the forest species planted. Journeaux et al. (2020) also reported that emissions intensities reduced for the first and second case study properties by 2% and 4%, respectively. These three studies confirm the results of previously discussed literature that concluded reductions in gross greenhouse gas emissions are modest (Ausseil & Dymond, 2010) and that differences in CO_2 sequestration rates between tree species exist (Ausseil & Dymond, 2010; Bergin, 2011; Pizzirani, et al., 2019).

Quinn et al. (2017) reported that profitability of the pastoral system in the Whatawhata Catchment rose from 30% below industry average to 13% above, a change of 43%. The increase in profitability of the pastoral enterprise is a result of removing steeper, less-productive areas of the farm that also had higher relative management costs (Quinn, et al., 2007). It is important to note that the increase in profitability is of the residual pastoral farming system, not of the entire property. Therefore, while per ha profitability increased for the remaining 131 ha pastoral system, overall farm economic impacts were not stated, as returns from the Pinus radiata plantation were unpredictable so were unable to be incorporated into the analysis (Quinn, et al., 2007). Dominati et al. (2019) found that with the afforestation of LMU 6 with Mānuka, overall farm profitability decreased by 7%, but profitability of the areas remaining in pasture rose by 5%. A shortcoming of the study by Dominati et al. (2019) is that the harvest of Mānuka honey was not incorporated in the economic analysis. However, the analysis did indicate that for farm profitability to be maintained when the 42 ha is afforested, the Mānuka plantation would have had to only generate returns of $320/ha/year, which is significantly lower than the stated current returns, which range from $500 to $1,200/ha/year. Furthermore, income from CO_2 sequestration was not incorporated by Dominati et al. (2020). In contrast, Journeaux et al. (2020) incorporated the revenue derived from the newly incorporated forestry enterprise to assess the economic impact on the overall business. For the first case study farm modelled by Journeaux et al. (2020), whole farm profitability (pastoral EBIT plus forestry annuity) increased by 10% for the Pinus radiata mitigation option, 2% for the Lusitanica option, and 6% for the Mānuka option, compared to the second case study farm, in which whole farm profitability increased by 2% for the Pinus radiata mitigation option and 5% for the Mānuka option. As Journeaux et al. (2020) took into consideration the afforestation sites within each case study farm, it is likely that farm heterogeneity is the cause of the differences in impacts on profitability between properties, which confirms the need for analysis of multiple cases to draw broad conclusions.

Journeaux et al. (2020) reported several interesting findings when CO_2 was priced differently. For example, at a price of $10/t CO2-e, profitability of the first case study farm increased for the Pinus radiata and Mānuka scenarios, but when CO_2 was priced at $25/t CO2-e, farm profitability decreased for both the Lusitanica and Mānuka mitigation options but stayed the same for the Pinus radiata option. It is unclear why the profitability of the Pinus radiata option stayed the same when carbon was priced at $10 and $25/t CO2-e. Logic would dictate that profitability would increase with an increase in carbon price of $15. Furthermore, it is odd that profitability increased by 3% for the Mānuka scenario at a carbon price of $10/t CO_2-e, but decreased by 2% at a carbon price of $25/t CO_2-e. Furthermore, it was reported that when no mitigation strategies are adopted to reduce greenhouse gas emissions, and emissions are priced at $10/t CO2-e and $25/t CO2-e, sheep and beef farm profitability fell from 5 to 8% and 12 to 20%, respectively.

In contrast to Quinn et al. (2007), Dominati et al. (2019), and Journeaux et al. (2020), the following two studies did not utilise case study farms. Instead, Vibart et al. (2011) utilised Farmax to assess the biological feasibility of nine representative sheep and beef farming scenarios in Southland. All farms were modelled as the same size, but with three varying degrees of intensification (base farm level, high intensification, low intensification) across three varying mixes of land use capabilities, being the ratio of rolling hill to steep hill (90:10, 70:30, 50:50) (Vibart, et al., 2011). Similarly, Reisinger et al. (2017) modelled four ‘average’ sheep and beef farms, being North Island hill country, North Island intensive finishing, South Island hill country, and South Island intensive finishing. Three afforestation scenarios were modelled by Reisinger et al. (2017); firstly, afforesting varying portions of the property (10%, 20%, and 30%), which were accompanied by an intensification of the balance of pastoral land; secondly, afforestation of 10% of the property was modelled but with no associated intensification of the balance of pastoral land; and thirdly, afforesting only marginal land, which comprised 5% of the property, and was accompanied by very slight intensification of the balance pastoral land. In contrast, Vibart et al. (2011) investigated two forestry scenarios for each of the nine modelled scenarios; firstly, no forestry was incorporated; secondly, 20 ha of Pinus radiata was incorporated on the least productive hill country. As ‘model’ farms were developed within both studies, it was sensible to apply generic afforestation options to all farms modelled. However, as demonstrated by Journeaux et al. (2020), and noted by Reisinger et al. (2017), real properties are diverse in nature and will likely require different solutions to differing challenges.

Vibart et al. (2011) assumed the 20 ha of forestry was planted in January 2011 and harvested at age 35 in 2045, which was modelled to be incorporated into the high intensification, 90:10 farm that had modelled emissions of 1,995 t CO2-e/year. Within the research of Vibart et al. (2011), the initial liable amount of CO_2 was 10% of livestock emissions in 2016, increasing by 1.6% of total emissions annually thereafter. Vibart et al. (2011) assumed that annual CO_2 sequestration by the Pinus radiata forest remained constant, at a rate of 22 t CO_2/ha/year, which does not reflect the actual sequestration rates of Pinus radiata in the Southland Region, which ranges from 0.2 to 25.9 t CO_2/ha/year and average 25.9 t CO_2/ha/year over a 35-year period (MPI, 2017). The adoption of a constant CO_2 sequestration rate likely means that many of the conclusions made around how long it will take for annual livestock greenhouse gas emissions to equal or surpass annual CO_2 sequestration, and at which point sequestration will no longer be able to offset emissions, will be incorrect. Reisinger et al. (2017) found that the introduction of forestry into sheep and beef farming systems significantly decreased greenhouse gas emissions. It was found that by afforesting 10% of the model North Island hill country farm, net emissions were reduced by 25% if only safe carbon was assumed, but the farm would be carbon neutral if the entire 28-year period of carbon sequestration was assumed, and if 30% of the property was afforested it would become a carbon sink. Net greenhouse gas emissions were reduced by 7 to 12% when only marginal land was afforested (Reisinger, et al., 2017).

The inclusion of a 20-ha forestry block (4% of farm effective area) by Vibart et al. (2011) had an insignificant impact on profitability of the pastoral farming system, which is due to the afforested area being small in comparison to the total property, and the afforestation being on the lowest-producing hill country. The inclusion of forestry into the 90:10 high intensification farm, only reduced farm profit by $14 per ha, which was the largest reduction calculated for all scenarios (Vibart, et al., 2011). The afforestation of 10% of one of the farms modelled by Reisinger et al. (2017) reduced the EBIT from the pastoral farming system by 16%, which is a result of the profitability of the pastoral system being greater than the forestry annuity, as well as total fixed costs not scaling back in proportion to a reduction in pastoral area. Assuming returns from the forestry annuity were similar to those from the pastoral system, overall combined profitability would still fall by 6% (Reisinger, et al., 2017). It is important to note that Reisinger et al. (2017) are assuming 'average' profitability of farming and forestry enterprises, which are challenging to extrapolate to other farms due to heterogeneity. Whilst it was found that the inclusion of forestry reduced the overall profitability of the modelled farms, it is possible that forestry would enhance the profitability of a farming system that had lower than ‘average’ returns. When 10% of the same model property was afforested by Reisinger et al. (2017), but there was no corresponding intensification of the balance pastoral land, profitability of the property was reduced by 22%. Afforestation of only marginal land within the properties resulted in a smaller reduction in profitability than both the other modelled afforestation scenarios, being less than 5%, or even improved profitability, which is a result of less productive areas being removed from production, and the higher relative productivity of remaining pastoral areas (Reisinger, et al., 2017). Therefore, afforestation of the least productive areas of the property can reduce the negative impacts upon profitability, and even increase profitability.

A limitation of the studies conducted by Vibart et al. (2011) and Reisinger et al. (2017) is that the only ecosystem benefit of carbon forestry measured was the reduction in greenhouse gas emissions. Furthermore, the studies did not consider tree species other than Pinus radiata, which limits the research as studies have shown that the ecosystem benefits of carbon forestry are dependent on forest species (Ausseil & Dymond, 2010; Journeaux, et al., 2020).

Summary of Carbon Forestry Integration Literature

The literature reviewed within this section investigated both the environmental and economic impacts of integrating carbon forestry into sheep and beef farms in New Zealand. It was widely reported that gross greenhouse gas emissions fell with the integration of carbon forestry. Furthermore, when CO_2 sequestration was incorporated into the analysis, net emissions fell further (Dominati, et al., 2019; Quinn, et al., 2007), but this reduction is dependent upon forestry species (Journeaux, et al., 2020) and the amount of carbon claimed (Reisinger, et al., 2017; Vibart, et al., 2011). It was also found that nutrient losses to waterways and waterbodies decreased with afforestation (Dominati, et al. 2019). However, results were conflicting in terms of economic impacts of carbon forestry integration, with it being apparent that the relative productivity of sheep and beef farming and forestry on the land that is to be afforested is an important driver of changes in profitability. It was, however, generally stated that afforestation of marginal pastoral land is more likely to increase overall profitability of the business (Journeaux, et al., 2020; Reisinger, et al., 2017).

Of the five studies that examined both economic and environmental impacts of carbon forestry integration in sheep and beef farms in New Zealand, several did not consider the added economic value of afforestation (Dominati, et al., 2019; Quinn, et al., 2007; Vibart, et al., 2011) and only two considered reductions in nutrient losses at the whole farm scale (Dominati, et al., 2019; Quinn, et al., 2007). Therefore, despite the extensive research conducted on the integration of carbon forestry into sheep and beef farms in New Zealand, no research has been completed that analyses the suite of economic and environmental impacts of carbon forestry integration and how these impacts are altered by tree species and farm heterogeneity.

Review of Methodology

Discounted Cash Flow

The production cycles of sheep and beef farming and forestry are in stark contrast to one another, with sheep and beef farming being on an annual basis, and forestry being spread over several decades (Fogan & Pollard, 2020). This has flow on impacts on timing and frequency of cash flows, as sheep and beef farming systems have regular, annual revenues and expenses, whereas forestry has intermittent expenses, with harvest revenue only received once per rotation, which can be every 30 years (Journeaux & Kingi, 2020; Maclaren,1993). As a result, economic comparison between forestry and sheep and beef farming is challenging. However, there is a method of economic comparison available – a DCF analysis, which is a method used to assess the value of an investment by considering future revenue and expenditure. A DCF analysis can express all revenue and expenditure at a single point in time, which is usually at the start of the investment period, by 'discounting' all cash flows at a pre-determined discount rate (Janiszewski, 2011). Therefore, DCFs can be used to compare profitability of investments with different timing of cash flows (Fogan & Pollard, 2020). Future cash flows have to be discounted to a single point in time due to the time value of money concept, which states that one dollar today is worth more than one dollar received at some point in the future (Maclaren, 1993).

The NPV of an investment is the sum of all revenue minus the sum of all expenditure over a specified period, discounted at an appropriate rate, whereas the IRR is the discount rate that will result in an NPV of zero (Agnes Cheng, et al., 1994). Both the NPV and IRR are two metrics upon which capital investments are assessed, however, they can provide different rankings, which leads to differences in the most desirable investment being recommended (Osborne, 2010). The differences in rankings between the two methods arise from each metric assessing a different aspect of profitability, the NPV calculates changes to net worth of the investor, and the IRR calculates the rate of return over a period based on the investment required (Agnes Cheng, et al., 1994). If the NPV is positive then it means that more cash is generated by the investment option than was required to be invested, so the investment should be accepted, whereas, when the IRR is higher than the discount rate used the investment should be undertaken (Bas, 2013). Investigating the impact of carbon forestry integration into sheep and beef farms on overall profitability requires an assessment of the additive wealth effect of the carbon forestry investment. As the IRR has only an implicit association with wealth maximisation, and the NPV has an explicit association with the wealth position of the overall business (Agnes Cheng, et al., 1994), NPV will be relied upon within this research as the primary metric for assessing profitability of carbon forestry integration.

DCFs have been utilised in numerous studies to examine the economic feasibility of various forestry and farming investments, however, various studies have treated the inclusion of income and expenditure differently, which gives cause for discussion. Several studies have included some or all of the timber harvest, Mānuka honey and/or Mānuka oil revenue, but have not included revenue from CO_2 sequestration (Douglas, 2019; Parminter, Dodd, et al., 2001; Pizzirani, et al., 2019). In contrast, studies by Trotter et al. (2005) and Funk et al. (2014) only compared returns from CO_2 sequestration, ignoring any other revenue streams. Furthermore, some studies excluded establishment costs of afforestation (Vibart, et al., 2011), whereas others did include establishment costs (Pizzirani, et al., 2019). As the studies have been conducted for a variety of reasons, and not necessarily to model the economic impacts of integrating carbon forestry into a sheep and beef farming business, care must be taken when comparing results from these studies. The varying treatments of costs also gives rise for a need for a study focused on the economic impacts when carbon forestry is integrated into a farming business, instead of merely being compared to pastoral farming. An additional consideration is the treatment of land values. Reisinger et al. (2017), Douglas (2019), and Journeaux et al. (2020) did not account for a purchase value and terminal value of land within their studies. However, depending on the status of forestry land, it can have differing land values i.e., post-1989 forest land that is able to generate income from both timber harvest and CO_2 sequestration has a higher value compared to pre-1990 forest land that is only able to generate income through timber harvest, assuming all other land characteristics are the same (M. Morice, personal communication, October 8, 2020). If forests are entered into the ETS under the 'averaging approach', revenue from CO_2 sequestration can only be earned for the first rotation of forestry, with no liabilities upon harvest (MPI, 2021a), which effectively means that after the first rotation of forestry, the land's ability to generate revenue is restricted to that from timber harvest, meaning it effectively has the same earning potential and value as pre-1990 land. Therefore, there is a decrease in land value that needs to be considered by landowners when making land use decisions.

Choice of Discount Rate

Discount rates allow investors to compare the economic desirability of alternative scenarios by assessing the NPV of all cash flows during the investment period (Pizzirani, et al., 2019). The literature reviewed within this research shows that a wide variety of discount rates have been used to assess the desirability of forestry investments.

For example, Fogan and Pollard (2020) relied upon Manley's bi-annual survey of forestry consultants (as cited in Crighton Anderson, 2014), which collects information pertaining to the discount rate forestry consultants use in forestry valuations. Fogan and Pollard (2020) then used a pre-tax discount rate of 7%, based on the report prepared by Crighton Anderson (2014), for both sheep and beef farming and Pinus radiata forestry investments in order to allow for an equal comparison between land uses. In contrast, research conducted by Dowling et al. (2017) calculated forestry annuities using discount rates of 8% and 5%, with the latter stated to commonly be used in long-term climate modelling. The rates used by Dowling et al. (2017) were similar to those of Pizzirani et al. (2019), who adopted pre-tax discount rates ranging from 2% to 8%, with low rates reflecting intergenerational aspects of iwi and the lack of a suitable alternative land use on the steep land. Douglas (2019) adopted a pre-tax discount rate of 8%, which was applied to annual cashflows over a 20-year investment period. Lastly, Journeaux and Kingi (2020) calculated the NPV of the forestry investment at a pre-tax discount rate of 5%. As can be seen, a wide range of discount rates have been adopted by the various studies, which is a result of both the timing of study and forestry species analysed.

FARMAX Advantage

Pastoral farming systems are heavily reliant upon striking a balance between pasture growth and livestock feed demand, with supplements often being used to fill feed deficits (Holmes, et al., 2002), and therefore, a sophisticated modelling system is required to analyse the feasibility of these farming systems. FARMAX Advantage (Farmax) has been developed as a tool to examine both physical and financial aspects of farming systems (Li, et al., 2012). The software's key service is to allow for an assessment of the biological feasibility of a proposed livestock system (Reisinger, et al., 2017; White, et al., 2010).

The assessment of a livestock policy's feasibility within Farmax is based upon an estimation of pasture cover (feed supply) vs livestock requirements (feed demand). If the forecast modelled pasture cover dips below the minimum allowed pasture cover at any stage, the modelled livestock policy is deemed 'infeasible' (White, et al., 2010). The user of Farmax can elect to either use regional average pasture growth rate data held within the Farmax library to estimate feed supply, or user-defined monthly pasture growth rates for the farm can be stipulated (Bryant, et al., 2010; White, et al., 2010). Internal calculations then estimate net growth by considering losses arising due to low photosynthesis potential of sub-optimal pasture covers, and losses arising due to decay when pasture covers are greater than optimum (Marshall, et al., 1991). Feed demand is modelled based on a set of assumptions contained within Farmax regarding livestock maintenance, pregnancy, lactation, and growth metabolisable energy (ME) requirements (Bryant, et al., 2008). ME requirements of livestock vary depending on sex, age, weight, number, and physiological status (Bryant, et al., 2008; White, et al., 2010). If Farmax has calculated that the minimum pasture cover required to meet the modelled management policy is insufficient, a number of optimisation options can be explored to create a biologically feasible farming system (Bryant, et al., 2010). Scenarios within Farmax can be run in either 'short-term' or 'long-term' modes (Reisinger, et al., 2017; Smith & Foran, 1988). Modelling in the long-term mode ensures that the modelled farming system is able to operate in perpetuity (Reisinger, et al., 2017). The Farmax model also incorporates economic analysis, based on schedules/pay-outs and expense data sourced from Beef + Lamb NZ and Dairy NZ, to allow for financial comparison of alternative management policies (Reisinger, et al., 2017).

Overseer FM

OVERSEER FM (Overseer) nutrient budget software is a tool used to model nutrient inputs, outputs, and balances for a variety of farming systems (Power, et al., 2002; Selbie, et al., 2013). Although originally designed to model maintenance fertiliser applications and changes in soil fertility, it has become an important regulatory tool (Reisinger, et al., 2017), now being the primary modelling system used in New Zealand to estimate emissions of nutrients from various farming systems (Holland & Doole, 2014). Overseer uses a combination of internal databases, empirical relationships, and farm specific data to model a farm system's nutrient inputs and outputs at both farm and management block scale. The results are reported in a nutrient budget (Cichota & Snow, 2009). Information required includes, but is not limited to: property location, rainfall, various livestock details, property topography, use of supplement, fertiliser applications, soil tests, and pasture types (Reisinger, et al., 2017). The Overseer model uses this information to provide an average annual estimation of nutrient loss and greenhouse gas emissions, which is then used to make informed decisions regarding alternative management practices, particularly decisions regarding application of fertiliser (Cichota & Snow, 2009).

Pathways of four main nutrients (N, P, K, and S) are modelled by the software. Boothroyd (as cited in Power et al., 2002) states that N is typically the most observed nutrient from an environmental perspective due to its significant impacts of water quality, with P typically being the second most observed. In order for Overseer to estimate nutrient losses, it must first calculate pasture dry matter intake (DMI). This is done by estimating livestock ME requirements that are derived from user input, and then making an adjustment for any dry matter (DM) supplied by supplements (Selbie, et al., 2013; Wheeler, Cichota, et al., 2011). According to Selbie et al. (2013) the intake of N and P is then estimated based on the nutrient content of the various sources of DM. The amount of N and P excreted by livestock is the balance of nutrient intake, less maintenance requirements and that removed as product, with the majority of N being excreted in urine, whereas the majority of P is excreted in dung (Selbie, et al., 2013). Pasture is the predominant fate of excreta, with the balance being split between laneways, structures, and effluent (Selbie, et al., 2013).

Selbie et al. (2013) also detail the four sub-models within Overseer that model N and P losses from the farm system. Two sub-models within Overseer handle the application of N to pasture, with each sub-model handling different sources. When N is calculated to have moved below the root zone, it is considered to have been leached, with this calculation done on a monthly basis. The immobilisation process keeps N within the system as it is recycled, in contrast, the processes of denitrification, volatilisation, and leaching cause the loss on N from the system. Within pastoral systems, there are only small losses from the background sub-model as much of the N is taken up by pasture. In contrast, the urine sub-model estimates larger leaching losses of N, that are primarily driven by drainage and water holding characteristics of the soil. Unlike N leaching loss, which is primarily from urine patches, P loss is predominantly from surface runoff of P derived from fertiliser, soil, supplements, effluent, and animal dung. Sources of P inputs are classified as incidental (fertiliser or effluent) or background (loss of natural soil P). The sum of the losses from these three sources is the total loss of P to water. Estimations of P loss through animal dung excreted directly into waterways, and deer fence-pacing and wallowing, are also considered. The P model within Overseer aims to model scenarios where sources of P runoff come into contact with waterways via transport drivers such as topography, soil properties, and various farm management practices (soil fertility, irrigation, drainage, fertiliser applications). Despite much of New Zealand's steep pastoral hill country being considered marginal for production due to high rates of erosion, Overseer does not consider P losses from erosion (Selbie, et al., 2013). Therefore, on marginal land that is subject to erosion, it is likely that Overseer is underestimating the losses of P from farming systems. Conversely, the environmental benefits of carbon forestry will be understated when integrated into farms that have significant portions of erosion as the benefit of reduced P runoff through reduced erosion is not being captured in the nutrient budget developed by Overseer. The main loss of N to water is via leaching and the main loss of P to water is via surface runoff. Both loss pathways will hereon be referred to as 'root zone' losses, or simply 'losses'.

In addition to modelling nutrient losses to soil, Overseer can also estimate greenhouse gas emissions (CH_4, CO_2, and N_2O) to air (Cichota & Snow, 2009; Reisinger, et al., 2017), which are expressed as CO_2-e over a 100-year period (Wheeler, Ledgard, et al., 2011). Within the Overseer model, emissions of enteric CH_4 are driven by livestock requirements for DMI and ME (de Klein, et al., 2017), with the resulting DMI values being multiplied by New Zealand National Greenhouse Gas Inventory emissions factors (MFE, 2021). De Klein et al. (2017) state that total enteric CH_4 emissions are calculated by applying known data regarding CH_4 emissions/kg DM to DMI figures derived from animal production and ME requirements. The calculation of DMI is also important for estimating N_2O emissions sourced from animal excreta, which are responsible for the majority of total N_2O emissions (de Klein, et al., 2017). Emissions of CO_2 are derived from either on-farm sources or are embodied in off-farm processes (Wheeler, Ledgard, et al., 2011). The composition of lime and fertiliser, and use of electricity and supplements, dictates the on-farm emissions of CO_2, whereas embodied off-farm CO_2 emissions are influenced by fuel use in transport, fertiliser and chemical manufacturing, and several other less significant sources (Wheeler, Ledgard, et al., 2011). Reisinger et al. (2017) concluded that enteric CH_4 is the predominant greenhouse gas emitted from pastoral farming systems, followed by N_2O, and then CO_2.

Radiata Calculator Pro Version 4.0

The Radiata Calculator Pro Version 4.0 (the Radiata Calculator) software is used for modelling Pinus radiata tree crop (Reisinger, et al., 2017). Narayan et al. (2012) investigated several growth and yield modelling software available for use in New Zealand and provides a more detailed description of the Radiata Calculator, which is summarised here. Development of the Radiata Calculator was a joint development project between two New Zealand forestry entities and is more commonly used by less-experienced users. The software is Excel based and provides several functions. It operates at the stand-level and comprises a growth model and carbon model. The growth model allows for user-defined location and productivity data to be input, as well as pruning and thinning parameters to be specified. A harvest simulation is then run to determine log volume by grade. The carbon model estimates the amount of CO_2 that is sequestered, based on the user-defined inputs. There are also several other useful aspects of the Radiata Calculator that enhance analysis, such as a financial model, multiple-run function, and incorporation of regional data.

Conclusion

New Zealand comprises a diverse landscape with a range of landforms throughout both the North and South Islands (Blaschke, et al., 1992; Lynn, et al., 2009). Processes of land formation and land settlement by European settlers has likely given rise to farm heterogeneity in terms of the quantum of marginal land contained within individual farms (MacLeod & Moller, 2006; McIvor, Douglas, et al., 2011). Furthermore, several studies have shown that pastoral farming has negative impacts on the environment (Dodd, et al., 2016; Franklin, et al., 2016; Reisinger, et al., 2017), with more intensively farmed land having a greater impact (Foote, et al., 2015). Carbon forestry has been shown to have numerous environmental benefits (Douglas, 2019; Moller, et al., 2008; Quinn & Stroud, 2002), however, the environmental benefits (Ausseil & Dymond, 2010; Pizzirani, et al., 2019) and economic benefits (Fogan & Pollard, 2020; Pizzirani, et al., 2019) do depend on the species of carbon forestry. Therefore, it is likely that economic and environmental impacts of carbon forestry integration on marginal pastoral land will vary between farms based on the quantum of marginal pastoral land, the carbon forestry species, and intensity of the base pastoral farming system.

Chapter Three: Materials, Methods, and Assumptions

Introduction

This research comprised of two quantitative case studies. It was proposed that the selected cases would provide differing insights into how the integration of carbon forestry on marginal pastoral land impacts economic and environmental performance of sheep and beef farms in New Zealand. This research intended to answer the question of:

> What impact does the integration of carbon forestry into marginal pastoral land within New Zealand sheep and beef farms have on the economic and environmental performance of the overall farm business?

Quantitative Case Study Research

The research strategy comprised the study of two cases, based on quantitative data analysis. By selecting multiple cases, as opposed to a singular case, this research provided a range of results that reflect the heterogeneity of sheep and beef farms within New Zealand to a greater extent (Seawright & Gerring, 2008).

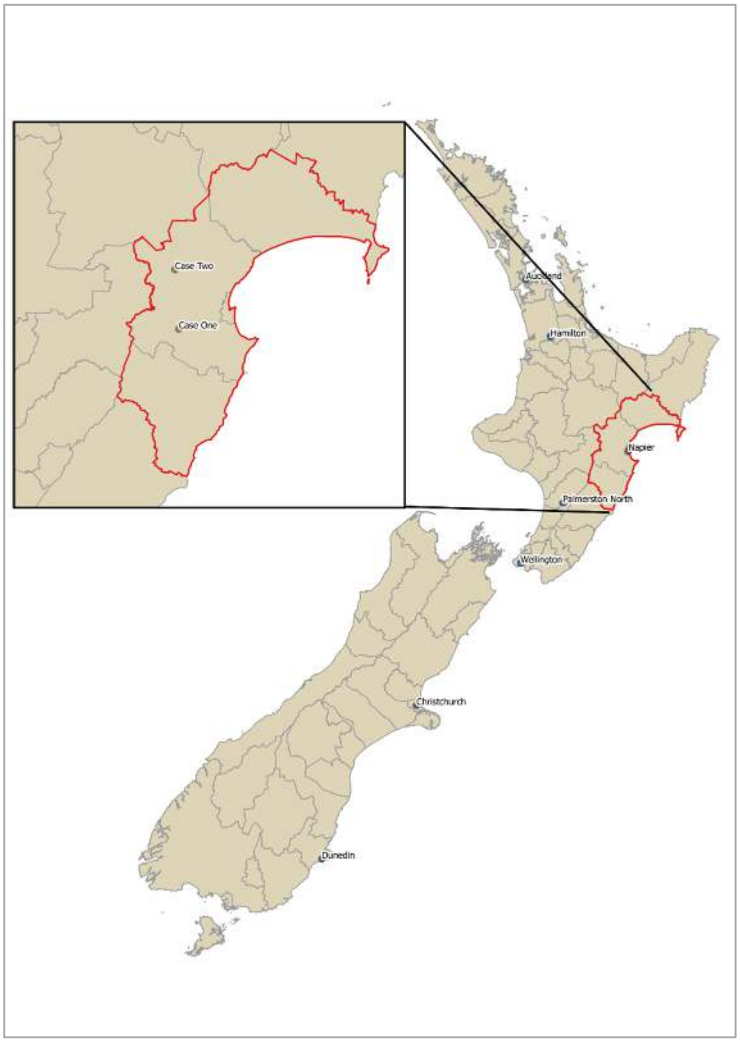
The variable upon which the diverse cases have been selected is the quantum of marginal pastoral land within them, expressed as a percentage of total farm effective area, which includes areas in crop, fallow, and pasture. The percentage of a farm that is marginal pastoral land was grouped into a categorical variable (i.e., 0 to 25%, 26 to 50%, 51 to 75%, and 76 to 100%), so cases that reflected both high and low values could be selected (Seawright & Gerring, 2008). By selecting case studies that reflected the full spectrum of variance of the variable, the representativeness of the research was increased (Seawright & Gerring, 2008). However, this research has not achieved saturation as only two cases have been researched (one each for two categories of 26 to 50% and 51 to 75%), and as there was only one case per category, there is the possibility that each does not fully represent other farms in the Hawke’s Bay Region that fall within that category. Therefore, this research will not be so comprehensive as to render the analysis of additional case studies unnecessary (Small, 2009).

As New Zealand sheep and beef farms are inherently different in many ways (Reisinger, et al., 2017), a typical case study was not suitable. A typical case is considered representative of the population (Seawright & Gerring, 2008), but a singular case cannot be considered to be typical of the entire range of sheep and beef farms, and therefore, an understanding of the economic and environmental impacts of carbon forestry integration into sheep and beef farms on marginal pastoral land cannot be gained from simply one case (Gerring, 2009). A selection of multiple case studies, each with varying characteristics, allowed for a more in-depth explanation of the results through cross-examination, and it also made the results more reliable if they were noted in more than one selected case.

Case Study Selection

The two cases that have been selected are sheep and beef farms within the Hawke's Bay Region of the North Island, New Zealand. Figure 1 outlines the territorial authority boundaries within New Zealand, and more specifically, the location of the two case study farms within the Hawke's Bay Region.

Figure 1: Map Showing Hawke's Bay Region in Wider Context of New Zealand



The selected case studies formed the 'base scenarios' of this research, and therefore, as part of the selection criteria they do not currently have any carbon forestry contained within them. If farms already had carbon forestry on them, their economic and environmental performance will have already been altered, and the integration of additional carbon forestry will likely result in a compounded effect to what is already altered economic and environmental performance. Furthermore, as this research involves investigating the impacts of carbon forestry integration within sheep and beef farms in New Zealand, the case study farms needed to exclusively run sheep and beef pastoral farming enterprises. Farms that ran dairying, cash cropping, or horticultural enterprises, for example, have not been considered. This is because the economic performance (Douglas, 2019; Reisinger, et al., 2017) and environmental performance (Journeaux, et al., 2020) of these enterprises is inherently different to sheep and beef farming and would not allow for a direct comparison.

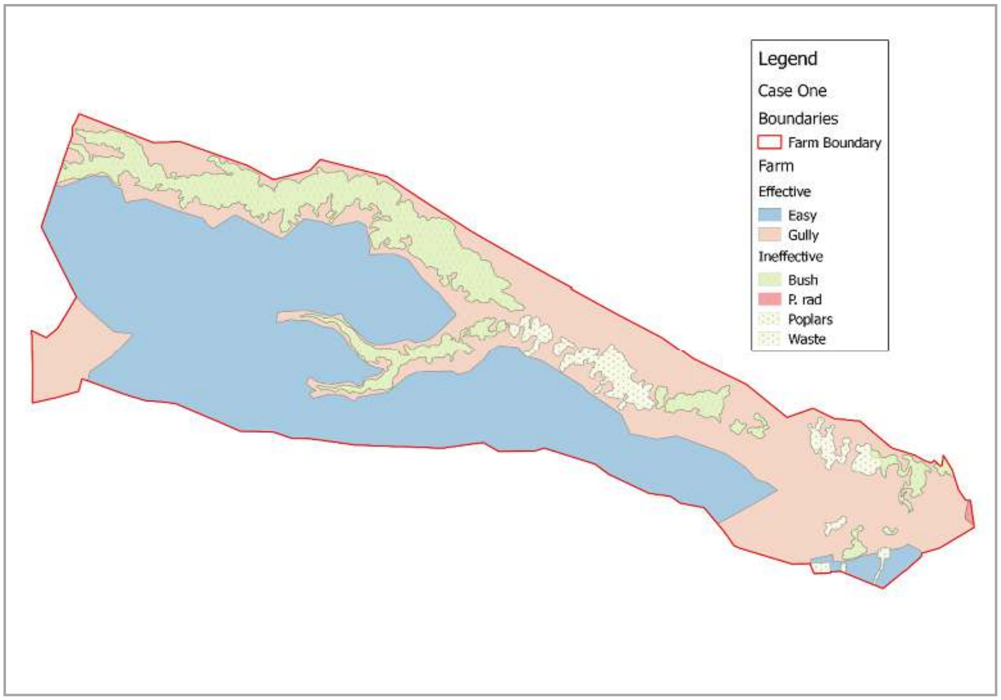
Case Study One

The first case study (Case One) is located near Maraekākaho, approximately 31 km west of Hastings. Median annual rainfall for the property is less than 800 mm, with rainfall typically being higher during the months of July to September, inclusive, and dry spells common over summer months (Chappell, 2013). Median annual average temperature is 12 to 13°C, with winters generally being July to August, inclusive, and mild in nature (Chappell, 2013). The property is 293 ha in size, with 247 ha effective farm area. Of the farmed area, 85 ha (34.3% of farmed area) is considered to be marginal pastoral land. Therefore, this case fell into the 26 to 50% category of quantum of marginal pastoral land. A livestock policy of lamb, steer, and heifer finishing is undertaken on the property, with no breeding stock. No cropping is undertaken, but a re-grassing programme is undertaken. No animal feed supplements are purchased.

A stock unit (SU) is a method of estimating livestock numbers for varying species and age classes based on feed demands. The farm/farmed ha includes all land that is used for pastoral production within the property boundary of a farm. From the base Farmax model, which further defines one SU as 550 kg DM eaten/year, a stocking rate of 7.1 SU/farmed ha was calculated, equating to a total of 1,762 SU.

Figure 2 is a map of LMUs identified for Case One, which have been used as the basis for formulating Farmax farmlets and Overseer management blocks, which are software-specific terms for LMUs, for the base scenario models. For the effective LMUs of both case study farms, the names are based upon case study farmer preference and have not been standardised, so as to avoid any potential confusion as to the similarity of LMUs of the same name between case study farms.

Figure 2: Map of Case One Base Scenario Land Use

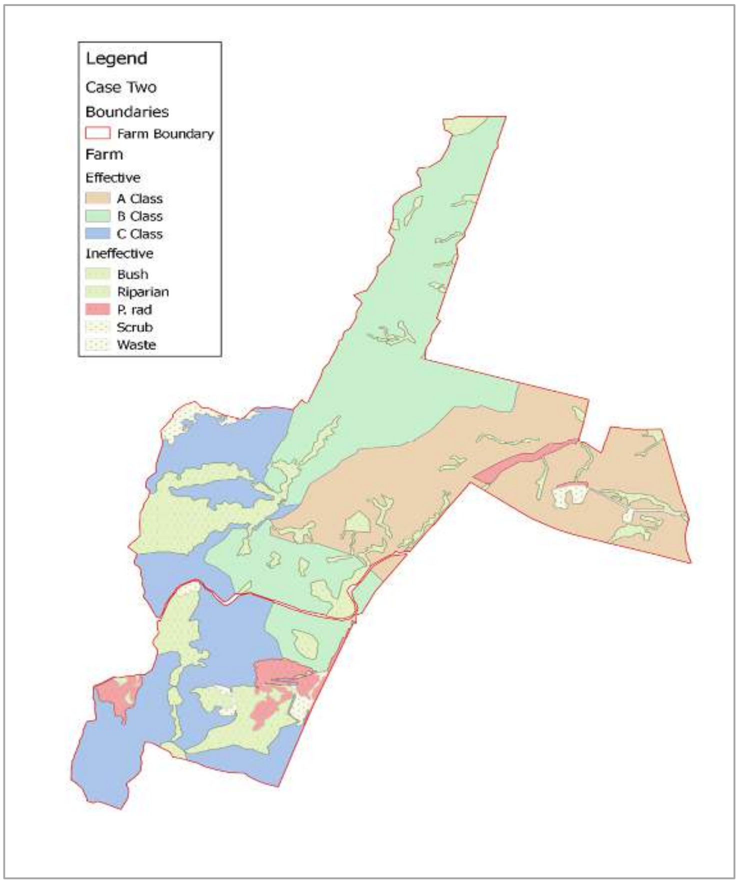


Case Study Two

The second case study (Case Two) is located near Puketitiri, approximately 68 km northwest of Hastings. Median annual rainfall for the property is from 1,500 to 1,600 mm, with rainfall typically being higher during the months of June to September, inclusive, with a relatively even distribution of rainfall among other months (Chappell, 2013). Median annual average temperature is 10 to 11°C, with winters generally being harsher than those experienced in the wider Hawke's Bay Region (Chappell, 2013). The property is 559 ha in size, with 443 ha effective farm area. Of the farmed area, 300 ha (67.8% of farmed area) is considered to be marginal pastoral land. Therefore, this case fell into the 51 to 75% category of quantum of marginal pastoral land. The livestock policy is based around sheep and beef breeding, with an element of stock finishing. Winter cropping for the purposes of livestock consumption is undertaken in the form of Kale and Swedes, as well as there being a permanent Lucerne forage crop. Additional animal feed supplements are produced and fed on-farm. From the base Farmax model, a stocking rate of 12.3 SU/farmed ha was calculated, equating to a total of 5,456 SU.

Figure 3 is a map of LMUs identified for Case Two, which have been used as the basis for formulating both the Farmax farmlets and Overseer management block for the base scenario models.

Figure 3: Map of Case Two Base Scenario Land Use



Comparison with Class Averages

As shown in Table 2, both case study farms are smaller, in terms of farmed ha, than the average for Class 4 N.I. Hill Country – East Coast. Furthermore, Case Two has a higher stocking rate than both Case One and the class average, with Case One having a lower stocking rate than both Case Two and the regional average. This is despite Case One have the smaller quantum of marginal pastoral land within it, compared to Case Two.

Table 2: Comparing Case Study Farms' Physical Parameters with Class Average

	Farmed ha	SU/ha	Total SU
Class Average	564	8.6	4,874
Case 1	247	7.1	1,762
Case 2	443	12.3	5,456

Note. Adapted from Eastern North Island – Class 4 Hill Country by Beef + Lamb New Zealand. 2021.

Case Study Methods

Data has been collected from two case study farms, which has then been analysed utilising a suite of modelling tools, with results from the modelling tools being collated and further analysed in an Excel spreadsheet (the spreadsheet).

Data Collection

Semi-structured interviews were the preferred data collection type when analysing cases as they allowed for a combination of both structure and flexibility (Legard, et al., 2013). It was proposed that part of the interview be more structured and formal, following a prescribed process, but that part of the interview be less formal, allowing for more of a discussion around the farmer's goals and objectives. An interview guide was used to provide structure and consistency to the formal part of the interview and ensured that the required data was collected for each case. The guide was based upon required inputs for the modelling software that are to be used to drive the analysis of the data – being Farmax and Overseer. The less formal part of the interview was held in conjunction with a field visit of the farm itself, consisting of a tour to gain an appreciation for its characteristics, such as access, topography, and land cover. A loose set of prompting questions that will encourage the farmer to discuss various aspects of the property were utilised to prompt answers. This part of the interview was critical for understanding the farmer's attitude towards carbon forestry integration, which species are preferred, and which areas of the farm should be afforested.

Quantum Geographic Information System

Quantum Geographic Information System (QGIS), which is a mapping software, was used to generate spatial information pertaining to numerous aspects of each case study farm. Several datasets were used to analyse topography, land cover, LUC class, forestry productivity, and ETS land eligibility information pertaining to each case study farm. Furthermore, spatial information was generated by the researcher based upon data collected from the farmer interviews to establish areas for afforestation and transport distances to forestry processing sites. All spatial information created within QGIS was exported into the spreadsheet where it was further analysed to formulate inputs for the remainder of the research. The information from QGIS was the foundation for all Farmax farmlets, Overseer management blocks, as well as productivity information for inputs into the Radiata Calculator.

The quantum of marginal pastoral land within each of the case study farms was estimated using QGIS. The farm boundary was mapped to the fence lines, and then all ineffective areas (e.g. native bush, forestry plantation, waterways, and any other non-grazing areas) were also mapped. The balance area (farm boundary less ineffective areas) was taken to be the farmed area, upon which the NZLRI Land Use Capability shapefile (Landcare Research, 2010) was overlayed to give an area breakdown of the effective farming area by LUC Class.

Figure 4 is a map of the LUC Classification of Case One, which has been used to identify the quantum of marginal pastoral land within the farm.

Figure 4: Map of Case One LUC Classification

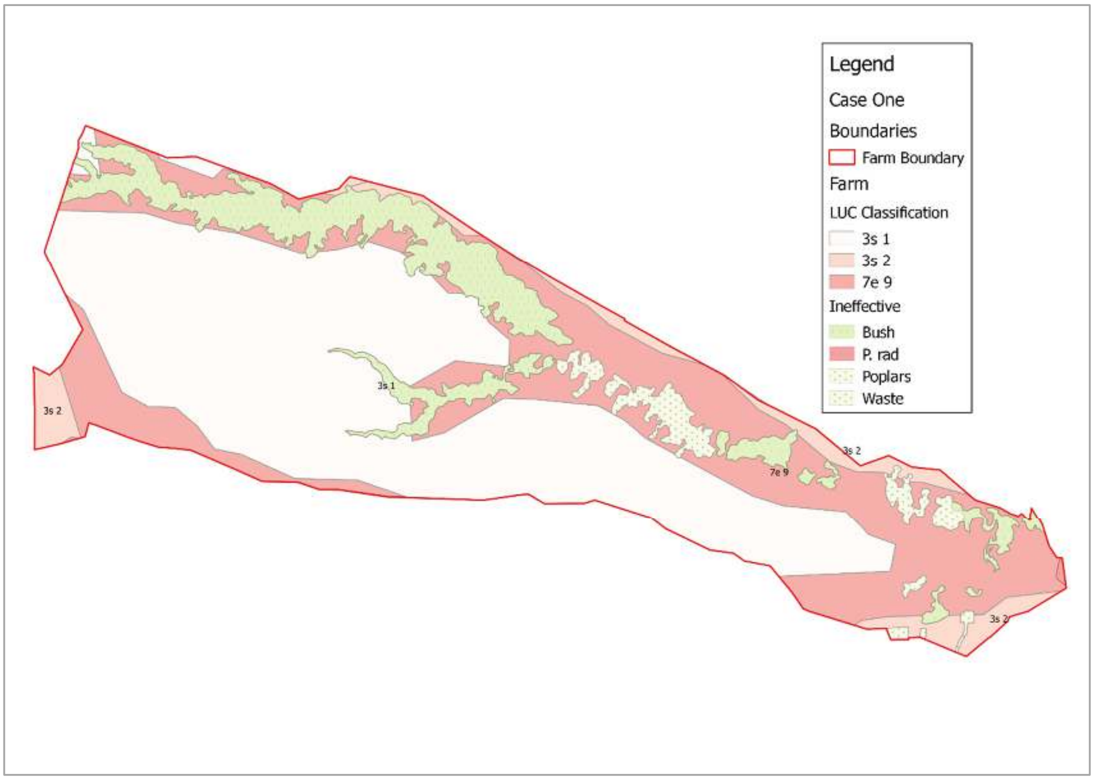
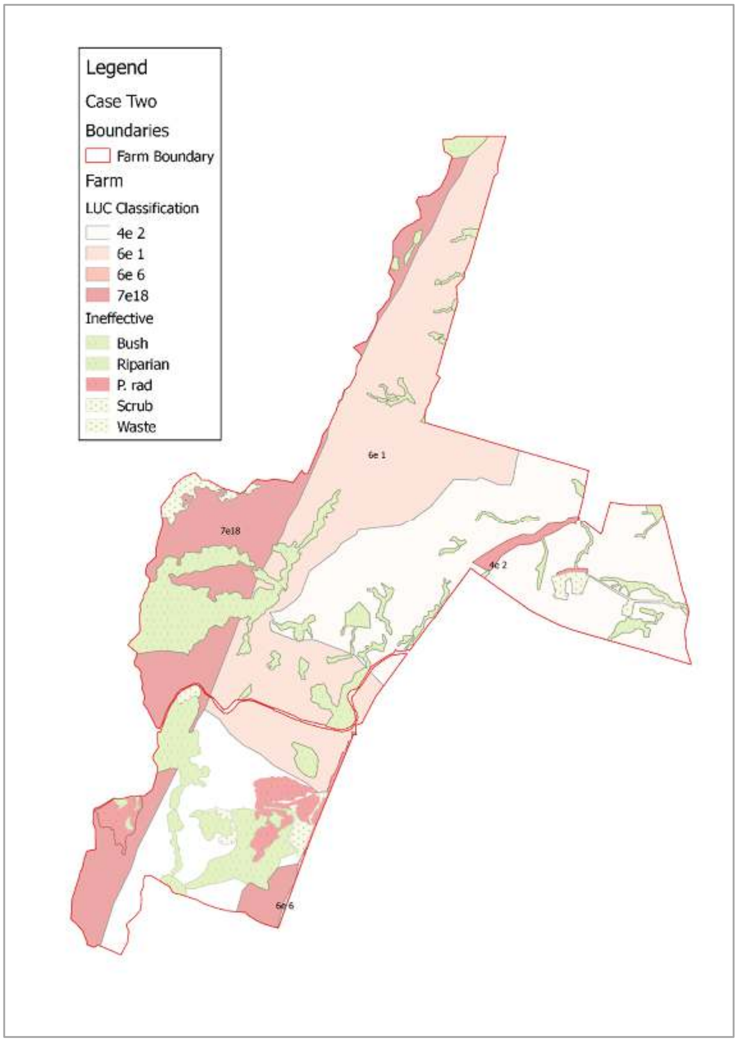


Figure 5 is a map of the LUC Classification of Case Two, which has been used to identify the quantum of marginal pastoral land within the farm.

Figure 5: Map of Case Two LUC Classification



The ETS eligibility of each case study farm has also been assessed within QGIS. As previously outlined, in order for land to be able to generate income through CO_2 sequestration, it must meet certain criteria. Post-1989 forest land means forest land that –

i. was not forest land on 31 December 1989
ii. land that was forest land on 31 December 1989 but was deforested in the period beginning on 1 January 1990 and ending on 31 December 2007 (Section Four, Climate Change Response Act 2002).

In order to assess whether land is Post-1989 eligible land within the ETS, several datasets were relied upon to create one shapefile layer in QGIS that accurately reflected the ETS status of land within each case study. Firstly, a shapefile layer that contains land use classifications in accordance with the Kyoto Protocol

(Landcare Research, 2020) was imported into QGIS. This shapefile layer was predominantly used as a guide to aid in classification when utilising the following aerial imagery sources. Secondly, historic imagery sourced online (Local Government Geospatial Alliance, 2020) was imported into QGIS and georeferenced. The aim was to source imagery as close to 31 December 1989, so the land use classification at that date could be most accurately determined. Thirdly, historic imagery captured as close to 2007 was also sourced (Google) to assess the land classification as at 31 December 2007. Thirdly, current aerial imagery (Aerial Surveys Ltd, 2016) of each farm was used in tandem with the field inspection to determine the current classification of land within each case study farm. Unlike mapping of other characteristics within this research, the ETS Eligibility mapping has been constrained to the legal boundary of each case study farm. This has been done as without an agreement in place, a landowner of one property cannot claim NZUs from another property (e.g. a neighbouring farm where there are “give/take” boundaries where fence lines do not run to the legal boundary).

The following land classifications have been derived from analysis of the above data sources, and have been included within this research:

Greenfields GB: land that is classified as being Post-1989 eligible within the ETS and able to generate revenue through CO_2 sequestration, but is currently used for pastoral farming. This land classification is also of easy contour (less than 30% slope), being able to be harvested by ground-base mechanisms.

Greenfields HB: land that is classified as being Post-1989 eligible within the ETS and able to generate revenue through CO_2 sequestration, but is currently used for pastoral farming. This land classification is also of steep contour (greater than 30% slope), being able to be harvested only by hauler-base mechanisms.

P89 Plantation: land that is classified as being Post-1989 eligible within the ETS and able to generate revenue through CO_2 sequestration, which is currently afforested.

P90 Plantation: land that is classified as being Pre-1990 within the ETS and unable to generate revenue through CO_2 sequestration, and that is currently afforested.

P89 Native: land that is classified as being Post-1989 eligible within the ETS and able to generate revenue through CO_2 sequestration, and that is currently covered with indigenous forest.

Native Forest: land that is classified as being Pre-1990 within the ETS and unable to generate revenue through CO_2 sequestration, and that is covered with indigenous forest.

Unplantable/setbacks: this is land that has been classified as setbacks from powerlines, waterways, property boundaries, 'give area', and land that is otherwise unplantable due to physical characteristics on the land.

Both the Greenfield GB and Greenfield HB classifications have been adopted as potential net stocked area (NSA), which is the area of land upon which the desired forest species in planted. The P89 Plantation, P90 Plantation, P89 Native, Native Forest, and Unplantable/setback classifications form the unproductive areas of the potentially plantable area (PPA), which includes the NSA of desired forest species, roads, skid sites, and unplantable areas such as boundary, waterway and powerline buffers, and other non-plantable areas. Figure 6 is a map of the ETS Eligibility land classification of Case One, which has been used to identify areas of the farm suitable for carbon forestry.

Figure 6: Map of Case One ETS Land Eligibility Classification

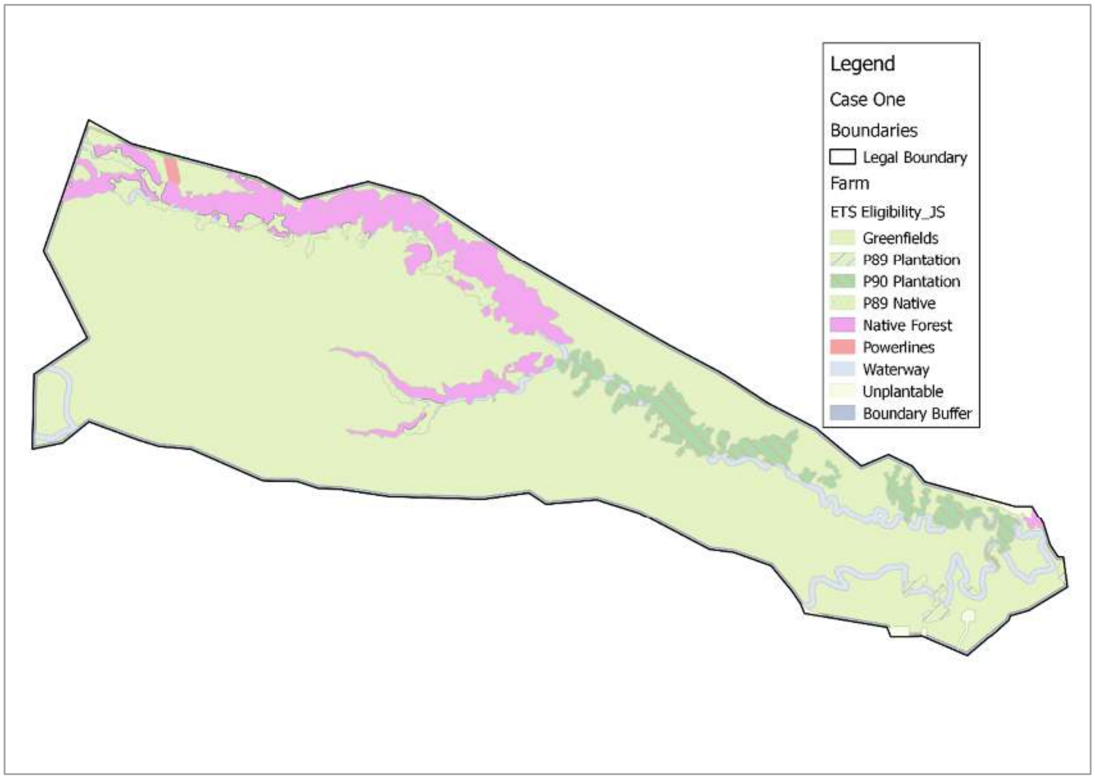
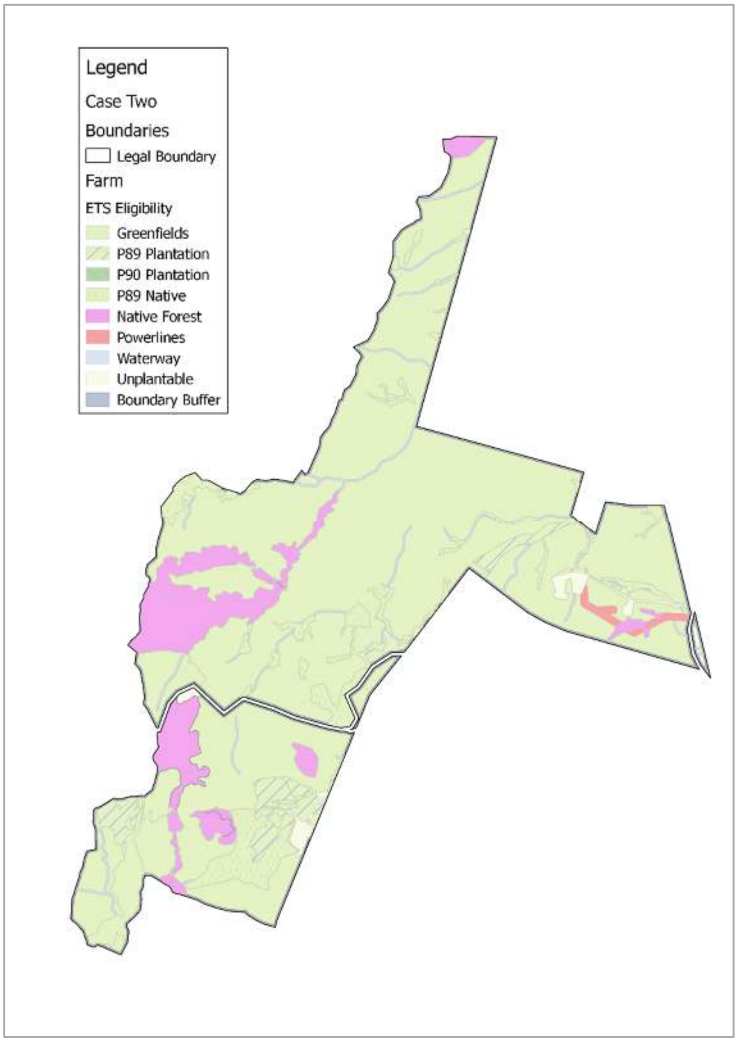


Figure 7 is a map of the ETS Eligibility land classification of Case Two, which has been used to identify areas of the farm suitable for carbon forestry.

Figure 7: Map of Case Two ETS Land Eligibility Classification



The QGIS software used within this research was Version 2.18.27 ('Las Palmas').

Farmax Modelling

During the interview stage, information was gathered from the case study farmers to allow for the creation of a Farmax 'base scenario'. The base scenario reflects the case study farmers' preferred management plan for their property. Modelling the preferred management plan, instead of the management plan that was actually implemented in the modelling year, ensured that a stressed farm system e.g. by climatic conditions, market anomalies, or budget constraints, was not modelled. This was done as it is likely that a stressed farm system would have different economic returns than the preferred base scenario, and it also would not accurately reflect the environmental footprint of the farm, which would influence the results of this research. The modelled preferred management plans for both case studies that formed the base scenarios were not significantly different to the actual management plans that were implemented by each farmer in the year that was modelled. This means that the preferred management plans reflect the core of the currently operated management plans of each case study farmer. The year modelled within this research is 2019/20.

When modelling the base scenario; livestock, cropping, and supplement data from the farmer were input based on farmer knowledge. Pasture growth rates were initially based on those contained within the Farmax library but were subsequently altered based on farmer knowledge. Farmax has the ability to divide the farm into farmlets to separately assess the biological feasibility of a stock policy, and the associated profitability, for individual parts of the farm. The relative productivity of each farmlet was estimated based on stock grazed on each farmlet, at specific times of the year. The base scenario was then finessed to create a biologically feasible scenario in the ‘long-term’ state. Refer to Appendix A for feasible Farmax scenarios.

Current schedule prices for the 2019/20 year were used to estimate gross revenue from livestock sales. This was done to reflect the case study farmers’ ‘base scenario’, which has been developed in response to current market prices, not an average of prices from several years ago. Gross revenue was apportioned between farmlets based on total kg DM eaten per farmlet. This method has, however, given rise to potential issues, with livestock revenue from one farmlet being apportioned to another farmlet that said livestock are not present on, and therefore, do not derive any benefit from. There are, however, issues with the assumptions that drive the calculation of gross revenue for each farmlet within Farmax that made it unsuitable to utilise this feature within this research. Therefore, in the absence of an alternative method, gross revenue has been apportioned to each farmlet based on total kg DM eaten per farmlet, as calculated within the Farmax base scenario.

In contrast to income, expenditure has been based on a modified version of the Beef + Lamb New Zealand Farm Survey of Class 4 N.I. Hill Country – East Coast and averaged over several years. An average of three years of expenditure data (2017/18, 2018/19, and 2019/20 provisional) was used because at the time the research was undertaken only provisional results, that had not been finalised for the modelling year, were available from Beef + Lamb NZ. By adopting the three-year average figures compared to the provisional 2019/20 year, there was only an average difference of 1.7% in per ha expenditure. Where the Farmax model estimates costs (animal health, shearing, velveting, feed, crops, and grazing, nitrogen) the Beef + Lamb NZ costs have been overridden and the Farmax expenses adopted. Furthermore, the Beef + Lamb NZ costs have been manipulated where necessary to reflect actual practices of the case study farm (e.g., wages, fertiliser, lime, rates, wages of management), and reflect the higher costs associated with some farmlets. For example, if re-grassing was only undertaken on one farmlet, the cost of re-grassing was assigned only to this farmlet. Furthermore, if the costs of weed and pest control, for example, were higher on one farmlet (as outlined by the case study farmer) then a higher weighting of this expenditure type was apportioned to that farmlet. Interest and principal repayments, rent/lease, drawings, tax, and depreciation have been excluded. The modelled gross farm revenue and total expenditure were then exported in the spreadsheet to be apportioned between farmlets based on total feed eaten on each farmlet. Refer to Appendix B for a summary of the livestock schedule prices and expenditure adopted for each case study farm. The software used within this research was Farmax Red Meat Advantage Version 8.1.0.19.

Overseer Modelling

During the interview stage with case study farmers, data was also collected to allow for the preparation of an Overseer model that reflected the same base scenario that had been prepared within Farmax. The same spatial information from QGIS that was used to form farmlets within Farmax, has been used to create management blocks within Overseer to ensure that the areas in both Farmax and Overseer were identical. Data that had been used to prepare the base scenario within the Farmax model was manually imported into Overseer to mirror the base scenario from Farmax. This mirroring required the transferring between software of farmlet areas, livestock numbers, relative productivity of management blocks, cropping regimes, crop yields, and supplements. Other data required to complete the Overseer models was sourced from the farmer during the interview. Refer to Appendix C for base scenario Overseer summaries.

As Farmax and Overseer have different definitions of a SU, an adjustment had to be made when transferring livestock data from Farmax to Overseer. Farmax defines one SU as “550 kg DM eaten/year” (T. Botica, December 11, 2020), whereas Overseer defines one SU as “6,000 MJME consumed/year” (White, et al., 2010). Therefore, entering stock numbers directly from Farmax into Overseer as a stock reconciliation resulted in variances in total SU, which is a result of different assumed levels of feed quality (ME content) between the two models. Therefore, a calculation was done in the spreadsheet to allow for conversion of stock numbers from Farmax to Overseer, and stock numbers were entered using the ‘revised stock unit (RSU) method’ in

Overseer, which means that instead of a detailed stock reconciliation being input, only total SU for each enterprise were input. The software used within this research was OverseerEd Model Version 6.3.5.

Development of Afforestation Scenarios

Three levels of carbon forestry integration were modelled for each carbon forestry type, for each case study farm as part of this research. Firstly, a 'preferred afforestation' integration level was modelled, which reflected the farmer's preferred area of afforestation and preferred carbon afforestation type (carbon forestry species that accounts for the adopted regime). Secondly, a 'total afforestation' scenario was modelled, which reflected afforestation of the entirety of the marginal pastoral land within the case study farm, once again, with the farmer's preferred afforestation type. Both the preferred and total afforestation integration levels were modelled over a base 27-year period. Finally, a 'permanent afforestation' scenario was modelled, which reflected the level of afforestation that is required for the case study farm to be CO_2 neutral over a base 50-year period, using the farmer's preferred afforestation type. Spatially, the preferred afforestation area was identified by the farmer on a map, with boundaries of the afforestation area typically being fence lines. The total afforestation area was identified by selecting the entirety of the marginal pastoral land in the created LUC Classification shapefile within QGIS. Figure 8 is a map of Case One, showing the afforestation PPA for the preferred afforestation integration level, as well as the land use of the balance farm.

Figure 8: Map Showing Land Use of Case One for Preferred Afforestation Integration Level

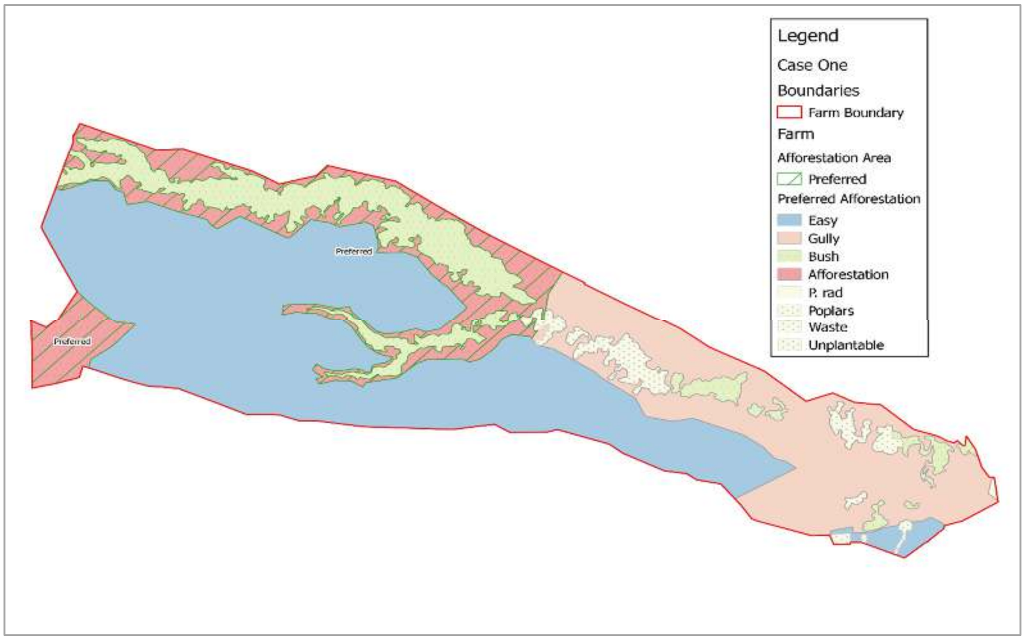


Figure 9 is a map of Case Two, showing the afforestation PPA for the preferred afforestation integration level, as well as the land use of the balance farm.

Figure 9: Map Showing Land Use of Case Two for Preferred Afforestation Integration Level

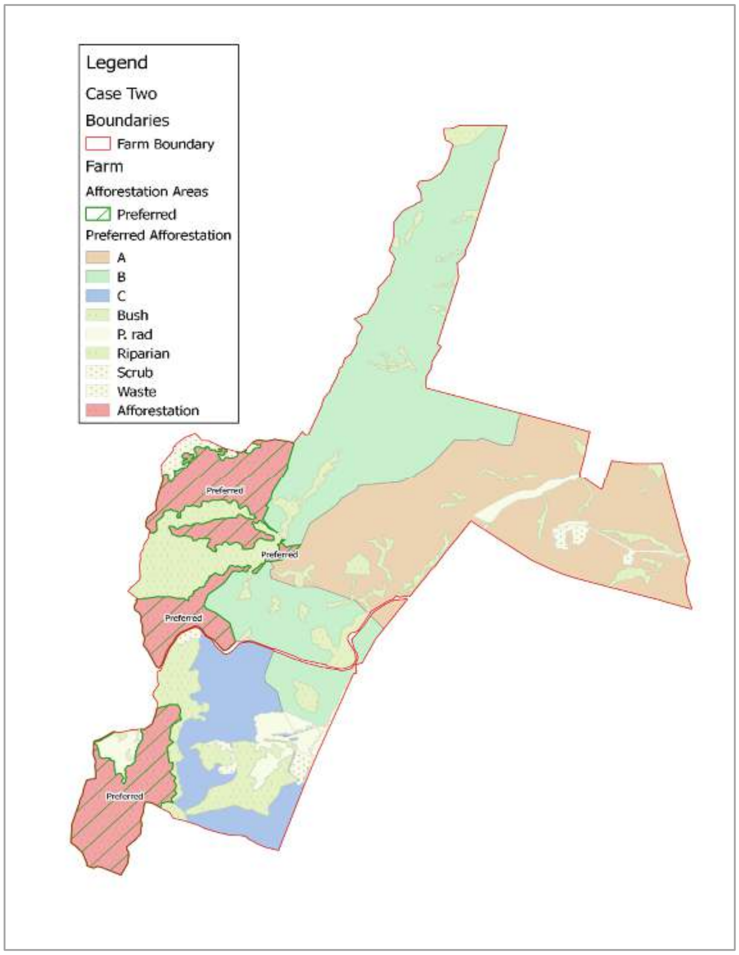


Figure 10 is a map of Case One, showing the afforestation PPA for the preferred and total afforestation integration levels, as well as the land use of the balance farm. Note: both the areas labelled ‘preferred’ and ‘total’ are included within the total afforestation PPA.

Figure 10: Map Showing Land Use of Case One for Total Afforestation Integration Level

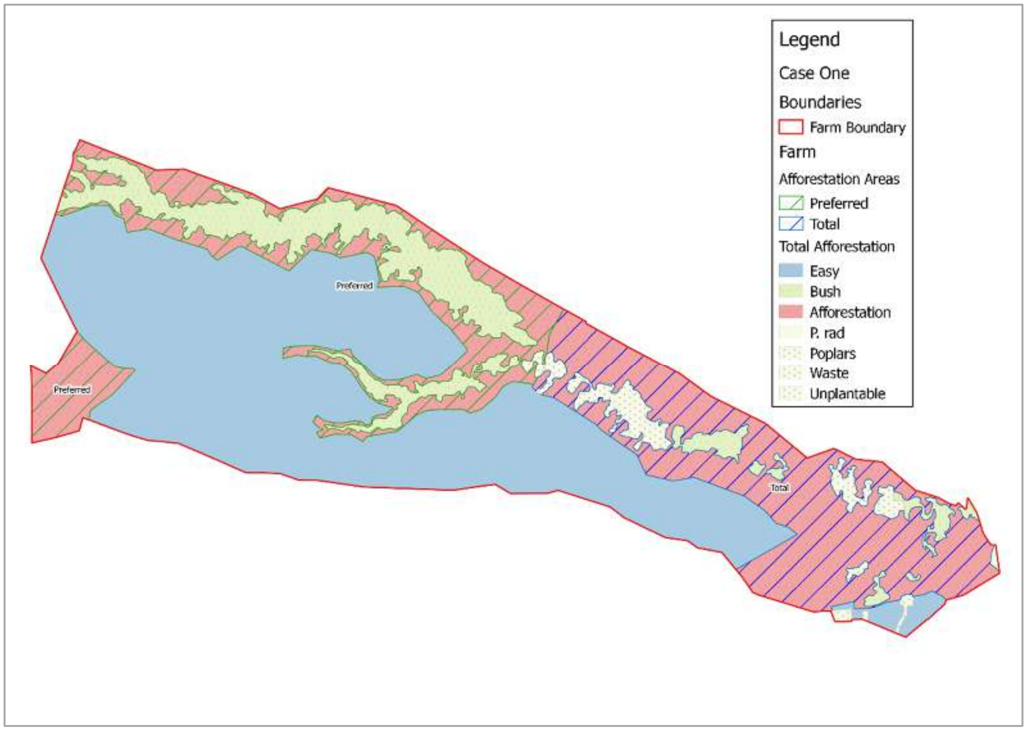
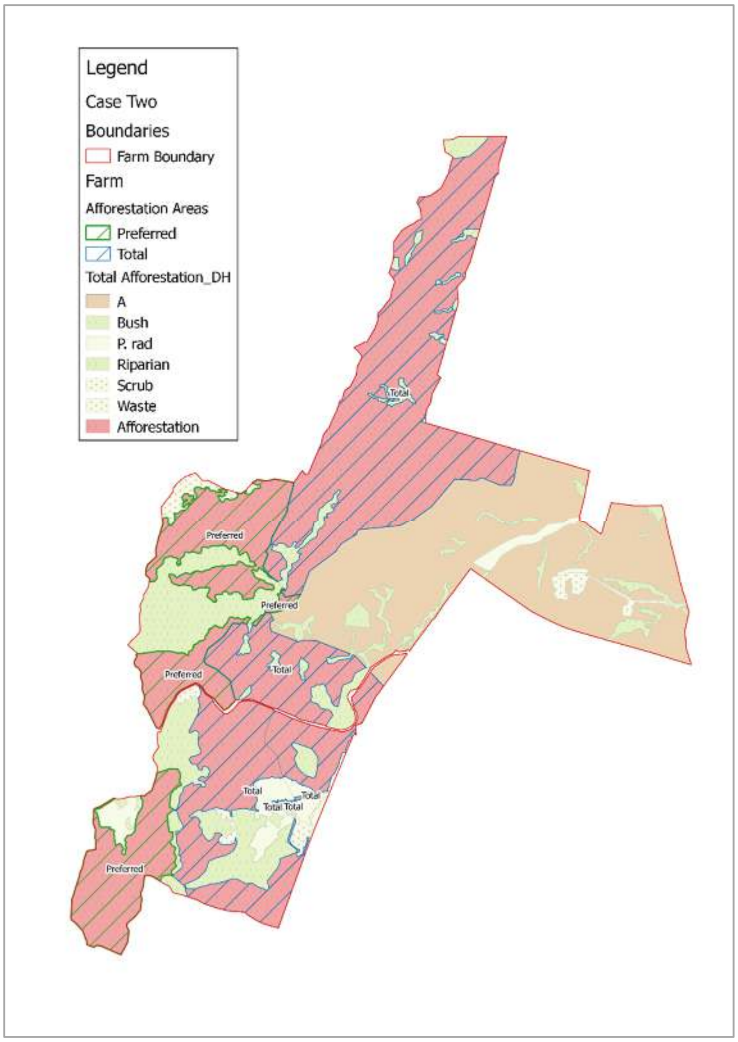


Figure 11 is a map of Case Two, showing the afforestation PPA for the preferred and total afforestation integration levels, as well as the land use of the balance farm. Note: both the areas labelled ‘preferred’ and ‘total’ are included within the total afforestation PPA.

Figure 11: Map Showing Land Use of Case Two for Total Afforestation Integration Level



Once the areas of afforestation had been identified and quantified using QGIS, reductions to sheep and beef enterprise total SU were estimated within the spreadsheet, based upon the reduction in total kg DM eaten as a result of the part of the farmed area now being afforested, and no longer being able to be used for pastoral production. The exception to this was the space-planted poplars afforestation type, in which it was assumed that some livestock grazing would still occur on the afforested land. Therefore, the reduction in SU took into consideration the retained pastoral grazing on the land that the space-planted poplars were to be afforested. Refer to section 'Space-planted Poplars' for an overview of this calculation. The reduced farmed areas and SU figures were then input into a new Overseer model ('preferred afforestation'), which also accounted for any changes in fertiliser, cropping, and other management practices. This method was repeated for the total afforestation and permanent afforestation integration levels.

Additional Farmax models were not run to reflect the three afforestation scenarios as there was no intensification of the remaining pastoral land, so the physical and economic productivity of the balance land on a per farmed ha basis was assumed to remain constant. This allowed for the same method that has been used to reduce SU between afforestation integration levels to be applied to reductions in gross revenue and expenditure. As it was assumed that no intensification of the balance of the pastoral farming system occurred within the afforestation integration scenarios, care was taken when transferring data into the new corresponding Overseer file that the levels of pasture eaten on each management block remained similar to that of the base scenario. A change of less than 100 kg DM per ha per management block was tolerated, with larger variations requiring investigation. This process was repeated for each of the three afforestation integration levels.

Forestry Modelling

Various methods were used for modelling the economic and environmental impacts of carbon afforestation types subject to this research and they will be discussed in detail in the following sub-sections. For each of the carbon forestry types, both a short-term and long-term option was modelled. The short-term option is based on a 27-year period, being adopted within the preferred afforestation and total afforestation integration levels, and the long-term option is based on a 50-year period, being adopted within the permanent afforestation integration level. This has been done to allow for comparison of pastoral farming to a harvest regime or a permanent carbon sink initiative. The NZU price has been assumed at $35/unit for all forestry scenarios.

Two different carbon accounting approaches have been adopted within this research. Firstly, the 'averaging approach' has been adopted for the short-term Pinus radiata afforestation scenarios (afforestation type/integration level), which assume a harvest at year 27. The averaging approach allows carbon forests to earn NZUs up until the 'average age', which is calculated as the forest age at which the average CO_2 storage over multiple rotations (including growth and harvest) is reached (MPI, 2021a). The average age adopted within this research is 17. If carbon forests are entered into the averaging approach, NZUs are only generated for the first rotation of forestry, but there are no deforestation liabilities upon harvest (MPI, 2021a). The second approach, which has been adopted for the long-term Pinus radiata afforestation scenarios, as well as for all other afforestation types (space-planted poplars and Mānuka/conifer-broadleaved native forest), is the permanent post-1989 approach. Essentially, it has been adopted for all afforestation scenarios in which timber harvest is not assumed. The permanent post-1989 category within the ETS allows for the generation of NZUs so long as the carbon forest is sequestering CO_2 (MPI, 2021b). This means the carbon forest cannot be harvested for a minimum of 50 years without facing deforestation liabilities (MPI, 2021b). At the end of the initial 50-year period, the carbon forest can be harvested, requiring the surrender of NZUs claimed, or it can be registered for another 25-year period for the continued earning of NZUs (MPI, 2021b). Within this research, where the stock change approach has been adopted, it is assumed that NZUs are earned for the entirety of the investment period, as opposed to only a 17-year period under the averaging approach.

The Site Index and 300 Index are two commonly used measures of site quality for growing of Pinus radiata in New Zealand (Kimberley, et al., 2005). The 300 Index is the average annual growth (expressed as m^3/ha/year) of a stand that has been pruned to a final height of six metres and thinned to a final stocking of 300 sph on a 30-year rotation, whereas, the Site Index is the average top height (expressed in metres of the largest 100 diameter sph) at year 20 (Kimberley, et al., 2005). The Site Index has been sourced from an internal library in the Radiata Calculator, with a figure of 31 used for all afforestation scenarios in both cases. In contrast, the 300 Index has been separately assessed by analysing a shapefile layer in QGIS that contains data outlining the spatial variability of the 300 Index productivity measure throughout the North Island of New Zealand, down to an area of 0.1 ha. This shapefile categorises the 300 Index into 11 categories, with each generally having a range of 2.5 units. Therefore, a different 300 Index range has been assigned to each afforestation integration level for both case study farms. These results are outlined in Table 3.

Table 3: Analysed 300 Index Range for Each Afforestation Integration Level

	Afforestation Integration Level	
	Preferred	Total
Case One	27.5-30	27.5-30
Case Two	30-32.5	30-32.5

As only a range has been able to be extrapolated from the 300 Index shapefile analysed in QGIS, expert opinion has been relied upon to determine a single 300 Index figure within the analysed range. The Site Index and 300 Index figures adopted for the preferred afforestation integration level have also been adopted for the permanent afforestation integration level. These figures are shown in Table 4.

Table 4: Adopted 300 Index Values for Each Afforestation Integration Level

	Afforestation Integration Level	
	Preferred	Total
Case One	29	28
Case Two	30	32

Both Site Index and 300 Index have been input into the Radiata Calculator to estimate CO_2 stocks for both the Pinus radiata and space-planted poplars, as well as the expected log yields of the Pinus radiata plantation option. CO_2 stock estimates generated by the Radiata Calculator have been adopted as the CO_2 sequestration rates when the afforested area is 100 ha or more in size (MPI, 2018b) to estimate a yield table specific to the case study farm. In contrast, for afforested areas less than 100 ha in size, default Look-up tables have been used (MPI, 2017).

Pinus radiata

The land preparation and silvicultural regime adopted for both the short-term and long-term Pinus radiata afforestation types is outlined below:

- Aerial desiccate pre-plant spray in year zero
- Establishment at 833 sph in year one
- Spray release in year one
- Blanking of 10% of stems in year two
- Waste thin to 450 sph in year 10
- Pre-harvest inventory in year 26 (short-term option only)

A spray release is used to reduce seedling growth competition from grass (Balneaves, 1982), whereas, blanking is the process of replacing dead seedlings to achieve initial stocking levels (Chavasse, et al., 1981). A blanking rate of 10% (equating to 83 sph) has been assumed as survival rates for Pinus radiata seedlings are typically high, providing sound management (Menzies, et al., 2001).

The costs of land preparation and silvicultural regime adopted for the Pinus radiata afforestation types are outlined in Table 5.

Table 5: Pinus radiata Land Preparation/Silvicultural Costs

Land Preparation/Silvicultural Costs						
Operation	Preferred		Total		Permanent	
	Year	Cost $/ha	Year	Cost $/ha	Year	Cost $/ha
Operation Costs						
Aerial Desiccate - Grass	0	$356	0	$356	0	$356
Planting	1	$1,384	1	$1,384	1	$1,384
Releasing - Grass	1	$331	1	$331	1	$331
Releasing - Scrub	1	$0	1	$0	1	$0
Blanking	2	$115	2	$115	2	$115
Thin to Waste	10	$952	10	$952	10	$952
Pre-harvest Inventory	26	$50	26	$50	n/a	n/a
Operation Cost Total		$3,187		$3,187		$3,137

The short-term option is modelled to be harvested at age 27, whereas the long-term option remains unharvested at year 50. The log grades and adopted prices per grade for the short-term production forestry option are outlined in Table 6.

Table 6: Showing Log Grades and Adopted Prices

Log Prices (NZD $\$/m^3$)	
Grade	**18 mth avg.**
Export AL	113
Export AS	113
Export KIL	95
Export KIS	95
Export KL	101
Export KS	101
Ex Pulp	83
Dom Pulp	51

Log prices as shown above have been sourced from M. Morice (personal communication, October 8, 2020). All log grades, with the exception of Dom Pulp, are assumed to be transported to Napier Port, with the Dom Pulp transported to Pan Pac Forest Products Limited, Whirinaki. For a detailed breakdown of harvest revenue and costs, refer to Appendix D.

Space-planted Poplars

Two silvicultural regimes were adopted for this species: firstly, to reflect sites that are subject to high erosion an ‘intensive poplars’ regime was modelled, and secondly, for sites that are not subject to heavy erosion an ‘extensive poplars’ regime was modelled. The development of the two regimes has been based on numerous studies investigating the benefits of space-planted poplars for reducing hillside erosion (Horizons Regional Council, 2014; McIvor & Douglas, 2012; National Poplar and Willow Users Group, 2007; Plant and Food Research, 2011; Wilkinson, 1992).

The land preparation and silvicultural practices adopted for the ‘intensive poplars’ regime are outlined below:

- Establishment at 160 sph in year one
- Spray release in year one
- Blanking of 20% of stems in year two
- Form prune 60 sph to a dominant leader in year three
- Prune 60 sph to four metres in height in year five
- Prune 60 sph to six metres in height in year nine
- Waste thin to 60 sph in approximately year 13

The silvicultural practices adopted for the ‘extensive poplars’ regime are outlined below:

- Establishment at 60 sph in year one
- Spray release in year one
- Blanking of 20% of stems in year two
- Form prune 60 sph to a dominant leader in year three
- Prune 60 sph to four metres in height in year five
- Prune 60 sph to six metres in height in year nine

Blanking rates adopted for the space-planted poplars are higher than those adopted for Pinus radiata. However, the adoption of 20% is in line with research by McIvor and Hedderley et al. (2011), who investigated the survival rates of poplars within six climatic zones in New Zealand. The same 60 sph receive each of the three modelled prunes, with the remaining 100 sph within the ‘intensive poplars’ regime receiving no pruning as they will be thinned in approximately year 13. The costs of land preparation and silvicultural regime adopted for the intensive and extensive space-planted poplars afforestation types are outlined in Table 7.

Table 7: Space-planted Poplars Land Preparation/Silvicultural Costs

Land Preparation/Silvicultural Costs				
Operation	Intensive		Extensive	
	Year	Cost $/ha	Year	Cost $/ha
Operation Costs				
Planting	1	$2,342	1	$878
Releasing Grass	1	$201	1	$75
Blanking	2	$299	2	$112
Prune 1	3	$184	3	$184
Prune 2	5	$615	5	$615
Prune 3	9	$1,229	9	$1,229
Thin to Waste	13	$159	n/a	n/a
Operation Cost Total		$5,029		$3,094

The following assumptions have been made when calculating the sph required to meet the 30% crown cover requirement to be eligible within the ETS:

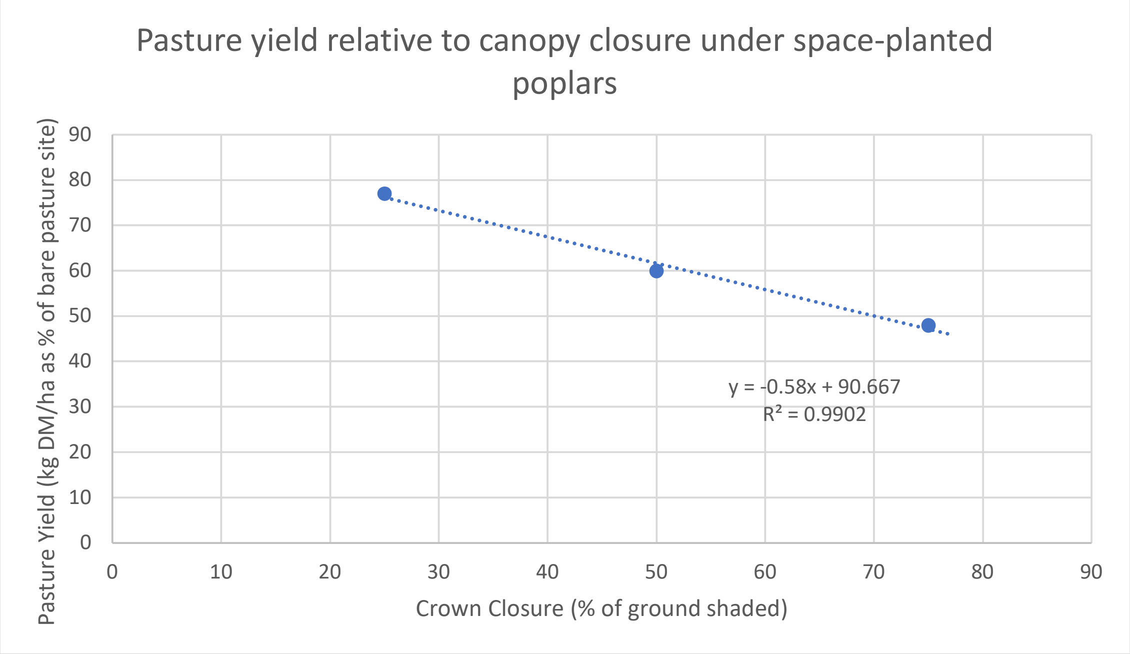
i. 5 m radius of tree crown

ii. 3,000 m^2 coverage required per ha

This has resulted in a minimum required amount of trees of 38 sph, at a spacing of 16.2 metres between tree stems, which means the 15 m rule between tree drip lines is met (16.2 m gap between stems less 10 m for the radius of two trees, equals a 6.2 m gap between driplines). However, this calculation gives the bare minimum sph required to be eligible within the ETS. Therefore, if some of the trees don’t establish, or their crown cover does not meet the assumed 5 m radius, then the stand will become ineligible within the ETS. Therefore, a final crop stocking of 60 sph has been modelled within this research.

On account of the poplars being space-planted, there is still an opportunity for livestock to be grazed once the poplars have reached a certain age (McIvor, Hedderley, et al., 2011). However, as the trees mature, the canopy continues to close in. From information contained within a study conducted by Wall et al. (2006) on the effects of canopy closure on pasture yields, a regression analysis has been conducted. The analysis has then been applied to results of the crown closure calculation from the Radiata Calculator, which estimates the percentage of ground area shaded by a stand canopy, to calculate the pasture yields under both the ‘intensive’ and ‘extensive’ space-plated poplar regimes. Figure 12 shows that there is a strong correlation between canopy closure and reductions in pasture yields, evidenced by a high R^2 value.

Figure 12:Pasture Yield Relative to Canopy Closure Under Space-Planted Poplars



Different canopy closure estimates were calculated for each case study farm, and for each afforestation integration level, but Table 8 provides an example of the estimated pasture yields by age beneath the preferred afforestation integration level for Case One, which are expressed as a percentage of pasture grown on an un-afforested site.

Table 8: Pasture Yields Modelled Space-planted Poplars for Preferred Afforestation Option of Case One

	Pasture Yield	
Stand Age	**Intensive**	**Extensive**
1	91%	91%
5	90%	91%
10	79%	89%
20	65%	71%
30	57%	57%
40	54%	51%
50	51%	48%

The results from the calculation of pasture growth under the space-planted poplars have been applied as factors to a case-specific, weighted average net income of livestock grazing derived from the marginal pastoral land is being afforested. Therefore, as the calculated pasture yields change from year to year, so does the estimated net income of retained livestock grazing within the afforestation area. Livestock have been assumed to be excluded from the afforested area for a period of five years after establishment. When establishment took more than one year, livestock grazing was phased back in incrementally.

Mānuka/Conifer-Broadleaved Native Forests

Two regimes were adopted for this afforestation type: firstly, a pure native Mānuka stand for honey production was modelled, and secondly, a mixed Mānuka/conifer-broadleaved native forest purely for income from CO_2 sequestration was modelled.

Parameters for the pure native Mānuka stand are detailed below:

- Aerial desiccate pre-plant spray in year zero
- Establishment at 1,111 sph in year one
- Hand release in year one
- Blanking of 30% of sph in year two
- One hive per ha
- 25 kg honey produced per hive
- $30 per kg of honey
- 30% share of revenue returned to landowner
- Honey production begins in year five at 15 % of full production levels
- Full honey production realised in year ten and continues until year 25
- Honey production drops to 5% of full production by year 31 and remains at this level

Blanking rates have been based on research by Douglas (2019), who found that survivability of planted Mānuka stands ranged from 0 to 100% where site conditions were extremely poor (e.g. weed competition, low fertility soils) and extremely favourable (e.g. high fertility soils, low weed and pest presence), respectively. However, the majority of sites had survivability of 70 to 80% (Douglas, 2019). Honey yields and prices have been based on conservative estimates (Boffa Miskell Limited, 2017). Honey production peaks in year ten, which reflects the time it takes for the established Mānuka plants to begin flowering, before declining from year 25 and bottoming out in year 31, which reflects the decrease in flowering of the Mānuka plants as the plants mature and flower less (Boffa Miskell Limited, 2017)

The costs of land preparation and silvicultural regime adopted for the Mānuka afforestation type are outlined in Table 9.

Table 9: Mānuka Land Preparation/Silvicultural Costs

Land Preparation/Silvicultural Costs		
Operation	Year	Cost $/ha
Operation Costs		
Aerial Desiccate - Grass	0	$356
Planting	1	$2,654
Hand Release	1	$1,397
Blanking	2	$3,117
Operation Cost Total		$7,524

Parameters for the mixed Mānuka/conifer-broadleaved native forest are outlined below:

- Aerial desiccate pre-plant spray in year zero
- Native conifer-broadleaved species establishment at 500 sph in year one
- Native Mānuka establishment at 1,500 sph in year one
- Hand release in year one
- Blanking of 30% of sph in year two

The costs of land preparation and silvicultural regime adopted for the mixed Mānuka/conifer-broadleaved native forest afforestation type are outlined in Table 10.

Table 10: Mixed Mānuka/Conifer-Broadleaved Native Forest Land Preparation/Silvicultural Costs

Land Preparation/Silvicultural Costs		
Operation	Year	Cost $/ha
Operation Costs		
Aerial Desiccate - Grass	0	$356
Planting	1	$8,530
Hand Release	1	$2,976
Blanking	2	$6,224
Operation Cost Total		$18,086

Within this study, afforestation is being proposed on areas of marginal land up to several hundred ha in size. This means that high-density plantings become uneconomic (Bergin, 2011), and therefore, a mixed planting of native trees and shrubs has been modelled for the mixed Mānuka/conifer-broadleaved native forest, as opposed to a pure stand of conifer-broadleaved species. This planting strategy allows for concurrent planting of native conifer-broadleaved species and native shrub species, such as Mānuka. Native timber species are established at near-final crop stocking and the native shrub species are used to 'bulk-out' the planting thereby, planting fewer high-cost timber species, and more low-cost shrub species (Bergin, 2011). As the cost of purchasing native seedlings from nurseries makes up a significant portion of the total cost of establishing native timber and shrub species (Bergin & Gea, 2007), using greater numbers of low-cost shrub species should have a marked impact on profitability of this afforestation option.

CO_2 sequestration rates for both the pure native Mānuka stand and the mixed Mānuka/conifer-broadleaved native forest were based upon the standard Look-up tables (MPI, 2017). However, as these tables show national averages (MPI, 2017), there is the possibility that CO_2 sequestration rates are understated in high growth regions, such as the Hawke's Bay. It outside the scope of this research to investigate this.

Summary of Afforestation Scenarios

Table 11 shows a summary of the expenditure and revenue items included within each of the afforestation scenarios.

Table 11: Expenditure and Revenue Included for each Afforestation Type

	Afforestation Type					
	Pinus Radiata		**Space-planted poplars**		**Indigenous vegetation**	
	Harvest	**Permanent**	**Intensive**	**Extensive**	**Pure Mānuka**	**Native Mix**
Operational Expenditure						
Desiccate Spray	✓	✓			✓	✓
Establishment	✓	✓	✓	✓	✓	✓
Release	✓	✓	✓	✓	✓	✓
Blanking	✓	✓	✓	✓	✓	✓
Prune			✓	✓		
Thin	✓	✓	✓	✓		
Pre-harvest Inventory	✓					
Timber Harvest	✓					
Revenue						
Timber Harvest	✓					
Residual grazing			✓	✓		
Mānuka honey					✓	
CO_2 sequestration	✓	✓	✓	✓	✓	✓

There is a total of six afforestation types investigated, and with the exception of the Pinus radiata, each of the afforestation types has been investigated for each of the afforestation integration levels investigated (preferred, total, and permanent). The short-term harvest Pinus radiata option has been investigated for the preferred and total afforestation integration levels, whilst the long-term permanent carbon sink Pinus radiata option as only been investigated for the permanent afforestation integration level. Therefore, there is a total of 15 afforestation scenarios investigated for each case study farm.

Not shown in Table 11 are annual costs that have also been included. The annual costs that have been adopted for each afforestation scenario for each case study are shown in Table 12.

Table 12: Annual Forestry Costs

Per Annum Expenses	Case One	Case Two
Forest Annual Costs ($/ha)		
Administration	$5	$5
Maintenance and protection	$10	$10
Insurance	$0	$0
Forest Management	$10	$10
Rates	$46	$35
Annual Cost Total	$71	$60
ETS Annual Costs ($/ha)		
ETS Management	$10	$10

The forest annual costs (administration, maintenance and protection, insurance, forest management, and rates) have been included separately from the ETS annual costs. This allows for comparison of the economic desirability of the timber harvest/residual grazing/Mānuka honey production (excluding CO_2 sequestration revenue), against the economic desirability of timber harvest/residual grazing/Mānuka honey production (including CO_2 sequestration revenue).

Excel Spreadsheet

The outputs from QGIS, Farmax, Overseer, and the Radiata Calculator were compiled in a Microsoft Excel spreadsheet. The spreadsheet was used to firstly analyse data from one model so it could be input into another model, such as spatial information from QGIS relating to LMUs to be input into Farmax and Overseer, forestry production information to be input into the Radiata Calculator from QGIS, and SU figures from Farmax to be input into Overseer. Secondly, the spreadsheet was used to analyse the final data outputs from the several models to allow for comparison between N and P root zone loss, greenhouse gas emissions, and economic desirability of the three afforestation integration levels i.e. preferred, total, and permanent. It also allowed for direct economic comparison of afforestation types, both against one another and against pastoral farming.

Discounted Cash Flow Analysis

Multiple DCF analyses were used to assess the economic desirability of both pastoral farming and carbon forestry. In all DCFs, the main metrics used to assess the economic desirability of pastoral farming and carbon forestry were NPV and IRR. However, there was also an annuity for each of the two land uses, which was calculated by averaging the NPV over the investment period. This allowed for a crude comparison of the annual returns from pastoral farming and carbon forestry. Of the three metrics outlined, NPV was the metric ultimately relied upon when making recommendations as this metric has an explicit association with the wealth position of the overall business (Agnes Cheng, et al., 1994).

Firstly, two DCFs were created to reflect the base scenario pastoral farming land use, utilising the net income figure from Farmax as the revenue input. One DCF was constructed on a short-term (base 27-year period) basis to provide a benchmark against which economic desirability of the preferred and total afforestation integration levels can be compared. The other DCF was constructed on a long-term (base 50-year period) basis to provide a benchmark against which economic desirability of the permanent afforestation integration levels can be compared. Secondly, a DCF was created that reflected the short-term (base 27-year period) economic desirability of pastoral farming on the marginal pastoral land within a case. Once again, the net income figure from Farmax was used as the revenue input, but only income and expenditure derived from farmlets that formed the marginal pastoral land within a case were included. Therefore, revenue and expenditure associated with non-marginal pastoral land within a case was excluded from this DCF. This DCF has allowed for the direct comparison of the economic desirability of pastoral farming on marginal pastoral land against carbon forestry that would be established on this land. Thirdly, a DCF analysis was created for each afforestation scenario, which equated to 15 DCF analyses in total, per case. These DCF analyses included timber harvest, residual grazing, or Mānuka honey production, depending on the afforestation type. Operational costs were then included to determine net income (without the benefit of revenue from CO_2 sequestration) and both NPV and IRR metrics were reported. Within the same DCF, the revenue from CO_2 sequestration, and any related ETS costs, were then also included to determine net income including CO_2 sequestration revenue, with NPV, IRR and annuity metrics reported. The construction of these DCF analyses allowed for the comparison of afforestation scenarios, but also for the comparison of economic desirability of carbon forestry against pastoral farming. Lastly, three DCF analyses were constructed, one for each of the preferred, total, and permanent afforestation integration levels (Refer to Appendix E). These DCFs reflect the integration of carbon forestry into the pastoral farming business, and consequently, reflect the economic impacts of carbon forestry integration on marginal pastoral land on a whole-farm basis. Therefore, the reduced net income figure from Farmax for each afforestation integration level is input into these DCFs to reflect the economic performance of the remaining pastoral enterprise, with the corresponding carbon forestry revenue and expenditure being sourced from the relevant DCF (i.e., those that were outlined previously). The three DCFs that reflect the overall farm impact of carbon forestry integration included the farmer's preferred afforestation type. For example, if the farmer indicated that Pinus radiata was the preferred afforestation type for the total afforestation integration level, then revenue and expenditure information would be linked through from the 'Pinus radiata – Total Afforestation' DCF.

The short-term (base 27-year period) and long-term (50-year period) terms have been adopted as the standard investment periods within this research. As previously stated, the short-term period is used for the preferred and total afforestation integration levels as 27 years is the adopted harvest age for the Pinus radiata afforestation type. Furthermore, the long-term period is used for the permanent afforestation integration level as 50 years is the minimum length of time that a forest has to be registered as permanent post-1989 forest within the ETS (MPI, 2021b). However, for some afforestation scenarios, establishment of the entire NSA within one year is not feasible or desirable. Therefore, for some afforestation types, the base short-term and long-term periods extend by the number of years it requires to complete planting. When this has happened for a case study farm, the rest of the afforestation scenarios, and base pastoral farming scenarios, have been compared over the same investment period e.g., if the 'Pinus radiata – Total Afforestation' scenario takes two years to plant (28-year period total), all other afforestation and pastoral scenarios will be evaluated over a 28-year period.

An important inclusion within the DCF analyses was the incorporation of land values, both as a purchase cost in year zero, and as a terminal value at the end of the relevant investment period. The Government Valuation of the property's land was used to assess this. Firstly, ineffective areas were deducted from the total land value at a rate of $1,200/ha based on researcher knowledge, which reflects the relatively low value of unproductive land from a pastoral farming perspective. The balance of the land value was then apportioned between farmed LMUs based on the total pasture grown within each LMU, as reported by Farmax. This reflected the higher productivity of some LMUs compared to others, and therefore, also reflected the higher value of these areas. The apportioned land values were then incorporated into the relevant DCFs as the purchase cost and terminal value of pastoral land and assumed to be no change in land value over the investment period.

The value apportioned to marginal pastoral land was also used as the input forestry land value. The output forestry land value was calculated as the weighted average of the ground base and hauler base land values for Pre-1990 forest land, with the contour being assessed for the NSA of each specific afforestation area. A separate land value was adopted for unplantable/buffer areas that formed the balance of the PPA of each afforestation area. Ground base rates for Pre-1990 land have been assessed at $3,000/ha, and hauler base rates assessed at $2,400/ha, with waste forestry rates assessed at $100/ha.

Discount Rate

A discount rate of 4.60% has been used within this research to evaluate both the pastoral and carbon forestry economic desirability. From 1998 to 2017, the Reserve Bank of New Zealand conducted surveys of six-month term deposit rates and business lending rates but has since ceased the survey of business lending rates (Reserve Bank of New Zealand, 2021). During the 1998 to 2017 period, the two rates were shown to have a high correlation (0.89), with the business lending rate being an average of 1.69% higher than the six-month term deposit rate (Reserve Bank of New Zealand, 2021). The average difference has been applied to the more recent six-month term deposit rates to calculate a corresponding business loan rate from 2017 to the end of 2020. The average of the previous five years has been adopted as the discount rate used within this research, which is 4.60%. A sensitivity analysis has been conducted to ascertain the influence of the discount rates upon results of economic desirability, with rates ranging from 2 to 8%, which are based on the reviewed literature.

Carbon neutrality

The spreadsheet was also used to calculate the area of each case study farm that would need to be afforested for the farm to become ‘carbon neutral’ over a 50-year period (assume planting is in year zero, with a subsequent 50-year rotation). This was firstly calculated on a ‘static’ basis, where only the CO_2 sequestration was accounted for, with no corresponding reduction in gross greenhouse gas emissions from pastoral land use.

An alternative, and preferred method, where reductions in gross greenhouse gas emissions were accounted for as well was also evaluated. A key assumption for this was that the afforested land was marginal pastoral land. The methodology for estimating carbon neutrality is outlined below:

1) Apportion the annual greenhouse gas emissions (as calculated for the base scenario within Overseer) to the marginal pastoral land based on total feed consumed (kg DM eaten) by livestock on the marginal pastoral land
2) Divide the annual greenhouse gas emissions from the marginal pastoral land (as calculated in step one) by the total area of the farm
3) Multiply the result from step two above by the 51-year period to calculate total greenhouse emissions from the marginal pastoral land over the desired carbon neutrality period
4) Input above results into the below equation and use the 'goal seek' function in Microsoft Excel to set the left side of the equation (net emissions) to equal the right side of the equation (total sequestration):

$$(a \times b) - (c \times d) = e \times d$$

Where:

- *a = total farm emissions over the 50-year period per ha*
- *b = total farm size*
- *c = total farm emissions over the 50-year period per ha*
- *d = area afforested*
- *e = total CO_2 sequestration over 50-year period*

The above outlined method of estimating carbon neutrality has been adopted because Overseer does not report greenhouse gas emissions at the management block level. Whilst Farmax does estimate CH_4 and N_2O greenhouse gas emissions at the LMU level, there is however, no calculation of CO_2 emissions. Furthermore, there are no soil type, drainage characterises, or fertiliser application details required to be input into Farmax, and therefore, it is unlikely that the calculated greenhouse gas emissions are accurate.

The adopted methodology has overestimated the area of afforestation required for carbon neutrality – Case One by 23.98 t CO_2-/year (approximately 3.3% of gross emissions), and Case Two by 205.96 t CO_2-e/year (13% of gross emissions). It is thought that this is due to the carbon neutrality equation not accounting for differences in emissions of N_2O and CO_2. For example, the equation may assume that the C Class farmlet within Case Two is responsible for 10% of total feed eaten, however, it may be responsible for 30% of N_2O emissions from fertiliser application. Therefore, the equation is underestimating the emissions from the marginal pastoral land, which results in a greater amount of land afforested to offset this. However, in the Overseer budget, N_2O emissions are dropping greater than expected by the carbon neutrality equation, so the result of the 'permanent afforestation' Overseer budget indicates that the farm is now a carbon sink, instead of being neutral. However, this remains unconfirmed and requires further investigation.

The area that was calculated to be required to be afforested for the case study farm to be carbon neutral was used as the input NSA figure for the preferred afforestation integration level for all afforestation types. It was assumed that the area of permanent afforestation would be established on the same site as the preferred afforestation area, so the same forestry productivity inputs have been used for both the preferred and permanent afforestation areas. Furthermore, as the area calculated is the required NSA, no unplantable/setback areas have been identified.

As previously stated, the stock change approach has been adopted for modelling long-term CO_2 sequestration. However, for comparative purposes, carbon neutrality has been estimated over the same 50-year period as outlined above, but by adopting the averaging approach. By aiming to be carbon neutral over a 50-year period by using carbon forestry that is registered under the averaging approach, timber can still be harvested without any NZUs having to be surrendered, so long as the afforested area is replanted (MPI, 2021a).

Conclusion

This research comprises of two quantitative case studies, which are sheep and beef farms located in the Hawke's Bay Region of the North Island, New Zealand. Data has been collected from the two case study farms, which has then been analysed utilising QGIS, Farmax, Overseer, and the Radiata Calculator, with results from the modelling tools being collated and further analysed in the spreadsheet. A total of 15 afforestation scenarios (options/types mixes) have been investigated for each case study farm. Multiple DCF analyses were used to assess the economic desirability of both pastoral farming and carbon forestry. In all DCFs, the main metrics used to assess the economic desirability of pastoral farming and carbon forestry were NPV and IRR. However, there was also an annuity for each of the two land uses analysed and compared.

Chapter Four: Results

Introduction

This chapter presents the results of the research, which has been undertaken in line with the materials, methods, and assumptions outlined in the previous chapter. This research encompasses the investigation of numerous aspects relating to the integration of carbon forestry on marginal pastoral land. Therefore, this section aims to present results in a logical manner and attempts to present results in the order of the research objectives as outlined in Chapter One.

Quantum of Marginal Pastoral Land and Farm Heterogeneity

It was found that heterogeneity did exist between the two case study farms in terms of the quantum of marginal pastoral land within them. Table 13 contains the breakdown of Case One, which shows that only 34.3% of the farmed area is considered to be marginal pastoral land.

Table 13: LUC Breakdown of Case One Base Scenario

Case Study One			
LUC	**Area (Ha)**	**% of Total**	**% Marginal**
3s1	148.0	59.9%	
3s2	14.4	5.8%	
7e9	84.8	34.3%	34.3%
Total Effective	247.1	100.0%	34.3%

In contrast to Case One, Table 14 shows that Case Two has a significantly higher proportion of marginal pastoral land, equating to 67.8% of the farmed area.

Table 14: LUC Breakdown of Case Two Base Scenario

Case Study Two			
LUC	**Area (Ha)**	**% of Total**	**% Marginal**
4e2	142.5	32.2%	
6e1	170.1	38.5%	
6e6	0.6	0.1%	
6e12	45.0	10.2%	
7e18	84.3	19.0%	67.8%
Total Effective	442.5	100.0%	67.8%

Physical Productivity of Pastoral Farming on the Case Study Farms

Table 15 shows the LMUs for the base scenario of Case One. The ‘Easy’ LMU is comprised of the 3s1 LUC Class land, with the ‘Gully’ LMU comprised of the 3s2 and 7e9 LUC Classes that were shown in Table 13. Although the 3s2 LUC Class is not defined as marginal pastoral land by the definition adopted within this research, due to its historical land use (i.e., lower inputs, poorer fertility, inferior pasture species) it has been treated the same as the 7e9 LUC Class land on a productive basis, and therefore, has been included as marginal pastoral land at the request of the case study farmer. Case One is predominantly farmed pastoral land (84.4%), with ineffective areas predominantly comprising native bush. There are slight differences in areas of marginal pastoral land (Table 13) compared to the LMUs created (Table 15) for Case One, which are due to differences in rounding of the two datasets in the QGIS software.

Table 15: Base Scenario LMUs of Case One

Case Study One - Base Scenario LMUs		
Farmed	Area (ha)	% of Total Farm
Easy	147.4	
Gully	99.7	
Total Farmed	247.1	84.4%
Ineffective		
P. rad	0.2	
Bush	36.5	
Poplars	8.3	
Buildings	0.7	
Total Ineffective	45.7	15.6%
Total Farm	292.8	

Table 16 shows the LMUs for the base scenario of Case Two. The ‘A Class’ land comprises the 4e2 LUC Class, which is the entirety of the non-marginal land. The balance of the farmed area, being marginal pastoral land, is split between ‘B Class’ and ‘C Class’ LMUs. Despite both of the LMUs being defined as marginal pastoral land, they have been differentiated as the ‘B Class’ LMU is significantly more productive than the ‘C Class’ LMU as a result of contour, pasture species, and fertility. Therefore, these two LMUs are managed differently, so to amalgamate them on the basis that they are both marginal pastoral land would have been incorrect. Case Two has a similar percentage of farmed pastoral area (79.2%) to Case One, with ineffective areas comprising significant Pinus radiata plantations, bush areas, and riparian strips.

Table 16: Base Scenario LMUs of Case Two

Case Study Two - Base Scenario LMUs		
Farmed	Area (ha)	% of Total Farm
A Class	142.5	
B Class	173.5	
C Class	126.5	
Total Farmed	442.5	79.2%
Ineffective		
P. rad	18.3	
Bush	47.8	
Riparian	38.8	
Scrub	7.4	
Waste	4.1	
Total Ineffective	116.5	20.8%
Total Farm	558.9	

Once a biologically feasible farm system had been developed in Farmax, physical and financial summaries were able to be extracted. Table 17 shows the physical summary for the base scenario of Case One. The Easy farmlet within Case One is more productive than the Gully farmlet, which is expected due to its lower suitability to pastoral farming as per the LUC Class system (Lynn, et al., 2009). Relative to the Easy farmlet, the Gully farmlet grows 35% less pasture, and 54% less pasture is eaten by livestock. This is further reflected by the calculated stocking rates of the two farmlets, with the Easy farmlet supporting 4.9 SU/farmed ha more than the Gully farmlet.

Table 17: Case One Base Scenario Physical Summary

Case One - Base Scenario Physical Summary		**Easy**	**Gully**
Area	Total Area (ha)	148	145
	Farm Area (ha)	147	100
Feeding	Pasture Grown (t DM/Farm ha)	7.10	4.63
	Pasture Eaten (t DM/Farm ha)	5.02	2.31
	Supplements Eaten (t DM/Farm ha)	0.00	0.00
	Total Eaten (t DM/Farm ha)	5.02	2.31
Performance	Stocking Rate (SU/Farm ha)	9.10	4.20

Table 18 shows the physical summary for the base scenario of Case Two. It can be seen that the A Class farmlet within Case Two is more productive than both the B Class and C Class farmlets. However, despite the B Class farmlet being defined as marginal pastoral land within this research, it only grows 11% less pasture than the A Class farmlet, which is not marginal pastoral land. Furthermore, a greater amount of pasture is eaten on the B Class farmlet than the A Class farmlet. This is a result of the cropping programme being undertaken on the A Class land, and therefore, the total pasture grown, and total pasture eaten figures are reduced on account of land being in crop and not growing pasture. In contrast to the pasture eaten, 88% more supplement is eaten on the A Class farmlet compared to the B Class farmlet, which means that overall feed eaten (pasture and supplement) is 19% lower on the B Class farmlet than the A Class farmlet. It can also be seen that a significantly lower amount of pasture is grown (39%) and eaten (29%) on the C Class farmlet. Furthermore, there are no supplements fed on the C Class farmlet. These factors result in the C Class farmlet having 46% less total feed eaten compared to the A Class farmlet.

Table 18: Case Two Base Scenario Physical Summary

Case Two - Base Scenario Physical Summary		**A Class**	**B Class**	**C Class**
Area	Total Area (ha)	163	193	203
	Farm Area (ha)	143	174	127
Feeding	Pasture Grown (t DM/Farm ha)	9.20	8.23	5.58
	Pasture Eaten (t DM/Farm ha)	6.54	6.70	4.62
	Supplements Eaten (t DM/Farm ha)	1.97	0.23	0.00
	Total Eaten (t DM/Farm ha)	8.51	6.93	4.62
Performance	Stocking Rate (SU/Farm ha)	15.50	12.60	8.40

When comparing the physical performance of the two case study farms there are noticeable differences. Firstly, Case One is modelled to grow a weighted average 5.88 t DM/farmed ha from both farmlets, compared to the weighted average growth of Case Two, which is 7.55 t DM/farmed ha from the three farmlets. Furthermore, Case Two has better pasture utilisation (derived from pasture grown and livestock demand calculations within Farmax), eating 5.9 t DM/farmed ha (equating to 78.1% of total pasture grown), compared to only 3.68 t DM/farmed ha (equating to 62.6% of total pasture grown) within Case One. This means that not only is the Case Two farm capable of growing greater amounts of pasture, but the case study farmer is also better utilising the feed that is grown. Lastly, Case Two grows and harvests supplements to be fed on-farm, which Case One does not. As a result, livestock on Case Two are eating a total of 6.55 t DM/farmed ha, which is nearly double the 3.68 t DM/farmed ha of Case One. This has the impact of allowing Case Two to carry more livestock, which is reflected in the modelled stocking rates. It is calculated that Case One is carrying 7.1 SU/farmed ha across both farmlets, whereas Case Two is carrying 12.3 SU/farmed ha across the three farmlets.

Economic and Environmental Results of Base Scenario Pastoral Farming

A breakdown of the gross revenue and expenditure for both case study farms is shown in Table 19. It can be seen that for Case One, 76.2% of total feed consumed on the farm (t DM eaten) is done so on the Easy farmlet, which is a driving factor of its profitability relative to the Gully farmlet. As no pasture renewal or fertiliser applications are associated with the Gully farmlet, 100% of these costs have been apportioned to the Easy farmlet. Despite this, the Easy farmlet is more profitable than the Gully farmlet, with net income modelled for the Easy farmlet calculated to be $622/farmed ha, and only $307/ farmed ha for the Gully farmlet. In contrast, within Case Two, the A Class and B Class farmlets have a similar apportionment of total feed eaten, so have similar total gross revenue figures. However, as the winter cropping is undertaken on the A Class farmlet, along with there are also being slightly higher fertiliser application rates, the profitability of the A Class farmlet decreases in comparison to that of the B Class farmlet, having a net income per farmed ha of $727 vs $777 of the B Class farmlet. The C Class farmlet has a much lower profitability than the other two farmlets of Case Two, which is a result of only 19.5% of gross income being attributed to this farmlet, and also the majority of the weed and pest control expense is apportioned to this farmlet.

Table 19: Summary of Revenue and Expenditure for Base Scenario Case Farms

	Case One			**Case Two**			
	Easy $	**Gully $**	**Total $**	**A Class $**	**B Class $**	**C Class $**	**Total $**
Apportionment of Feed Eaten	*76.2%*	*23.8%*	*100.0%*	*40.5%*	*40.1%*	*19.5%*	*100.0%*
Farmed ha	*147*	*100*	*247*	*143*	*173*	*126*	*442*
Revenue							
Total Sheep	106,289	33,272	139,561	232,352	230,063	111,798	574,213
Total Beef	87,079	27,259	114,338	33,557	33,227	16,146	82,930
Total Revenue	193,368	60,531	253,899	265,910	263,289	127,944	657,143
Expenses							
Wages	44,347	13,882	58,229	54,877	54,336	26,404	135,617
Stock	2,216	694	2,910	16,981	16,814	8,170	41,965
Feed/Crops/Grazing	7,600	-	7,600	32,000	-	-	32,000
Fertiliser	23,077	-	23,077	21,276	20,156	14,557	55,990
Other Farm Working	15,382	6,037	21,419	24,495	24,805	14,654	63,955
Total Standing	9,257	9,257	18,513	12,718	12,344	12,344	37,405
Total Expenses	101,878	29,870	131,748	162,347	128,455	76,130	366,932
Net Income	91,490	30,661	122,151	103,563	134,834	51,814	290,211
Net Income per Farmed ha	622	307	495	727	777	410	656

As expected, Case Two is more profitable than Case One, with overall net income being $656/farmed ha for Case Two, compared to $495/farmed ha for Case One.

Table 20 shows the overall summary of the pastoral farming base scenario for each of the two case study farms, which includes a physical summary, a financial summary, and an environmental summary.

Table 20: Overall Economic and Environmental Results of Pastoral Farming Base Scenarios

Base Scenario Results - Short Term	**Case One**	**Case Two**
Physical		
Total Area	293 ha	559 ha
Farmed Area	247 ha	442 ha
Existing Ineffective	46 ha	116 ha
Afforested Area	0 ha	0 ha
Financial		
Per Farmed Ha		
IRR	4.69%	8.63%
NPV	$154	$4,985
Total Investment		
NPV	$37,963	$2,205,525
Environmental		
Nitrogen Root Zone Losses	2,694 kg N/year	11,900 kg N/year
Nitrogen Root Zone Losses	9.1 kg N/ha/year	21.1 kg N/ha/year
Phosphorus Root Zone Losses	222 kg P/year	1,130 kg P/year
Phosphorus Root Zone Losses	0.8 kg P/ha/year	2.0 kg P/ha/year
Gross GHG Emissions	718.90 t CO_2-e/year	2,099.40 t CO_2-e/year
Avg. CO_2 Sequestered	0.00 t CO_2/year	0.00 t CO_2/year
Net GHG Emissions	718.90 t CO_2-e/year	2,099.40 t CO_2-e/year
Net GHG Emissions	2.44 t CO_2-e/ha/year	3.73 t CO_2-e/ha/year

As can be seen above, there is no carbon forestry modelled within either of the case study farms for the base scenario. When the net income figures from Table 19 were input into the DCF analyses, the differences in profitability of the two case study farms were further reflected in the NPV and IRR metrics. It was calculated that the base scenario of pastoral farming within Case One has an NPV of only $154/farmed ha, compared to the NPV of Case Two, which is $4,985/farmed ha. Furthermore, there is a large difference in calculated IRRs between the two case study farms – being 4.69% for Case One and 8.63% for Case Two. Lastly, the NPV of the total investment for Case One is substantially lower than that of Case Two. This is a function of both per farmed ha profitability and overall farmed size.

For all environmental metrics assessed, Case Two is shown to have a greater environmental footprint than Case One. However, these metrics are a function of both emission intensity and farm size. Table 21 shows both total N and P lost from the root zone (kg/year), and N and P root zone loss rates (kg/ha/year), for each management block from Case One. The Easy management block has both the highest total N and P root zone loss rates, and highest N and P root zone loss rates of all the blocks. There are modest contributions made to total N and P root zone losses by the ineffective management blocks.

Table 21: N and P root zone loss from Case One Base Scenario

Case One - Base scenario N & P Leached	**Kg N/year**	**Kg N/ha/year**	**Kg P/year**	**Kg P/ha/year**
Management Block				
Easy	1,661	11.4	150	1.1
Gully	878	8.8	39	0.4
Bush	138	3.0	5	0.1
Other	17	0.1	28	0.1
Total Root Zone Loss	2,694	9.1	222	0.8

The main source of N added to Case One was biological fixation (35 kg/ha/year), with an additional 11 kg N/ha/year being added in fertiliser. Of the 9.1 kg N/ha/year lost from the root zone from Case One, 44.4% was from urine patches, and 55.6% was from the ‘leaching – other’ pathway. The main source of P added to Case One was fertiliser (12 kg/ha/year). The entirety of the 222 kg P lost/year from Case One was removed via runoff.

Table 22 shows that the three pastoral management blocks (A Class, B Class, and C Class) are the largest contributors to total N and P root zone loss from Case Two.

Table 22: N and P root zone loss from Case Two Base Scenario

Case Two - Base scenario N & P Leached	**Kg N/year**	**Kg N/ha/year**	**Kg P/year**	**Kg P/ha/year**
Management Block				
A Class	2,569	22.8	397	3.5
B Class	3,285	18.8	326	1.9
C Class	1,958	15.3	299	2.4
Lucerne	586	59.0	5	0.5
Kale	1,406	141.0	35	3.5
Swedes	1,589	159.0	34	3.4
Bush	178	3.0	6	0.1
P. Rad	46	2.0	2	0.1
Riparian	116	3.0	4	0.1
Other	167	0.3	22	0.0
Total Root Zone Loss	11,900	21.1	1,130	2.0

This is primarily a function of their size relative to the other productive management blocks (refer to Table 16), but also their root zone loss rates compared to the ineffective management blocks. Both the Kale and Swedes management blocks had very similar N root zone loss rates, which were much greater than all other management blocks. Despite their small size (each being only ten ha), the Kale and Swedes blocks still contributed a significant portion of total N root zone loss. The P root zone loss rates from the Kale and Swedes blocks were on par with those of the A Class management block, but their smaller size has limited their contribution to total P root zone loss. The main source of N added to Case Two was biological fixation (55 kg/ha), with an additional 13 kg N/ha being added in fertiliser. Of the 21.1 kg N/ha/year lost from Case Two, 57.1% was from urine patches, and 38.1% was from the 'leaching – other' pathway, and 4.8% from runoff. The main source of P added to Case Two was in fertiliser (21 kg/ha/year). The entirety of the 1,130 kg P/year lost from Case Two was removed via runoff.

Comparing the root zone loss profiles from both case study farms, irrespective of the crop management blocks within Case Two, the root zone loss rates from Case One are significantly lower than those of Case Two. The lowest N root zone loss rate of the pastoral management blocks within Case Two is 15.3 kg N/ha/year, whereas the highest N root zone loss rate of the pastoral management blocks within Case 1 is 11.4 kg N/ha/year. The same is true for P root zone loss rates, with the lowest P root zone loss rate for a pastoral management block from Case Two (B Class – 1.9 kg P/ha/year) being nearly double the highest P root zone loss rate for a pastoral management block within Case One (Easy – 1.1 kg P/ha/year).

Figure 13 and Figure 14 show the greenhouse gas emissions summaries for Case One and Case Two, respectively, as calculated in Overseer. Case One is modelled to have total gross emissions of 718.9 t CO_2-e/year (equating to 2.4 t CO_2-e/ha/year). In contrast, Case Two is modelled to have total gross emissions of 2,099.4 t CO_2-e/year (equating to 3.7 t CO_2-e/ha/year).

Figure 13: Greenhouse Gas Emissions from Base Scenario of Case One

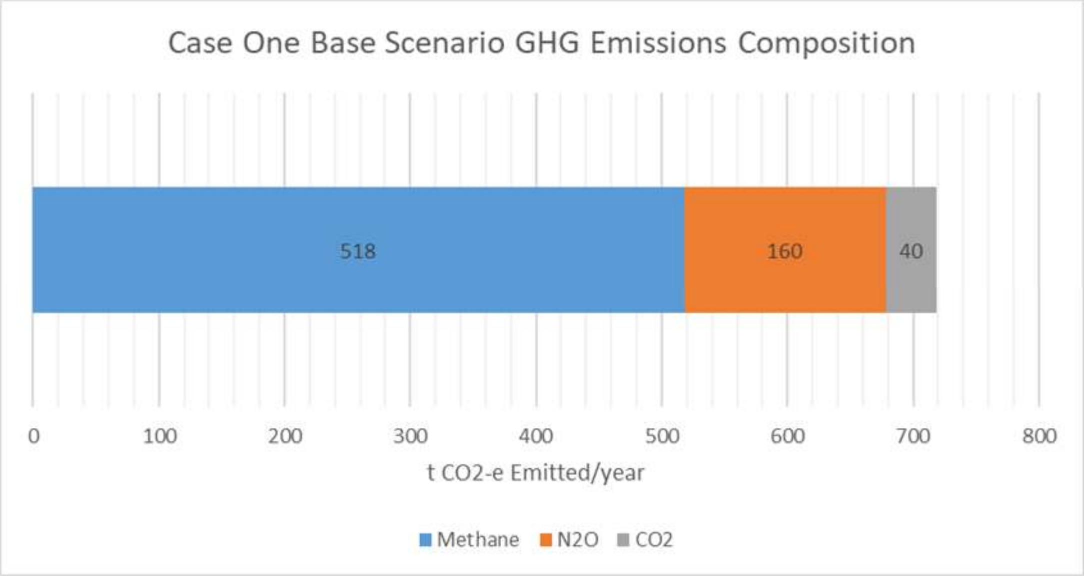
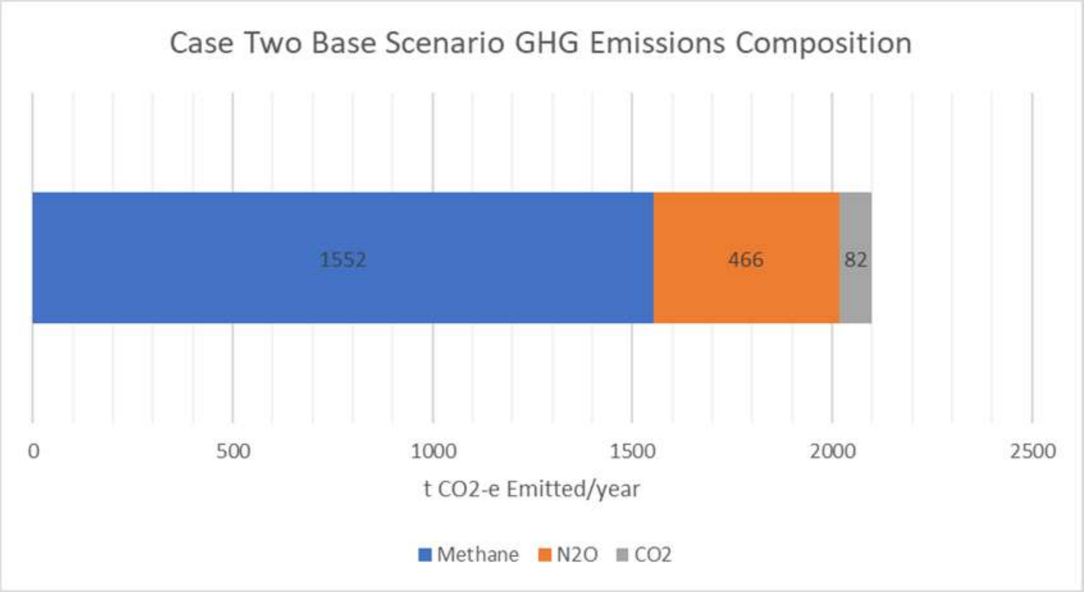


Figure 14: Greenhouse Gas Emissions from Base Scenario of Case Two



Within both case study farms, CH_4 is the predominant greenhouse gas emitted, contributing 72.1% and 73.9% of total greenhouse gas emissions from Case One and Case Two, respectively. Enteric fermentation was the main source of CH_4 emissions, with only modest CH_4 emissions being reported from dung. Emissions of N_2O contributed 22.3% and 22.2% of total emissions for Case One and Case Two, respectively. Paddock excreta was the main source of N_2O emissions. Lastly, CO_2 emissions were insignificant, contributing only 5.6% of emissions from Case One and 3.9% of emissions from Case Two. The main source of CO_2 emissions was from imbedded sources in fertiliser production.

Using the first two steps of the method used to calculate carbon neutrality, annual greenhouse gas emissions have been apportioned within Case One as follows: 492.21 t CO_2-e/year (68.5%) to the non-marginal pastoral land and 226.69 t CO_2-e/year (31.5%) to the marginal pastoral land. This calculation has also been used for Case Two, with the apportionment as follows: 1,425.12 t CO_2-e/year (67.9%) to the non-marginal pastoral land and 674.28 t CO_2-e/year (32.1%) to the marginal pastoral land.

Environmental Benefits of Carbon Forestry

Nutrient Root Zone Losses

Within Overseer, forestry management blocks can be entered as one of two species: Native or Pines, no other species are provided for. Table 23 shows the N and P loss rates for the two different forestry species. Both types of forestry have the same P loss rates, but there is a slight difference in N root zone loss rates of 1 kg/ha/year between the Pines and Native species. These results are the same for both case study properties.

Table 23: Root Zone Loss Differences Between Forestry Types in Overseer

	Pines	**Native**
Case One		
N Loss (kg/ha)	2.0	3.0
P Loss (kg/ha)	0.1	0.1
Case Two		
N Loss (kg/ha)	2.0	3.0
P Loss (kg/ha)	0.1	0.1

Sequestration of CO_2

The CO_2 sequestration rates of all afforestation scenarios (with the exception of the Mānuka/conifer-broadleaved native forest) were modelled for both case study farms in the Radiata Calculator. Annual CO_2 sequestration rates differ between all afforestation scenarios, as well as between cases. These differences are due to the afforestation types having inherently different CO_2 sequestration potential, as well as the different afforestation areas having varying productivity indices. Table 24 summarises the annual CO_2 sequestration figures modelled for the afforestation types of each case study, as well as figures derived from default Look-up tables for Pinus radiata in the Hawke's Bay/Southern North Island region, and national figures for Exotic hardwoods and indigenous vegetation.

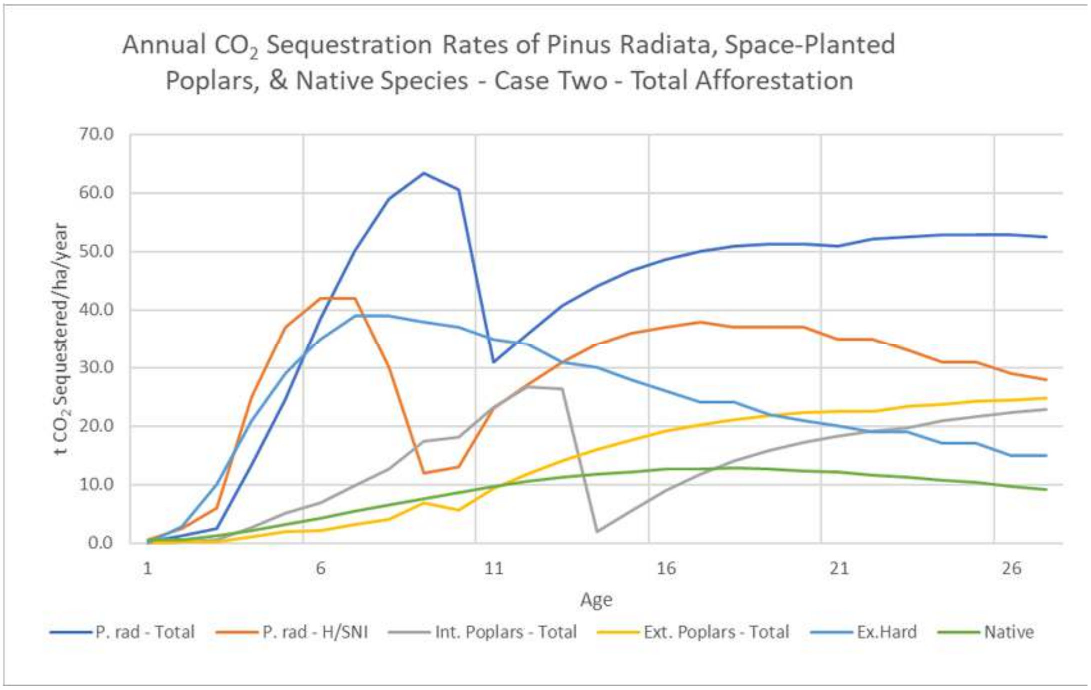
Table 24: CO_2 Sequestration Figures Modelled for Each Afforestation Scenario

	Case One		**Case Two**	
Afforestation Type	**Preferred**	**Total**	**Preferred**	**Total**
Average t CO_2/ha/year				
P. rad	38.4	37.2	39.4	41.9
H/SNI	28.5	28.5	28.5	28.5
Int. Poplars	12.7	12.2	12.6	13.7
Ext. Poplars	12.5	13.0	12.4	13.5
Ex. Hard	24.0	24.0	24.0	24.0
Mānuka	8.7	8.7	8.7	8.7
Native Mix	8.7	8.7	8.7	8.7
Total t CO_2/ha @ year 27				
P. rad	1,037	1,005	1,064	1,131
H/SNI	769	769	769	769
Int. Poplars	343	330	341	370
Ext. Poplars	337	352	335	364
Ex. Hard	648	648	648	648
Mānuka	234	234	234	234
Native Mix	234	234	234	234

It can be seen that the Pinus radiata afforestation type modelled for both case study farms has greater CO_2 sequestration rates than the H/SNI Region, as per the default Look-up tables. Furthermore, both space-planted poplar afforestation types have lower CO_2 sequestration rates than the national average of exotic hardwoods, as per the default Look-up tables. As the afforestation types for both case study farm were modelled using the same silvicultural regime, more in-depth analysis of results pertaining to CO_2 sequestration rates will only be presented for Case Two.

Figure 15 shows the annual CO_2 sequestration rates for the total afforestation integration scenario in Case Two. CO_2 sequestration rates for Pinus radiata in the Hawke's Bay/Southern North Island (P. rad – H/SNI), national rates for exotic hardwood (Ex. Hard), and rates for native vegetation (Native) from MPI (2017) default Look-up tables have been included as benchmarks in Figure 15, Figure 16, and Figure 17.

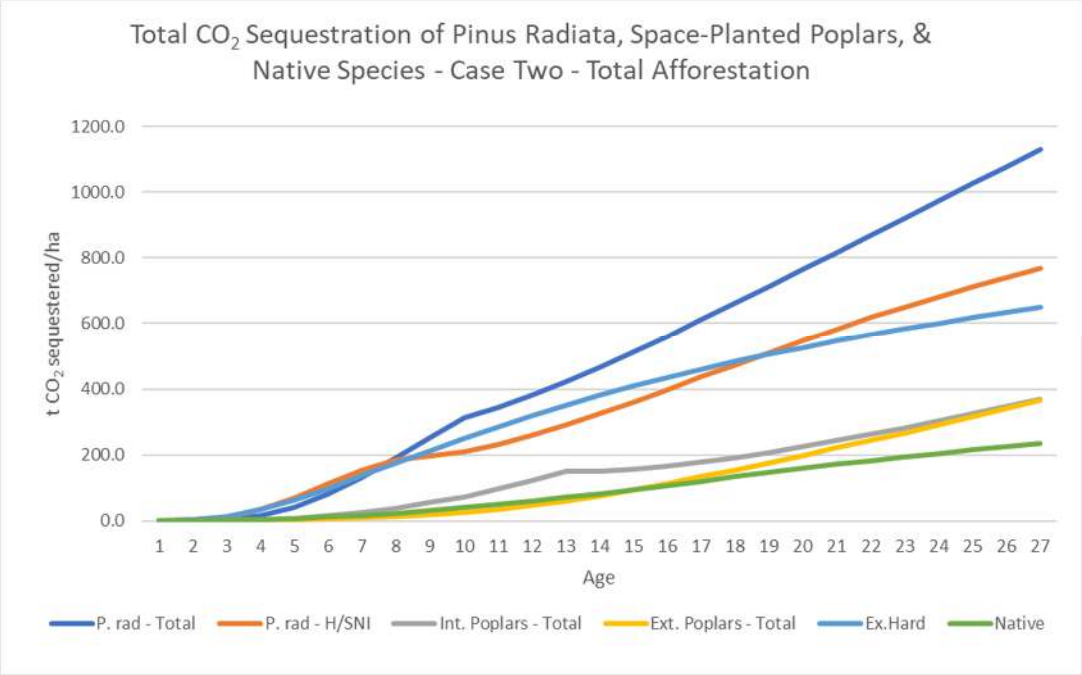
Figure 15: CO_2 Sequestration Rates of Afforestation Types for Case Two Total Afforestation Integration Level



Firstly, it can be seen that the Pinus radiata (P. rad – Total) has the highest annual sequestration rate, peaking in year nine at 63.5 t CO_2/ha/year. Sequestration rates drop for the Pinus radiata in year 11, which coincides with the modelled thinning event, before plateauing around year 19 at 51.3 t CO_2/ha/year and averaging 41.9 t CO_2/ha/year over the 27-year period. These rates are higher than the default Look-up tables for Pinus radiata in the Hawke's Bay/Southern North Island, which peak at 42 t CO_2/ha/year in year seven, before plateauing around year 16 at 37 t CO_2/ha/year, before then steadily declining until year 27. In contrast to the 'P. rad – Total', the 'P. rad – H/SNI' only averages 28.5 t CO_2/ha/year over the 27-year period. The Intensive ('Int. Poplars – Total') and Extensive ('Ext. Poplars – Total') poplars afforestation types are modelled to have very similar growth rates at year 27, however, there are significant differences in the rates prior to that year. Annual sequestration rates of the intensive poplars increase steadily as the trees age (with small reductions noted after pruning events) until year 12, when rates peak at 26.6 t CO_2/ha/year. Rates then sharply decline after the thinning event in year 13 to only 1.9 t CO_2/ha/year, before reaching double-digit rates again in year 17. This afforestation type averaged 13.7 t CO_2/ha/year. In contrast, the extensive poplars have a relatively smooth annual increase in rates (also noting small reductions after pruning) and peak in year 27 at 24.7 t CO_2/ha/year, averaging 13.5 t CO_2/ha/year. The profiles of both of these afforestation types differ significantly to the national sequestration rates of exotic hardwood (Ex. Hard) species. The exotic hardwood rates peak in year seven at 39 t CO_2/ha/year, and then steadily decline until year 27 when rates are only 15 t CO_2/ha/year, averaging 24 t CO_2/ha/year over the 27-year period. The sequestration rates for native forest (Native) are comparatively lower than all other afforestation types, peaking at 12.8 t CO_2/ha/year in year 18, and averaging only 8.7 t CO_2/ha/year over the 27-year period.

Figure 16 shows the total CO_2 sequestration modelled for the above scenario over the 27-year period.

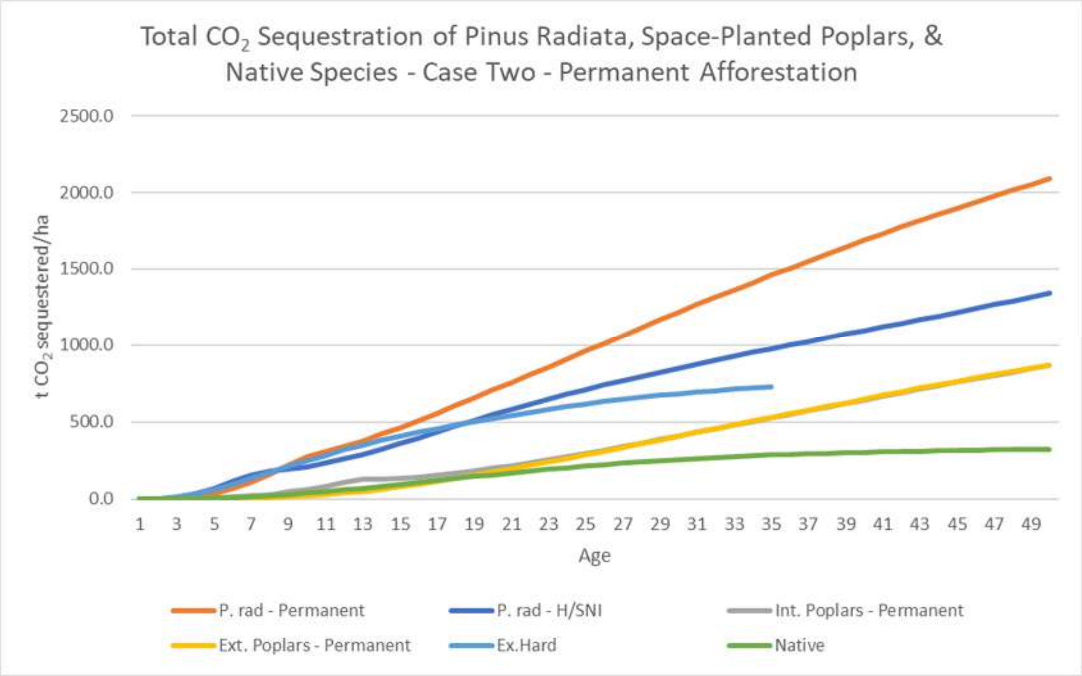
Figure 16: Total CO_2 Sequestration of Afforestation Types for Case Two – Total Afforestation



As expected, the annual sequestration rates shown in Figure 15 have a bearing on the total CO_2 sequestered at the end of the 27-year period. The modelled Pinus radiata had the highest average annual CO_2 sequestration rate, which has resulted in the highest total amount of CO_2 sequestered at the end of the 27-year period of all afforestation types. Conversely, the native forest (Native), which has the lowest annual sequestration rates, has the lowest total CO_2 sequestration. However, this is only over a 27-year period, when afforestation types were modelled over a 50-year period, total CO_2 sequestration results are different.

Results for the permanent afforestation integration level from Case Two (which has differing productivity inputs compared to the total afforestation integration level shown in Figure 15 and Figure 16) are shown in Figure 17. The ranking of total CO_2 sequestration by afforestation type does not change with the longer 50-year period. However, the variances in total CO_2 sequestered get larger as species with greater annual CO_2 sequestration rates have a longer time to accumulate CO_2 at a faster rate. Exotic hardwood sequestration rates are currently only available up to year 35 (MPI, 2017), so have not been included for the remainder of the 50-year time period. The modelled rates for the two space-planted poplar regimes are near-identical for the majority of the time period.

Figure 17: Total CO2 Sequestration of Afforestation Types for Case Two – Total Afforestation



Economic Desirability of Carbon Afforestation Scenarios

Comparison of Afforestation Scenarios

Table 25 shows the results of the DCF analyses of each afforestation scenario of Case One. Also included in Table 25 are the DCF analysis results of the economic desirability of pastoral farming on the marginal pastoral land. As the analysis of the pastoral farming on marginal pastoral land, and the analysis of the total afforestation integration level, comprises the entirety of the marginal pastoral land within the case study farm, the two results can be directly compared. When revenue from CO_2 sequestration is excluded from the analysis, NPV and IRR metrics are negative for all afforestation scenarios, with the exception of the Pinus radiata afforestation type, which has positive IRR metrics. The least economically desirable afforestation scenario is the 'Mānuka – Preferred' scenario, with an NPV of -$15,341/ha and an IRR of -5.08%. For all afforestation scenarios, the added benefit of revenue from CO_2 sequestration improves the economic desirability. When CO_2 sequestration revenue is considered, only the Mānuka and Native Mix afforestation types (across all integration levels) have negative NPV and IRR metrics. In contrast, NPV and IRR metrics are both positive for all other afforestation scenarios (except the NPV of the ‘Intensive Poplars’ preferred and total scenarios). The most economically desirable afforestation scenario is the ‘Extensive Poplars – Permanent’ scenario, which has an NPV of $5,401/ha.

Table 25: Economic Desirability of Afforestation Scenarios Within Case One

Case Study One	**Afforestation Integration Level**					
	Preferred		**Total**		**Permanent**	
	IRR	**NPV**	**IRR**	**NPV**	**IRR**	**NPV**
Marginal Land						
Base Scenario Pastoral Farming			3.81%	-$1,000		
Afforestation Option **Harvest/Grazing/Mānuka Only**						
P. rad	1.08%	-$8,170	1.17%	-$8,064	n/a	n/a
Intensive Poplars	-3.74%	-$10,790	-3.13%	-$10,132	-1.12%	-$9,435
Extensive Poplars	-3.01%	-$9,041	-2.41%	-$8,562	-0.65%	-$7,674
Mānuka	-5.08%	-$15,341	-4.89%	-$15,176	-3.73%	-$14,535
Native Mix	n/a	n/a	n/a	n/a	n/a	n/a
Harvest/Grazing/Mānuka & Carbon						
P. rad	5.30%	$1,430	5.34%	$1,536	6.30%	$3,989
Intensive Poplars	4.15%	-$624	4.50%	-$153	6.80%	$3,640
Extensive Poplars	5.46%	$1,125	5.53%	$1,417	8.20%	$5,401
Mānuka	-1.55%	-$11,601	-1.55%	-$11,675	-0.45%	-$10,187
Native Mix	-5.33%	-$23,553	-5.11%	-$22,800	-3.09%	-$22,173

Table 26 shows results of the DCF analyses of each afforestation scenario, as well as the DCF analysis results of the economic desirability of pastoral farming on the marginal pastoral land, for Case Two.

Table 26: Economic Desirability of Afforestation Options within Case Two

Case Study Two	**Afforestation Integration Level**					
	Preferred		**Total**		**Permanent**	
	IRR	**NPV**	**IRR**	**NPV**	**IRR**	**NPV**
Marginal Land						
Base Scenario Pastoral Farming			8.99%	$4,944		
Afforestation Option **Harvest/Grazing/Mānuka Only**						
P. rad	2.03%	-$4,808	2.56%	-$4,720	n/a	n/a
Intensive Poplars	3.17%	-$1,416	1.52%	-$2,439	5.90%	$1,545
Extensive Poplars	4.91%	$277	2.15%	-$1,868	7.59%	$3,126
Mānuka	-4.17%	-$11,409	-4.82%	-$14,834	-3.23%	-$11,689
Native Mix	n/a	n/a	n/a	n/a	n/a	n/a
Harvest/Grazing/Mānuka & Carbon						
P. rad	7.64%	$4,791	8.66%	$8,599	9.04%	$7,946
Intensive Poplars	11.74%	$8,599	4.32%	-$263	9.61%	$8,766
Extensive Poplars	13.75%	$10,292	4.87%	$259	10.60%	$9,902
Mānuka	-0.35%	-$7,752	-1.38%	-$11,177	0.24%	-$7,616
Native Mix	-4.61%	-$18,970	-2.81%	-$13,455	-2.72%	-$17,907

Similar to Case One, the Mānuka afforestation type is the least economically desirable afforestation type across all integration levels when CO_2 sequestration revenue is excluded from the analysis, with the 'Mānuka – Total' scenario having an NPV of -$14,834 and an IRR of -4.82%. In contrast to Case One, both space-planted poplar afforestation types have positive IRRs for all integration levels, with the greatest results being for the 'permanent' integration level, which shows both positive NPV and IRR metrics for both regimes. When the added benefit of revenue from CO_2 sequestration is incorporated into the analyses, the two space-planted poplar afforestation types have the highest NPV and IRR metrics of all afforestation scenarios, with the 'Extensive Poplars' afforestation type being the greater of the two, having an NPV of $10,292/ha and IRR of 13.75%. However, when these two afforestation types are modelled at the total afforestation integration level, economic desirability is significantly lower. Further similarities to Case One are noted, as both the Mānuka and Native mix afforestation types have negative NPV and IRR metrics for all integration levels, apart from the 'Mānuka – Permanent' scenario, which has an IRR of 0.24%, but an NPV of -$7,616/ha.

Economic Comparison of Pastoral Farming and Carbon Forestry on Marginal Pastoral Land

Both Table 25 and Table 26 also include the NPV and IRR metrics of the base scenario pastoral farming enterprise on the marginal pastoral land, which is the site of the total afforestation integration level. The results of the economic desirability of pastoral farming on marginal pastoral land vary significantly between the two case study farms. The pastoral farming of Case One is calculated to have an NPV of -$1,057/ha, and an IRR of 3.81%. In contrast, Case Two is calculated to have an NPV of $4,860/ha, and IRR of 8.99%. The economic desirability of pastoral farming on marginal pastoral land within Case One is greater (NPV metric) than all afforestation types for the total afforestation integration level when revenue from CO_2 sequestration is excluded. However, when revenue from CO_2 sequestration is included, the economic desirability of pastoral farming on marginal pastoral land is superior only to the Mānuka and Native Mix afforestation types (NPV metric). In contrast, for Case Two, the economic desirability of pastoral farming on marginal pastoral land is greater (NPV metric) than all afforestation types, irrespective of whether or not revenue from CO_2 sequestration is included in the analysis. The exception to this is the Pinus radiata when revenue from CO_2 sequestration is included in the analysis, which has an NPV of $8,599/ha. It should be cautioned that the purchase value and terminal value of land have been included within all DCF analyses (both pastoral and forestry), so the above metrics are not solely based on the relative productivity of each land use, but also the land values associated with each land use.

The results in Table 25 and Table 26 highlight the differences in rankings derived from the NPV and IRR metrics, which were discussed in Chapter Two. For example, when revenue from CO_2 sequestration is included in the analysis for the total afforestation integration level of Case One, the IRR metric ranks the ‘P. rad’ afforestation type lower than the ‘Intensive Poplars’ afforestation type, but the NPV metric ranks the ‘P. rad’ afforestation type higher than the ‘Intensive Poplars’ afforestation type. Differences in rankings are further seen for Case Two, where the IRR metric for the base farming scenario on marginal pastoral land is greater than that for the ‘P. rad’ afforestation type when revenue from CO_2 sequestration is included in the analysis, but the NPV shows the opposite. It is also important to highlight the scale of the differences between the NPV and IRR metrics for each land use. The IRR metric for the two land uses only differs by 0.33%, whereas the NPV metric for the two land uses differs by $3,655/ha (approximately 57.5%).

Table 27 shows the average annual net return (annuity) that has been derived from the total NPVs of pastoral farming on marginal pastoral land and carbon forestry, which allows for another type of analysis of the relative economic desirability of the two land use options, in terms of annual net income generated.

Table 27: Net Return Annuity for Pastoral Farming and Afforestation Types of 'Total Afforestation' Level

	Annuity Net Return ($/ha)	
Marginal Pastoral Land	**Case One**	**Case Two**
Base Scenario Pastoral Farming	$307	$622
Afforestation Type **Harvest/Grazing/Mānuka & Carbon**		
P. rad	$723	$1,157
Intensive Poplars	$340	$185
Extensive Poplars	$398	$219
Mānuka	-$154	-$139
Native Mix	-$611	-$246

It can be seen that the annuity for pastoral farming on marginal pastoral land within Case Two is greater than that for Case One. Furthermore, for Case One, the annuity of the Pinus radiata afforestation type is more than double that of the pastoral farming annuity. Both space-planted poplars afforestation types are similar, but slightly higher, and the Mānuka and Native Mix afforestation types are far lower, as compared to pastoral farming within Case One. For Case Two, the Pinus radiata afforestation type is also significantly greater than the pastoral farming annuity. However, unlike Case One, the annuities of both space-planted poplar afforestation types are significantly lower than that of the pastoral farming within Case Two.

Impacts of Carbon Forestry Integration at Preferred and Total Afforestation Integration Levels

The results of overall physical, financial, and environmental performance of the base scenario pastoral farming enterprise, compared to scenarios integrated with carbon forestry, for Case One are presented in Table 28. The preferred afforestation integration level has a PPA of 39.6 ha (rounded to 40 ha in Table 28), which comprises an NSA of 33.5 ha, and unplantable/setback areas of 6.1 ha. Refer to Figure 8 for a map of the land use of Case One for this integration level. The afforestation type is Pinus radiata. The total afforestation integration level also comprises of Pinus radiata as the afforestation type but has a PPA of 99.7 ha (rounded to 100 ha in Table 28), with an NSA of 83.9 ha and unplantable/setback areas of 15.8 ha. Refer to Figure 10 for a map of the land use of Case One for this integration level.

Table 28: Overall Results of Short-term Afforestation Integration Levels for Case One

Case Study One **Physical**	**Base Farm Results - Short Term**	**Preferred Afforestation Results**	**Total Afforestation Results**
Total Area	293 ha	293 ha	293 ha
Farmed Area	247 ha	207 ha	147 ha
Existing Ineffective	46 ha	46 ha	46 ha
Afforested Area	0 ha	40 ha	100 ha
Financial			
Per Farmed Ha			
IRR	4.69%	4.96%	5.35%
NPV	$154	$627	$1,373
Total Investment			
NPV	$37,963	$154,747	$339,224
Environmental			
Nitrogen Root Zone Loss	2,694 kg N/year	2,441 kg N/year	2,067 kg N/year
Nitrogen Root Zone Loss	9.1 kg N/ha/year	8.3 kg N/ha/year	7.0 kg N/ha/year
Phosphorus Root Zone Loss	222 kg P/year	203 kg P/year	174 kg P/year
Phosphorus Root Zone Loss	0.8 kg P/ha/year	0.7 kg P/ha/year	0.6 kg P/ha/year
Gross GHG Emissions	718.90 t CO_2-e/year	654.00 t CO_2-e/year	555.10 t CO_2-e/year
Avg. CO_2 Sequestered	0.00 t CO_2/year	520.86 t CO_2/year	1,306.82 t CO_2/year
Net GHG Emissions	718.90 t CO_2-e/year	133.14 t CO_2-e/year	-751.72 t CO_2-e/year
Net GHG Emissions	2.44 t CO_2-e/ha/year	0.45 t CO_2-e/ha/year	-2.56 t CO_2-e/ha/year

The integration of carbon forestry improved both the NPV and IRR metrics for both the preferred and total afforestation integration levels. The per farmed ha NPV increased by over four times from the base scenario to the preferred afforestation integration level, and by nine times to the total afforestation integration level.

Furthermore, environmental performance increased with each level of afforestation integration. N losses for the preferred afforestation integration level fell by 253 kg/year (9.4%) and P loss fell by 19 kg/year (8.6%) from the base scenario, whereas, the total afforestation integration level resulted in N loss being reduced by 627 kg/year (23.3%) and P loss being reduced by 48 kg/year (21.6%) from the base scenario. Moreover, both gross and net emissions of greenhouse gases reduced with afforestation integration. Notably, when the 84 ha of Pinus radiata was planted within the total afforestation integration level, the property became a CO_2 sink, sequestering an additional 751.7 t CO_2-e/year more than total gross emissions, which is a 205% decrease in net emissions from the base pastoral farming scenario.

Table 29 shows the overall physical, financial, and environmental performance results of the base scenario pastoral farming enterprise, compared to scenarios integrated with carbon forestry, for Case Two.

Table 29: Overall Results of Short-term Afforestation Integration Levels for Case Two

Case Study Two **Physical**	**Base Farm Results - Short Term**	**Preferred Afforestation Results**	**Total Afforestation Results**
Total Area	559 ha	559 ha	559 ha
Farmed Area	442 ha	362 ha	143 ha
Existing Ineffective	116 ha	116 ha	116 ha
Afforested Area	0 ha	81 ha	300 ha
Financial			
Per Farmed Ha			
IRR	8.63%	7.81%	8.19%
NPV	$4,985	$4,275	$5,954
Total Investment			
NPV	$2,205,525	$1,891,682	$2,634,511
Environmental			
Nitrogen Root Zone Loss	11,900 kg N/year	10,738 kg N/year	5,231 kg N/year
Nitrogen Root Zone Loss	21.1 kg N/ha/year	19.1 kg N/ha/year	9.3 kg N/ha/year
Phosphorus Root Zone Loss	1,130 kg P/year	948 kg P/year	546 kg P/year
Phosphorus Root Zone Loss	2.0 kg P/ha/year	1.7 kg P/ha/year	1.0 kg P/ha/year
Gross GHG Emissions	2,099.40 t CO_2-e/year	1,806.10 t CO_2-e/year	711.20 t CO_2-e/year
Avg. CO_2 Sequestered	0.00 t CO_2/year	785.70 t CO_2/year	5,381.63 t CO_2/year
Net GHG Emissions	2,099.40 t CO_2-e/year	1,020.40 t CO_2-e/year	-4,670.43 t CO_2-e/year
Net GHG Emissions	3.73 t CO_2-e/ha/year	1.81 t CO_2-e/ha/year	-8.34 t CO_2-e/ha/year

The preferred afforestation integration level comprises a PPA of 80.8 ha (rounded to 81 ha in Table 29), which comprises an NSA of 75.3 ha, and unplantable/setback areas of 5.5 ha. The afforestation type comprises a mix of 29.6 ha of Pinus radiata and 45.7 ha of Mānuka. Refer to Figure 9 for a map of the land use of Case Two for this integration level. The total afforestation integration level also comprises a mix of Pinus radiata (227.8 ha) and Mānuka (45.7 ha) afforestation types, resulting in a total NSA of 273.5 ha, with a further 26.5 ha of unplantable/setback areas creating a final PPA of 299.9 ha (rounded to 300 ha in Table 29). Refer to Figure 11 for a map of the land use of Case Two for this integration level.

Unlike with Case One, the introduction of carbon forestry into Case Two did not improve the NPV and IRR metrics of the preferred afforestation integration level, with both of these metrics indicating a decrease in economic performance of the overall farming business. However, when carbon forestry was integrated on a larger scale, the total afforestation integration level resulted in a higher NPV than the base scenario, but conversely, a slight decrease in IRR from the base scenario. Furthermore, environmental performance increased with each increased level of afforestation integration. N loss for the preferred afforestation integration level fell by 1,162 kg/year (9.8%) and P loss fell by 182 kg/year (16.1%) from the base scenario, whereas, the total afforestation integration level resulted in N loss being reduced by 6,669 kg/year (56.0%) and P loss being reduced by 584 kg/year (51.7%) from the base scenario. Moreover, both gross and net emissions of greenhouse gases reduced with afforestation integration. Notably, for the total afforestation integration level, similar to Case One, the property became a CO_2 sink, sequestering an additional of 4,670 t CO_2-e/year more than total gross emissions.

Impacts of Carbon Forestry Integration at Permanent Afforestation Integration Level

Table 30 shows the overall physical, financial, and environmental performance of the base scenario pastoral farming enterprise over the 50-year period for Case One. The results of the base scenario are presented three times; firstly, to reflect the base pastoral farming scenario with no liabilities for greenhouse gas emissions from pastoral farming practices; secondly, to reflect the scenario where NZUs generated from CO_2 sequestration of the permanent afforestation are surrendered to offset 5% of the total greenhouse gas emissions from farming practices, with the remaining 95% of NZUs from CO_2 sequestration assumed to be sold; and thirdly, to reflect the scenario where NZUs generated from CO_2 sequestration of the permanent afforestation are surrendered to offset 100% of the total greenhouse gas emissions from farming practices.

Table 30: Overall Results of Long-term Afforestation Integration Level for Case One

Case Study One	**Liable for 0 % of Emissions**	**Liable for 5 % of Emissions**	**Liable for 100 % of Emissions**
Physical	**Base Farm Results - Permanent**	**Permanent Afforestation Results**	**Permanent Afforestation Results**
Total Area	293 ha	293 ha	293 ha
Farmed Area	247 ha	219 ha	219 ha
Existing Ineffective	46 ha	46 ha	46 ha
Afforested Area	0 ha	28 ha	28 ha
Financial			
Per Farmed Ha			
IRR	4.63%	4.81%	3.96%
NPV	$61	$462	-$1,393
Total Investment			
NPV	$15,047	$114,021	-$344,021
Environmental			
Nitrogen Root Zone Loss	2,694 kg N/year	2,516 kg N/year	2,516 kg N/year
Nitrogen Root Zone Loss	9.1 kg N/ha/year	8.5 kg N/ha/year	8.5 kg N/ha/year
Phosphorus Root Zone Loss	222 kg P/year	207 kg P/year	207 kg P/year
Phosphorus Root Zone Loss	0.8 kg P/ha/year	0.7 kg P/ha/year	0.7 kg P/ha/year
Gross GHG Emissions	718.90 t CO_2-e/year	673.80 t CO_2-e/year	673.80 t CO_2-e/year
Avg. CO_2 Sequestered	0.00 t CO_2/year	697.78 t CO_2/year	697.78 t CO_2/year
Net GHG Emissions	718.90 t CO_2-e/year	-23.98 t CO_2-e/year	-23.98 t CO_2-e/year
Net GHG Emissions	2.44 t CO_2-e/ha/year	-0.08 t CO_2-e/ha/year	-0.08 t CO_2-e/ha/year

For Case One, it was modelled that using the farmer's preferred afforestation type of Pinus radiata, an NSA of only 28 ha was required to achieve a carbon neutral status over the 50-year period. The integration of carbon forestry improved both the NPV and IRR metrics when 5% of total farm greenhouse gas emissions were offset with NZUs generated from CO_2 sequestration, with the remaining 95% of NZUs generated being sold for profit. However, when 100% of total farm greenhouse gas emissions were liable to be paid for, both the NPV and IRR metrics fell below that of the base scenario pastoral farming. Environmental performance increased for the permanent afforestation integration level. N loss reduced by 178 kg/year (6.6%) and P loss reduced by 15 kg/year (6.8%) from the base scenario.

Table 31 shows the overall physical, financial, and environmental performance of the base scenario pastoral farming enterprise over the 50-year period for Case Two. The results of the base scenario are presented three times, to reflect; the base pastoral farming scenario with no liabilities for greenhouse gas emissions from pastoral farming practices, a scenario where 5% of greenhouse gas emissions are liable to be paid, and a scenario where 100% of greenhouse gas emissions are liable to be paid.

Table 31: Overall Results of Long-term Afforestation Integration Level for Case Two

Case Study Two	**Liable for 0 % of Emissions**	**Liable for 5 % of Emissions**	**Liable for 100 % of Emissions**
Physical	**Base Farm Results - Permanent**	**Permanent Afforestation Results**	**Permanent Afforestation Results**
Total Area	559 ha	559 ha	559 ha
Farmed Area	442 ha	307 ha	307 ha
Existing Ineffective	116 ha	116 ha	116 ha
Afforested Area	0 ha	136 ha	136 ha
Financial			
Per Farmed Ha			
IRR	8.57%	7.28%	5.84%
NPV	$6,073	$4,642	$2,162
Total Investment			
NPV	$2,687,150	$2,053,686	$956,798
Environmental			
Nitrogen Root Zone Loss	11,900 kg N/year	9,615 kg N/year	9,615 kg N/year
Nitrogen Root Zone Loss	21.1 kg N/ha/year	17.1 kg N/ha/year	17.1 kg N/ha/year
Phosphorus Root Zone Loss	1,130 kg P/year	834 kg P/year	834 kg P/year
Phosphorus Root Zone Loss	2.0 kg P/ha/year	1.5 kg P/ha/year	1.5 kg P/ha/year
Gross GHG Emissions	2,099.40 t CO_2-e/year	1,584.30 t CO_2-e/year	1,584.30 t CO_2-e/year
Avg. CO_2 Sequestered	0.00 t CO_2/year	1,790.26 t CO_2/year	1,790.26 t CO_2/year
Net GHG Emissions	2,099.40 t CO_2-e/year	-205.96 t CO_2-e/year	-205.96 t CO_2-e/year
Net GHG Emissions	3.73 t CO_2-e/ha/year	-8.34 t CO_2-e/ha/year	-8.34 t CO_2-e/ha/year

For Case Two, it was modelled that using the farmer's preferred afforestation mix of Pinus radiata (53.4 ha) and Mānuka (82.5 ha), an NSA of 136 ha was required to achieve a carbon neutral status over the 50-year period. Unlike with Case One, the integration of carbon forestry into Case Two reduced the NPV and IRR metrics when 5% of total farm greenhouse gas emissions were offset with NZUs generated from CO_2 sequestration, with the remaining 95% of NZUs generated being sold for profit, and also when 100% of total farm greenhouse gas emissions were liable to be paid for. Environmental performance increased for the permanent afforestation integration level. N loss reduced by 2,285 kg/year (19.2%) and P loss reduced by 296 kg/year (26.2%) from the base scenario.

Not shown in Tables 30 and 31 are the results of the pastoral farming base scenario when 100% of total farm greenhouse gas emissions were liable to be paid for, and no carbon forestry was integrated to attempt to offset emissions. For Case One, the NPV of the total investment for the pastoral farming base scenario when 100% of total farm greenhouse gas emissions were liable to be paid for fell to -$499,375 compared to $15,047 when no emissions were liable to be paid for. Similarly, for Case Two, the NPV of the total investment fell to $1,157,131 when 100% of total farm greenhouse gas emissions were liable to be paid compared to $2,687,150 when no emissions were liable to be paid for.

The carbon accounting approach used to calculate the required afforestation area to achieve a carbon neutral status is the stock change approach. However, the ETS also provides for the averaging approach, under which, less NZUs are generated but there are no deforestation liabilities upon harvest, providing the area is replanted in a forestry species (MPI, 2021b). Although no overall physical, financial, and environmental assessment has been conducted for a carbon neutrality scenario where the averaging approach is used, Table 32 and Table 33 show the required areas of afforestation to achieve a carbon neutral status over the 50-year period, for Case One and Case Two, respectively, utilising the averaging approach.

Table 32: Areas of Afforestation for Carbon Neutrality Different Carbon Accounting Approaches – Case One

Case Study One	Carbon Accounting Approach		
Afforestation Type	**Permanent**	**Averaging**	**Diff. (ha)**
P. rad	27.48	77.16	49.68
Poplars - Intensive	47.51	73.59	26.09
Poplars - Extensive	47.51	73.59	26.09
Native - Mānuka	100.88	229.16	128.28
Native - Mix	100.88	229.16	128.28
Overall	50.86	102.32	51.47

Table 33: Areas of Afforestation for Carbon Neutrality Different Carbon Accounting Approaches – Case Two

Case Study Two	Carbon Accounting Approach		
Afforestation Type	**Permanent**	**Averaging**	**Diff. (ha)**
P. rad	76.15	215.40	139.25
Poplars - Intensive	103.55	486.00	382.44
Poplars - Extensive	103.30	592.21	488.92
Native - Mānuka	275.80	588.68	312.87
Native - Mix	271.77	588.68	316.90
Overall	135.85	350.21	214.36

As can be seen, there are significant differences in the calculated areas required to achieve a carbon neutral status when contrasting carbon accounting approaches are adopted. Whilst adopting the averaging approach would allow for the timber harvest of carbon forestry types, the quantum of land required to be carbon neutral, in some instances, is greater than the farmed area of the case study farms.

Sensitivity Analysis

A sensitivity analysis has been conducted to show the impact of varying discount rates and NZU prices on economic feasibility of pastoral farming and carbon forestry. Table 34 shows the NPV of pastoral farming on marginal pastoral land and carbon forestry for the total afforestation integration level for both case study farms. The discount rate and NZU price have been altered from the base inputs of 4.60% and $35/NZU, respectively. It is assumed that 100% of total gross greenhouse gas emissions from pastoral farming practices are liable to be paid for.

Table 34: Sensitivity Analysis of NPV - Discount Rate and NZU Price

Sensitivity Analysis - NPV/ha @ 100% of Emissions Liable for Total Afforestation Integration Level							
		Discount Rate					
	NZU Price	**Case One**			**Case Two**		
Land Use	**($/unit)**	**2.0%**	**4.6%**	**8.0%**	**2.0%**	**4.6%**	**8.0%**
Pastoral Farming	$15	$2,388	-$1,553	-$4,203	$10,165	$4,395	$382
	$35	$1,403	***-$2,292***	-$4,744	$9,189	***$3,663***	-$154
	$50	$665	-$2,845	-$5,150	$8,457	$3,114	-$557
P. rad	$15	$2,453	-$4,016	-$8,028	$9,434	$886	-$4,403
	$35	$9,567	***$1,536***	-$3,905	$19,825	***$8,599***	$960
	$50	$14,902	$5,699	-$814	$27,619	$14,384	$4,983
Intensive Poplars	$15	-$3,753	-$6,491	-$8,321	-$616	-$2,679	-$4,096
	$35	$3,471	***-$1,486***	-$5,133	-$521	***-$2,838***	-$4,432
	$50	$8,889	$2,268	-$2,741	-$449	-$2,958	-$4,684
Extensive Poplars	$15	-$1,968	-$4,937	-$7,001	$96	-$2,151	-$3,701
	$35	$5,230	***$47***	-$3,828	$248	***-$2,367***	-$4,137
	$50	$10,628	$3,785	-$1,449	$361	-$2,529	-$4,464
Mānuka	$15	-$12,112	-$13,756	-$14,560	-$11,495	-$13,350	-$14,407
	$35	-$8,872	***-$11,675***	-$13,330	-$8,191	***-$11,177***	-$13,084
	$50	-$6,442	-$10,114	-$12,407	-$5,713	-$9,547	-$12,092
Native Mix	$15	-$24,912	-$24,881	-$24,184	-$15,074	-$15,210	-$14,703
	$35	-$21,671	***-$22,800***	-$22,954	-$12,054	***-$13,455***	-$13,784
	$50	-$19,241	-$21,240	-$22,031	-$9,789	-$12,139	-$13,094

It can be seen that for the pastoral farming land use, returns are greatest when a discount rate of 2.0%, and an NZU price of $15/unit, is used. The NPV of pastoral farming within Case One is only positive at a discount rate of 2.0%, whereas, for Case Two, pastoral farming still has a positive NPV at a discount rate of 8.0% and NZU price of $15/unit. In contrast, the NPVs of all afforestation options are highest at a discount rate of 2.0% and an NZU price of $50/unit. Irrespective of discount rate and NZU price, the Mānuka and Native Mix afforestation options did not return positive NPVs.

Conclusion

The results of this research show that not only does the quantum of marginal land contained within farms differ, but so too does the physical and financial performance of marginal pastoral land. Furthermore, there are shown to be differences between both economic and environmental performance of pastoral farming compared to carbon forestry. However, these differences do vary between carbon forestry species and between case study farms. Lastly, when 100% of total farm greenhouse gas emissions were liable to be paid for, overall economic performance of both case study farms decreased compared to the base pastoral farming scenario where no emissions were liable to be paid.

Chapter Five: Discussion

Introduction

This chapter aims to answer the research question: What impact does the integration of carbon forestry on marginal pastoral land within New Zealand sheep and beef farms have on the economic and environmental performance of the overall farm business? This chapter does delve deeper than simply answering the research question and also aims to answer the seven research objectives that have also been posed. These research objectives have been designed to provide insight into driving factors behind the answer to the research question.

Quantum of Marginal Pastoral Land and Farm Heterogeneity

New Zealand has a diverse range of land types throughout both the North and South Islands (Blaschke, et al., 1992) that vary in their physical characteristics (McIvor, Douglas, et al., 2011) and productivity (Lynn, et al., 2009). A study by Basher et al. (2008) states that heterogeneity of land also occurs at a regional scale.

The results of this study corroborate statements made by Basher et al. (2008), Blaschke et al. (1992), Lynn et al. (2009), and McIvor and Douglas et al. (2011), showing that heterogeneity in the quantum of marginal pastoral land does exist between farms. This is an important consideration when extracting results of afforestation upon marginal pastoral land from studies such as Vibart, et al., (2011) and Reisinger, et al., (2017), who integrated a generic quantum of carbon forestry into their modelled farms. As not all farms have the same quantum of marginal pastoral land, care must be taken when applying the results of one study to another farm outside the study, as the impacts upon economic and environmental performance do alter given the quantum of marginal pastoral land within a farm, which is a point that will be discussed later in this chapter.

Physical Productivity of Pastoral Farming on the Case Study Farms

The differing physical production metrics of the two case study farms are partly a reflection of climatic conditions, with Case One having a significantly lower annual rainfall as compared to Case Two (less than 800 mm vs 1,500 to 1,600 mm) (Chappell, 2013). As previously outlined, this has resulted in disparities between total pasture grown on each case study farm.

However, a further factor that has influenced the total feed eaten (t DM/farmed ha) and SU per farmed ha, is the individual case study farmer's management response to the climatic challenges. The farm of Case One is subject to prolonged seasonal dry spells over summers but has relatively mild winters (Chappell, 2013), so pasture growth is limited over summer, with the highest pasture growth rates recorded from late winter to very early summer (refer to Appendix F for detailed pasture growth rates). In response to this, the farmer of Case One operates strictly trading livestock enterprises, where fewer livestock are carried over the dry summer months and more are carried from autumn to spring, to capture the higher pasture growth. In contrast, the farmer of Case Two is situated at a higher altitude, with the property experiencing winters that are generally harsher and longer than the wider Hawke's Bay Region but does have reliable rainfall throughout the spring and summer months (Chappell, 2013). Therefore, pasture growth is at its lowest over winter months, peaks in spring and autumn, and a slight reduction is experienced over a short summer period. Instead of farming to the climatic conditions as the farmer of Case One does, the farmer of Case Two relies upon winter crops and silage to fill the feed deficit over winter months. This is a more intensive management system than that of Case One, which has subsequently resulted in higher physical performance. Therefore, it is apparent that the chosen livestock management system of farmers can impact the physical performance of their business, and it is likely to have flow-on impacts on profitability.

Furthermore, it appears that the quantum of marginal pastoral land within a hill country sheep and beef farm is not necessarily a predictor of physical farm performance. Table 17 and Table 18 outline the physical summary of each case study farm. Both the Gully farmlet of Case One, and the B Class and C Class farmlets of Case Two, are defined as marginal pastoral land within this study, however, the physical productivity of the three farmlets varies significantly. Firstly, it is likely that climatic conditions, grazing management, and soil fertility, among other factors, have combined to create differences in the amount of pasture grown (t DM/farmed ha) between the farmlets. The differences in livestock management policies between Case One and Case Two have further compounded these differences, with the higher pasture utilisation rates of B Class and C Class farmlets increasing the difference in productivity compared to the Gully farmlet. However, it is possible that the pasture utilisation rates for the B Class and C Class farmlets have been overestimated, at 81.4% and 82.8%, respectively, so are potentially overstating the productivity of these areas of the Case Two farm.

Moreover, the Easy farmlet of Case One comprises LUC Class 3s1 land that is described as being suitable for pasture production, being of an undulating contour, that is however, predominantly limited by its soil properties (Lynn, et al., 2009). Whereas the B Class farmlet of Case Two comprises LUC Class 6e1, which is described as having moderate limitations for pasture production, and is predominantly limited by its erosion susceptibility (Lynn, et al., 2009). Despite the Easy farmlet being classified by the LUC system as being more productive than the B Class farmlet, the modelled pasture grown (t DM/farmed ha) within this research would suggest that the B Class farmlet, despite it having a poorer LUC classification, is the more productive. It is likely that lower rainfall of Case One is also a contributing factor.

Perhaps consideration needs to be given to the definition of marginal pastoral land that has been used within this research. Using the NZLRI Land Use Capability shapefile (Landcare Research, 2010) has made the task of spatially identifying marginal land (LUC Class VI to VIII) relatively straightforward. However, it is clear that this method has not identified what several other studies would define as marginal pastoral land (Resiginer, et al., 2017; Trotter, et al., 2005; and Van Kooten & Cornelius, 2000). It is possible that dissection of the NZLRI Land Use Capability shapefile with a rainfall map overlay could better identify marginal pastoral land.

Economic Results of Base Scenario Pastoral Farming

Livestock Enterprise Profitability

As well as there being differences in profitability between the two case study farms because of differences in physical production, there are also differences created by choice of livestock policy. Case One has a sheep to cattle ratio of 29:71, whereas Case Two has a sheep to cattle ratio of 76:24, which are nearly identically inverse of one another. The gross revenue derived from the sheep enterprise (mixed-sex lamb finishing) within Case One is calculated to be 51.2 c/kg DM eaten, which is significantly higher than the gross revenue of the beef enterprise (steer and heifer finishing), which is calculated to be 16.9 c/kg DM eaten. Similarly, the sheep enterprise (breeding/finishing) of Case Two returns a higher gross revenue (25 c/kg DM eaten) compared to the beef enterprise (breeding/finishing) (11 c/kg DM eaten). Despite the sheep enterprise of Case One returning the highest gross revenue per kg DM eaten of all enterprises across both case study farms, the ratio of sheep to cattle is low, meaning that Case One runs a higher proportion of a lower-profitability stock enterprise. However, the beef enterprise is crucial to ensure the success of the sheep enterprise of Case One, with the steers/heifers utilised to control pasture growth at crucial times of the year to ensure pasture quality remains high for the lambs. In contrast, Case Two runs a higher ratio of sheep to cattle, and therefore, is further maximising gross revenue through selection of livestock enterprise.

Incorporation of Land Values into DCF

As previously discussed, physical performance and livestock enterprise profitability have influenced the gross revenue per farmed ha derived from the various farmlets within each case study, as well as the overall profitability of each case study. However, the incorporation of land values within the DCF analyses is another factor that has influenced the relative economic desirability of the base scenario pastoral farming of each case study farm. However, several key studies into the profitability of pastoral farming compared to carbon forestry (Douglas, 2019; Fogan & Pollard, 2020; Journeaux, et al., 2020; Reisinger, et al., 2017), have all excluded the cost of land associated with the relevant land use.

Table 35: Land Values of Case Studies Relative to Physical Productivity

Land Value Metric	Case One	Case Two
Farmed Area	247 ha	442 ha
Total Pasture Grown (t DM)	1,507	3,456
Total SU	1,762	5,456
Net Income	$122,151	$290,211
GV Land Value	$2,830,000	$3,820,000
Ineffective Land Value	$54,801	$139,759
Farmed Land Value	$2,775,199	$3,680,241
Farmed Land Value/Farmed ha	$11,236	$8,318
Farmed Land Value/t DM Grown	$1,842	$1,065
Farmed Land Value/SU	$1,575	$675
Net Income/Farmed Land Value	4.4%	7.9%

Table 35 summarises the physical and financial performance of each case study farm, the assumed land value inputs, and several metrics. It can be seen that on a per farmed ha basis, the farmed land of Case One ($11,236/farmed ha) is more valuable than that of Case Two ($8,318/farmed ha), $2,918/farmed ha more valuable. Farmed land values per t DM grown and per SU are also both significantly higher for Case One than Case Two. This may initially seem logical because only 34.3% of Case One is classified as marginal pastoral land, in contrast to 67.8% of Case Two being classified as marginal pastoral land. However, Case Two has higher physical productivity than that of Case Two, in terms of both total pasture grown and total SU carried. Therefore, it is likely that other factors such as total farm size, distance from main centres, climate, and options for subdivision, have combined to raise the value of the smaller, better located, warmer climate, Case One farm, relative to the larger, poorer located, colder climate, Case Two farm. Therefore, the modelled investment of Case One comes at a higher cost per farmed ha compared to the investment into Case Two. Moreover, the modelled pastoral farming returns from the Case One investment are lower than the pastoral farming returns from the investment into Case Two, as evidenced by the net income/farmed land value metric in Table 35. This metric has calculated a net income return of 4.4% on the total land value of Case One, compared to a net income return of 7.9% for Case Two. Therefore, as there are differences in this metric, the inclusion of land value within the DCF analysis will disproportionately impact Case One, as it is the lower performing of the two case study farms.

Despite this disproportionate impact of including land values within the analysis, the inclusion of land values is crucial for comparing the returns of pastoral farming against those of carbon forestry. As the continuation of pastoral farming is not predicted to restrict the land's future potential for revenue generation, no decrease in land value has been modelled (i.e., purchase cost and terminal value are the same) for the pastoral farming land. In contrast, the afforestation of pastoral land is predicted to decrease the value of the land as once the NZUs have been claimed, the generation of revenue from that land is limited only to timber harvest, residual grazing income, or Mānuka honey production. Therefore, as the land has lost a revenue stream, it is less valuable than it was at the start of the investment period when it could have been used for both carbon revenue and timber harvest, residual grazing income, or Mānuka honey production (M. Morice, personal communication, October 8, 2020).

Environmental Results of Base Scenario Pastoral Farming

Nutrient Losses from the Root Zone

As outlined in Table 21 and Table 22, there are differences in N and P losses between the case study farms, as well as differences between management blocks within each case study. For Case One, levels of N required to maintain current fertility levels were modelled to be less than the 22 kg N/ha/year that were applied to the Easy farmlet as fertiliser. The 'leaching – other' pathway estimates background losses from effluent, several other nutrient sources, and fertiliser (Overseer, 2020). Therefore, the high rates of N being applied in fertiliser contribute largely to the overall N losses from Case One. As the 'leaching – other' results are area-weighted and applied pro-rata to each management block (Overseer, 2020), this also accounts for the high ‘leaching – other’ rate from the Gully block. As only 35% of the N leached from the Gully block is from urine patches, reducing the N surplus created through fertiliser applications will potentially have a greater reduction impact on total N loss from the Gully block than reducing stock numbers. It is possible that reducing the N surplus through applying less fertiliser would result in lower physical productivity of the Case One property if nitrogenous fertiliser is applied when pastures are responsive to N, which could equate to a loss of 5 to 12 kg DM/kg N applied. It is also possible that financial performance would decrease as less fertiliser is being applied but production is declining. However, investigation of this is outside the scope of this research. The P maintenance requirements for the Easy farmlet within Case One were modelled to be 19 kg P/ha/year, but there were 25 kg P/ha/year applied in fertiliser. Furthermore, for the Easy farmlet, the risk of P loss from fertiliser is high, which could either be from timing of applications, or application rates being too high. In comparison to the Easy farmlet, the Gully farmlet is modelled to have a lower P loss rate, despite its steeper topography, which is a driver of P loss (Selbie, et al., 2013).

All pasture management blocks within Case Two had large N surpluses, ranging from 54 to 85 kg N/ha, excluding the Lucerne block, which had a deficit of - 144 kg N/ha. Unlike Case One, the main source of N loss from pastoral management blocks within Case Two, and the Kale crop block, was from urine patches. In contrast, the Lucene pasture management block and Swedes crop block leached nearly all N from the ‘leaching – other’ pathway. Therefore, in contrast to Case One, it is likely that reductions in stock numbers will result in more significant N loss reductions than reducing fertiliser applications. For the A Class, B Class, and C Class pasture management blocks of Case Two, fertiliser P applications exceeded maintenance requirements, but did not meet maintenance levels required for the Lucerne block. For the A Class, B Class, and C Class pasture management blocks, P loss risk from soil was high, and P loss risk from fertiliser was extreme for all three blocks, which is likely to be a factor of soil fertility levels and slope (Selbie, et al., 2013).

The results from Case Two, which show losses from urine patches is the predominant loss pathway of N from the pastoral system, support previous research (Di & Cameron, 2002). However, the results of Case One, contradict those of Case Two, and Di and Cameron (2002), as the majority of N loss is from the ‘leaching – other’ pathway. The results of both case study farms show that P loss is predominantly from runoff, which is consistent with previous research (Gillingham & Thorrold, 2000; McDowell, et al., 2001). As stated by Craighead (2004) and confirmed within this study, the untargeted application of P fertiliser results in higher risk of loss to waterways. Moreover, the root zone loss rates of N and P modelled from Case One are consistent with the research of Plantinga and Wu (2003), and Ausseil and Dymond (2010), finding that marginal pastoral land only accounts for small amounts of total N and P losses. However, the results of Case Two, which show that N and P loss rates from the marginal pastoral land are comparable to those of non-marginal pastoral land, contradict the results of the Case One farm within this study, Plantinga and Wu (2003), and Ausseil and Dymond (2010). As has been discussed, the physical productivity of the marginal pastoral land of Case Two is greater than that of the marginal pastoral land within Case One and is similar to the performance of the non-marginal pastoral land within Case Two. This is partly driven by fertiliser use, but mainly stocking rates, which can cause higher rates of P loss (McDowell, et al., 2001). The results of Case Two do, however, corroborate the results of Power et al. (2002), who found that intensification and optimisation of pastoral farming systems can result in higher N loss rates.

Greenhouse Gas Emissions

The results of greenhouse gas emissions from the pastoral farming base scenario of both Case One and Case Two align with those reported in several previous studies, finding that CH_4 is the predominant gas emitted, followed by N_2O (Reisinger, et al., 2017), then there are only small emissions of CO_2 (Johnson, et al., 2007), mainly from embedded processes of fertiliser manufacture (Houghton, et al., 1983). The method of apportioning greenhouse gas emissions to the marginal pastoral land has produced results that are in line with those discussed by Ausseil and Dymond (2010), and Journeaux et al. (2020), who also estimate that greenhouse gas emissions from marginal pastoral land are lower than those from non-marginal pastoral land.

Environmental Benefits of Carbon Forestry

Sequestration of CO_2

The differences in modelled CO_2 sequestration rates between carbon forestry species are predominantly due to growth characterises. Whereas, differences for the same afforestation type but for different integration levels, as well as differences between modelled sequestration rates and corresponding rates outlined in the default Look-up tables, are a result of different productivity indices used (300 index and Site Index) and different regimes being adopted (e.g. intensive vs extensive space-planted poplars).

Growth characteristics of Pinus radiata and native conifer-broadleaved species are well understood and have been documented in numerous studies to date. The results of this research, which show that the CO_2 sequestration rates of Pinus radiata are far superior to those of native conifer-broadleaved species, corroborate a study by Franklin (1972), who outlines slow growth rates of conifer-broadleaved species, and Mead (2013), who states that Pinus radiata is preferred to native conifer-broadleaved species for rapid CO_2 sequestration on account of its growth characteristics. Pinus radiata is also suited to a wider range of sites (Mead, 2013; Watt, et al., 2008; Will, 1978) than conifer-broadleaved forests (Cockayne, 1926; Kerr & Stewart, 2013), which means it is better suited to thriving, and outperforming conifer-broadleaved species. Only one study has been identified that has estimated CO_2 sequestration rates of space-planted poplars. Guevara-Escobar et al. (2002) calculated CO_2 sequestration rates of space-planted poplars (at a density of 37 sph) over a 30-year timeframe to be 2 t CO_2/ha/year, which is significantly lower than rates modelled calculated within this research, as shown in Table 24. However, Guevara-Escobar et al. (2002) reported a much lower density of trees and did not outline silvicultural management history of the stand. Overall, the CO_2 sequestration rates for carbon forestry species generally correspond with prior research as to their relative CO_2 sequestration rates. However, this research does not reflect the benefit of long-term CO_2 storage by conifer-broadleaved native forests, which is have longer lifespans than Pinus radiata and poplars (Pizzirani, et al., 2019).

The differences in CO_2 sequestration rates between afforestation types are a result of differences in both productivity indices and tending regimes. Figure 15, Figure 16, and Figure 17 outline the differences in annual CO_2 sequestration rates and total CO_2 sequestration. Firstly, the differences between CO_2 sequestration rates of modelled afforestation types compared to the standard rates from default Look-up tables (e.g. 'P. rad – Total' vs 'P. rad – H/SNI', and 'Int. Poplars – Total' vs 'Ex. Hard') are due to site-specific productivity indices being adopted within this research, and much broader regional-specific indices being adopted to formulate the default Look-Up tables (MPI, 2017). As the modelled growth rates used to determine CO_2 sequestration rates in the default Look-up tables for Pinus radiata are calibrated against measurements from a number of sites throughout each region (MPI, 2017), it is likely that both high and low productivity sites would have been used to calibrate the modelled growth rates. Within the Hawke's Bay/Southern North Island Region, Palmer et al. (2010) estimated the 300 and Site Indices for three sub-regions, being Hawke's Bay, Manawatu/Whanganui, and Wellington. For the three sub-regions, the 300 Index was shown to range from 13.5 to 45.5, with averages ranging from 27.6 for Wellington to 31.3 for the Hawke's Bay (Palmer, et al., 2010). For the three sub-regions, the Site Index was shown to range from 13.5 to 46.3, with averages ranging from 27.2 for Wellington to 30.9 for the Hawke's Bay (Palmer, et al., 2010). The Site Index adopted for both case studies was 30, which is at the upper end of those modelled by Palmer et al. (2010). Combined with the 300 Index figures adopted, as outlined in Table 36, which are generally on par with those outlined by Palmer et al. (2010), it is feasible that based on higher productivity assumptions, the modelled CO_2 sequestration rates within this research for Pinus radiata are higher than those in the default Look-up tables.

Table 36: 300 Index Values and Altitudes for Afforestation Scenarios

	Afforestation Integration Level			
	Case One		**Case Two**	
300 Index	**Preferred**	**Total**	**Preferred**	**Total**
0-17.5	0.0	0.0	0.0	0.0
17.5-20	0.0	0.0	0.0	0.0
20-22.5	0.0	0.0	0.0	0.0
22.5-25	0.0	3.0	0.0	0.0
25-27.5	4.2	29.3	0.0	0.0
27.5-30	17.7	41.9	19.7	34.9
30-32.5	7.0	10.0	22.1	54.5
32.5-35	10.6	15.6	38.1	186.6
35-37.5	0.0	0.0	0.9	23.9
37.5+	0.0	0.0	0.0	0.0
Total (ha)	39.6	99.7	80.8	299.9
Area Weighted Avg. Class	6.0	5.5	7.0	7.0
Area Weighted Avg. Index	27.5-30	27.5-30	30-32.5	30-32.5
Adopted Index	29.0	28.0	30.0	32.0
Avg. Altitude (masl)	220	180	740	700

Secondly, modelled silvicultural management regimes and planting densities of the carbon forest species will have caused differences in modelled CO_2 sequestration rates. This is firstly seen in Figure 15, where the annual CO_2 sequestration rates of 'P. rad – Total' and 'P. rad – H/SNI' have the same general profile but are not identical. This is because the default Look-up tables were derived from growth models for 'commonly used' regimes within New Zealand (MPI, 2017), which can encompass differences in planting density (Mead, 2013), and usually have three pruning events coupled with two thinning events (Mead, 2013; West, 1996). However, there have been significant changes in both thinning and pruning trends, with a smaller proportion of forests now being thinned and pruned (Forest Owners Association, 2004; Forest Owners

Association, 2019). This trend reflects the regime adopted within this study, with the only silvicultural practice modelled being one thinning event. Because thinning has a larger impact on total CO_2 sequestered by a forest than pruning (MPI, 2017), modelling differences in thinning regimes will cause differentiation in CO_2 sequestration rates. This differentiation can be seen in Figure 15, as rates for 'P. rad – Total' drop in year 11 after the thinning event in year ten, whereas rates for 'P. rad – H/SNI' drop in year nine, after a thinning event in year eight. Further significant differences in CO_2 sequestration rates are noted to exist between the space-planted poplar regimes, as compared to the exotic hardwood shown in the default Look-Up tables. Firstly, this is due to this research adopting the Radiata Calculator to model space-planted poplar growth rates, whereas the default Look-up tables rely upon the growth model for Eucalyptus species and assume no thinning (MPI, 2017). It is also thought that the variation in CO_2 sequestration exists largely due to regime differences. Firstly, there will be differences in initial stocking densities, with the modelled space-planted poplar regimes within this research being established with the intention of having a final crop stocking that only just exceeds the minimum requirements of 30% crown per ha. Whereas, the exotic hardwood species in the default Look-up tables more accurately reflect a stand of trees that have been established at higher densities to optimise timber production, and not allow for continuation of livestock grazing. The large differences in CO_2 sequestration rates between 'Int. Poplars – Total' and 'Ext. Poplars – Total' in Figure 15 are due to differences in initial stocking and the subsequent thinning for the 'Int. Poplars – Total'. These two factors have allowed for more rapid accumulation of CO_2 before the thinning event, with rates then aligning better with the 'Ext. Poplars – Total' option post-thinning.

Economic Desirability of Carbon Afforestation Scenarios

Comparison of Afforestation Scenarios

The Pinus radiata afforestation type was more profitable than the Mānuka and Native Mix afforestation types across all integration levels, for both case studies. These results corroborate those of Pizzirani et al. (2019), who found that Pinus radiata was more profitable than native conifer-broadleaved forest. However, unlike Pizzirani et al. (2019), who incorporated the timber harvest revenue from conifer-broadleaved forests, this research assessed income from CO_2 sequestration. Therefore, whilst both this research and that of Pizzirani et al. (2019) have concluded that Pinus radiata is more economically desirable than native conifer-broadleaved forests, neither study has incorporated both revenue streams for this afforestation type. Subsequently, there is potential for further research to investigate economic desirability of native conifer-broadleaved forests taking into consideration both timber harvest and CO_2 sequestration revenue. Whilst the establishment costs of the Native Mix afforestation type were significantly lower than those stated by Bergin and Gea (2007), and those in Davis' study of establishing indigenous forest on erosion-prone grassland (as cited in Bergin, 2011), the afforestation type was still not economically desirable under any integration level.

Furthermore, Pizzirani et al. (2019) found that Mānuka established for oil production was largely uneconomically desirable. The results within this research also confirmed that this is the case when Mānuka is established for honey production, with high costs of establishment being of significant detriment to the economic desirability of this afforestation type. However, the results of this study do conflict with those of Funk et al. (2014) and Trotter et al. (2005), who calculated greater profitability of Mānuka for revenue generation from CO_2 sequestration. Funk et al. (2014) and Trotter et al. (2005) assumed lower annual CO_2 sequestration rates, and lower NZU prices, but reported higher annuities/ha/year than what was reported in this study. However, these studies gave no consideration to the establishment costs of the Mānuka plantation (Funk, et al., 2014; Trotter, et al., 2005), and therefore, it is logical that the profitability would be higher than that calculated within this research, as the cost of purchasing native trees for planting is significant (Bergin & Gea, 2007). Lastly, the results of the Mānuka afforestation corroborate those results of Douglas (2019), who found that plantation Mānuka (including establishment costs) with 30% of honey revenue returned to the landowner, had an average return of $141/ha/year, and an NPV of -$837/ha, and were lower than returns of pastoral farming. The results of economic desirability of Mānuka within this research are worse, however, in order for Mānuka plantations to be of significant enough size for Mānuka to be the dominant source of nectar, Douglas (2019) estimates that a minimum plantation size of 100 ha is required. As the area of Mānuka plantation does not exceed 100 ha in any of the afforestation scenarios, estimates of Mānuka honey quantity and quality have been conservative.

The results of economic desirability of the space-planted poplars afforestation types varied significantly between both afforestation integration levels and case study farms. The value of the residual livestock grazing was a significant factor in determining the economic desirability of both space-planted poplar afforestation types. For example, Case One had a pastoral net income from marginal pastoral land of

\$307/ha/year. When this figure was input as the per farmed ha residual grazing input into the Case One ‘Intensive Poplars – Preferred’ afforestation scenario, the net income from residual pastoral farming contributed 23.6% of total gross revenue, with CO_2 sequestration revenue contributing 65.9%. In contrast, Case Two had a pastoral net income from marginal pastoral land of \$701/ha/year, which contributed 42.7% of total gross revenue for the ‘Intensive Poplars – Preferred’ afforestation scenario, with CO_2 sequestration revenue contributing 50.6%. There was only a small difference (10.9%) in total revenue from CO_2 sequestration per ha between the two aforementioned afforestation scenarios, but total revenue differed largely (44.3%). Therefore, the large variation in economic desirability between the two afforestation scenarios is due to residual pastoral net income.

A further difference in profitability of space-planted poplar afforestation types is shown in Table 26 between the total and preferred afforestation integration levels of Case Two, when revenue from CO_2 sequestration is incorporated into the analysis. This is due to the area afforested for the preferred integration level falling below the greater-than-100-ha threshold to allow for the default Look-up tables to be used for CO_2 sequestration rates (MPI, 2018b). Therefore, CO_2 sequestration rates from the default Look-up tables have been adopted for the preferred afforestation integration level, which are higher than the modelled rates from the Radiata Calculator, which have been adopted for the total afforestation integration level. The adoption of the lower modelled CO_2 sequestration rates from the Radiata Calculator within the total afforestation integration level has significantly decreased the profitability of both space-planted poplars afforestation types. There was no difference in the residual pastoral farming net income between the two integration levels.

Economic Comparison of Pastoral Farming and Carbon Forestry on Marginal Pastoral Land

Results from the DCF analyses indicate that there are multiple factors that combine to determine whether or not pastoral farming on marginal pastoral land is more economically desirable than carbon forestry. The comparisons of economic desirability in Tables 25, 26, and 27, show that no two afforestation scenarios, and no two pastoral farming scenarios, return the same NPV, IRR, or annuity. Factors such as profitability of pastoral farming, forestry site productivity, forestry regime, size of afforestation area, and value of residual grazing income, all have been shown to influence the relative economic desirability of pastoral farming on marginal pastoral land and carbon forestry. As a result, this research has not conclusively found that either pastoral farming or carbon forestry are more economically desirable on marginal pastoral land. However, it can be concluded that the economic desirability of Mānuka plantations for honey production, and native Mānuka/conifer-broadleaved forests for CO_2 sequestration revenue, are typically the least profitable afforestation types.

There have been numerous studies that have investigated the economics of both pastoral farming and carbon forestry (Douglas, 2019; Fogan and Pollard, 2020; Funk, et al., 2014; Parminter, et al., 2001; Trotter, et al., 2005), however, it is difficult to draw direct comparisons between the results of those studies and the results within this research on account of the aforementioned factors. Furthermore, comparisons are complicated by the inclusion/exclusion of some costs between each piece of research.

Impact of Land Values Upon Economic Desirability of Carbon Afforestation Types

Table 37 shows a range of metrics for each case study farm relating to the influence of land values upon economic desirability of pastoral farming on marginal land, Pinus radiata (high economic desirability), and Native Mix (low economic desirability).

Table 37: Land Value Change Impact on Profitability

	Case One			Case Two		
	Marginal Pastoral	**P. rad - Total**	**Native Mix - Total**	**Marginal Pastoral**	**P. rad - Total**	**Native Mix - Total**
Land Purchase Cost per Ha	8,523	8,523	8,523	7,597	7,597	7,597
Terminal Land Value per Ha	8,523	2,249	2,249	7,597	2,522	2,437
PV of Terminal Land Value per Ha	2,498	659	550	2,227	675	714
Total Period Gross Revenue per Ha	17,108	30,552	8,907	26,265	45,860	9,980
NPV of Total Gross Revenue per Ha	7,466	13,331	3,590	12,456	19,370	3,246
Land Purchase Cost as % of GR	49.8%	27.9%	95.7%	28.9%	16.6%	76.1%
Terminal Land Value % of GR	49.8%	7.4%	25.3%	28.9%	5.5%	24.4%
Terminal Value PV as % of GR	14.6%	2.2%	6.2%	8.5%	1.5%	7.2%
Terminal Value PV as % of GR NPV	33.5%	4.9%	15.3%	17.9%	3.5%	22.0%

There was a two-fold land value reduction modelled for the afforestation scenarios. Firstly, land that was included within the NSA was reduced to pre-1990 land values, and secondly, land that was included within the PPA as unplantable/buffer land was reduced to ‘waste’ values. Therefore, those afforestation scenarios with a larger proportion of unplantable/buffer areas had a lower total terminal value than those with a lower proportion of unplantable/buffer areas.

For the low economic desirability land use options (pastoral farming of Case One, and Native Mix within both case study farms), the land purchase cost was between 49.8% and 95.7% of total gross revenue for that land use option. In contrast, for the high economic desirability land uses (pastoral farming on Case Two, and Pinus radiata within both case study farms), the land purchase cost was no more than 28.9% of total gross revenue. Therefore, for the low economic desirability land use options, the inclusion of a land value purchase cost impacted the profitability to a greater extent. Furthermore, for the Native Mix afforestation option (low economic desirability) the inclusion of land values was of greater detriment than it was for the other low economic desirably land use option of marginal pastoral farming within Case One. This is evidenced in Table 37 by the greater differential between the 'Land Purchase Cost as % of GR' and 'Terminal Value PV as % of GR NPV' metrics. For example, while the land purchase cost for the Case One marginal pastoral farming land use option comprised 49.8% of gross revenue, the present value of the land terminal value contributed 33.5% of the gross revenue NPV. In contrast, the land purchase cost for the Case One Native Mix afforestation option comprised 95.7% of gross revenue, but the present value of the land terminal value only contributed 15.3% of the gross revenue NPV. As a result, it can be seen that the inclusion of land value within the DCF analyses has more than likely disproportionately impacted the economic desirability of low-returning land uses, especially low-returning afforestation types, as compared to high-returning land uses. However, the inclusion of land values within the DCF analyses is deemed critical as reductions in total capital of a business should be a consideration when making decisions regarding alternative land uses.

Impacts of Carbon Forestry Integration

Impacts Upon Overall Economic Performance

The impacts of carbon forestry integration into the two case study farms corroborated results reported by Quinn et al. (2007) and Dominati et al. (2020). Although remaining pastoral land was not intensified alongside afforestation integration, the net income per farmed ha did increase due to there now being a greater proportion of higher profitability land comprising the farmed area. As Quinn et al. (2017) found, part of this increased profitability is also due to some expenses (e.g., weed and pest control) decreasing at a greater rate than the decrease in gross revenue when marginal pastoral land is taken out of production. Both Quinn et al. (2007) and Dominati et al. (2020) omitted the revenue/expenditure of the carbon forestry that was integrated, so the results of this study cannot be directly compared to the overall economic impact noted within these two studies. However, the results of carbon forestry integration within this research did corroborate those of Journeaux et al. (2020), who also found that the integration of carbon forestry improved overall farm profitability, with Pinus radiata generating the greatest gains in profitability, as compared to Mānuka. These results further corroborate the findings of Reisinger et al. (2017), who stated that when marginal land is afforested, the negative economic impacts on the overall business are minimised and can even be positive.

Impacts Upon Nutrient Loss from the Root Zone

Tables 28, 29, 30, and 31 summarise the impacts of carbon forestry integration upon N and P losses. In line with the results of Journeaux et al. (2020), this research found that there were no reductions in N or P loss rates (kg/ha/year) at the management block level, which is due to the intensification of the balance pastoral farmland not altering between integration levels. However, there were reductions in total root zone losses (kg/year), which was a result of pastoral marginal land being taken out of pastoral production. This meant that at the farm level there were reductions in loss rates when carbon forestry was integrated into both case study farms. This was a result of the lower-loss carbon forestry replacing the higher-loss pastoral farming enterprise. Therefore, the integration of carbon forestry into sheep and beef farms in New Zealand does improve total nutrient loss (kg/year) at the management block and farm levels, and nutrient loss rates (kg/ha/year) at the farm level when pastoral farming of the area afforested is losing more than the carbon forestry species. Furthermore, when the nutrient loss rates from carbon forestry are lower than those from pastoral farming on land that is to be afforested, reductions in total nutrient losses at the farm level increase with greater levels of carbon forestry integration.

The modelled reductions in nutrient losses (kg/year) are similar to those of Dominati et al. (2019) for all afforestation integration levels, with the exception of the total afforestation integration level within Case Two, which has reductions more in line with those reported by Quinn et al. (2007). The differences in nutrient loss reductions are largely explained by the area of carbon forestry integration assumed. Dominati et al. (2019) afforested a much smaller area of their case study farm than Quinn et al. (2007), who afforested over half the total area, which is similar to the area afforested on Case Two within the total afforestation integration level. The results within this research show greater reductions in nutrient loss rates than those reported by both Plantinga and Wu (2003), and Ausseil and Dymond (2010). While both of the studies focused on marginal pastoral land, it has been shown that marginal pastoral land is inherently variable, so it is hard to draw direct comparison with these studies.

Impacts Upon Greenhouse Gas Emissions

Both the gross and net greenhouse gas emissions of the case study farms within this research dropped with the integration of carbon forestry, but by larger amounts than those reported by Ausseil and Dymond (2010), Dominati et al. (2019), and Journeaux et al. (2020). However, this is largely due to much greater percentages of the case study farms being afforested within this research than in these studies. It is likely that the relatively high intensity of the Case Two marginal pastoral land also contributed to the large reductions in gross greenhouse gas emission reductions, as stocking rate and fertiliser use are large drivers of greenhouse gas emission intensity (Reisinger, et al., 2017). This study does corroborate the results of Reisinger et al. (2017), Dominati et al. (2019), and Journeaux et al. (2020), who all found that incorporating the CO_2 sequestration benefit of carbon forestry caused much greater reductions in net greenhouse gas emissions than the reductions in gross greenhouse gas emissions alone. As further stated in several studies (Ausseil & Dymond, 2010; Bergin, 2011; Journeaux, et al., 2020; Pizzirani, et al., 2019), there are differences in total net greenhouse gas emission reductions depending upon the carbon forestry species, which was also found within this research.

Impacts of Achieving Carbon Neutrality Status

Reisinger et al. (2017) used two different carbon accounting approaches to model the level of carbon forestry integration within the North Island model farm for it to be carbon neutral, with one of these approaches being similar to the stock change approach used within research. Reisinger et al. (2017) found that by afforesting 10% of the model North Island hill country farm, the farm would be carbon neutral if the entire 28-year period of CO_2 sequestration was assumed, which is similar to the result of Case One, which is modelled to require 11.1% of the farmed area to be afforested when the entire 50-year period of CO_2 sequestration was assumed. In contrast, Case Two required 30.7% of the farmed area to be afforested, which is due to both its higher relative productivity than Case One, and the inferior afforestation mix (Pinus radiata and Mānuka) in terms of CO_2 sequestration potential. Therefore, slower-growing carbon forestry species require a greater area of afforestation to offset greenhouse gas emissions from pastoral farming practices. Furthermore, when the averaging carbon accounting approach was adopted, the area of afforestation required to be carbon neutral increased dramatically, which is a result of the lesser amount of CO_2 sequestration provided for under this approach.

The impacts upon financial performance of the overall pastoral farming business when greenhouse gas emissions are liable to be paid are not insignificant. For Case One, when NZUs were surrendered to offset 5% of the total greenhouse gas emissions from farming practices, with the remaining 95% of NZUs from CO_2 sequestration assumed to be sold, the overall financial performance of the farm business increased. This is due to the Pinus radiata afforestation type being more profitable than the farming of pastoral marginal land, even when 5% of NZUs are surrendered. In contrast, when NZUs are surrendered to offset 100% of the total greenhouse gas emissions from farming practices, both NPV and IRR fall significantly for both case study farms. This is because the case study farmer is having to outlay costs of establishing and tending the carbon forestry, and is also experiencing a decrease in capital value of the land, while generating no income from the forestry enterprise, only having the ability to offset pastoral farming emissions.

For Case One it was modelled that carbon afforestation to offset greenhouse gas emissions from pastoral farming practices was more economically desirable than purchasing NZUs to offset emissions, with the opposite being true for Case Two. The difference in preferred strategies (i.e. sequestration vs purchase of NZUs to offset emissions) between the two case study farms is again related to the relative profitability of the pastoral farming enterprise against the carbon forestry, and the CO_2 sequestration potential of the chosen afforestation type.

The requirement for the case study farms to be liable for 100% of total greenhouse gas emissions from pastoral farming practices resulted in large decreases in profitability when no carbon forestry was integrated. For Case One, at a price of $35/NZU, the annual liability for total farm greenhouse gas emissions is $26,093, which equates to 19.8% of modelled total annual expenses for the pastoral farming base scenario. The annual liability for Case Two is much higher than for Case One, which is calculated to be $76,013, which equates to 20.7% of modelled total annual expenses for the pastoral farming base scenario. More importantly, the annual liability for total farm greenhouse gas emissions equates to 19.6% and 11.6% of gross revenue for Case One and Case Two, respectively. For both case study farms, the emissions liabilities become the second largest expense as a percentage of gross revenue, behind only wages. It was found that the liabilities for greenhouse gas emissions from pastoral farming practices added a significant cost to both case study farms that reduced profitability.

Sensitivity Analysis

The results of economic profitability, as measured by the NPV metric, vary significantly with the use of different discount rates and NZU prices. The inclusion of a pricing mechanism for greenhouse gas emissions (i.e. NZU) becomes a cost for the pastoral farming land use, but a revenue for the carbon forestry land use. Therefore, it is logical that the results shown in Table 34 show a decrease in profitability of pastoral farming when the NZU price increases, but an increase in profitability of carbon forestry. For the base discount rate used (i.e. 4.60%), when the NZU price is modelled at $15/unit, the annual greenhouse gas liabilities for pastoral farming practices fall to 8.4% of annual gross revenue for Case One, and 5.0% of annual gross revenue for Case Two. In contrast, when the NZU price is modelled at $50/unit, the annual greenhouse gas liabilities for pastoral farming practices are 28.1% and 16.5% of annual gross revenue for Case One and Case Two, respectively. These results show that changes in NZU price have a large impact upon the profitability of pastoral farming. The increase in carbon forestry profitability with a change in NZU price was greatest for the Pinus radiata, which is likely a reflection of the greater CO_2 sequestration rates of this afforestation type. In contrast, the changes in profitability for the space-planted poplar afforestation types was lower, which is because of not only the lower CO_2 sequestration rates of this afforestation type, but also an increase in the cost of liabilities associated with the residual livestock grazing within this afforestation type. Furthermore, the space-planted poplars afforestation types within Case One benefited more from an increase in the NZU price than those within Case Two, which is due to the lower modelled CO_2 sequestration rates from the Radiata Calculator being adopted within Case Two, but also the higher relative physical productivity of the residual livestock grazing enterprise.

The results of changes in discount rates used are generally similar to those of Pizzirani et al. (2019), who found that decreasing the discount rate increased the profitability of carbon forestry. However, Pizzirani et al. (2019) found that the Rimu afforestation type did have a positive NPV at a discount rate of 2%, which is in contrast to this study that found the Native Mix afforestation type did not return a positive NPV at any of the modelled discount rates. However, it is important to note that Pizzirani et al. (2019) excluded potential benefits from CO_2 sequestration, but did include revenue from timber harvest.

Chapter Six: Conclusions

This case study analysis has provided results that allow for conclusions to be made about the research questions that were set out to be investigated:

1) Farms are heterogenous in nature in regard to the quantum of marginal pastoral land within them. However, the physical productivity and financial profitability of marginal pastoral land within one farm is not necessarily comparable to that of another farm. Climatic conditions and management factors play a big role in determining the physical and financial performance of marginal pastoral land. In particular, pasture growth, stocking rate, and livestock enterprise, were all found to be driving factors of profitability on marginal pastoral land used for pastoral farming.
2) Economic and environmental performance of pastoral farming base scenarios varies between farms on account of the aforementioned climatic conditions and management factors. Furthermore, despite some pastoral land within this research being defined as marginal, it had greater economic and environmental performance than non-marginal pastoral land. Therefore, the assumption that marginal pastoral land, as defined within this research, is less productive than non-marginal pastoral land has been shown to not be true for all farms.
3) The environmental benefits of carbon forestry vary by afforestation species and type. Whilst there are small differences modelled in Overseer for N root zone loss rates within forestry management blocks for Pinus radiata and Natives, the main environmental difference found was in CO_2 sequestration potential. As well as differences between afforestation types, there were also differences between modelled CO_2 sequestration rates derived from the Radiata Calculator, and rates from the default Look-up tables. Therefore, consideration needs to be given to the size of the area of afforestation, as well as to the planting density, pruning, and thinning practices for each afforestation type.
4) The profitability of carbon forestry is dependent upon the afforestation type, site productivity, inclusion/exclusion of CO_2 sequestration revenue, profitability of residual grazing income, and the size of the afforestation area. The Mānuka and Native Mix afforestation types had the lowest economic desirability irrespective of the inclusion/exclusion of revenue from CO_2 sequestration. In contrast, for the Pinus radiata and space-planted poplar afforestation types, economic desirability was heavily influenced by the combination of the aforementioned factors, with differing combinations resulting in

either the Pinus radiata or space-planted poplar afforestation type being the most economically desirable.

5) The aforementioned factors impacting the profitability of both pastoral farming and carbon forestry on marginal pastoral land dictate the relative productivity of the two land uses. This research showed that relative profitability of the two land uses does vary between farms, and that the results from one property cannot be adopted for another property as farm heterogeneity extends to characteristics beyond the quantum of marginal land.
6) The integration of carbon forestry on marginal pastoral land was found to increase the environmental performance of the overall farm business, with larger areas of carbon afforestation integration resulting in greater reductions in nutrient losses and greenhouse gas emissions. The main driver of this improvement was the reduction in livestock, which was found to be the largest contributor to greenhouse gas emissions, and either the largest or second largest source of N loss, of all sources from within the farming system. The impact on economic performance of the overall farm business depended upon the relative profitability of pastoral farming and carbon forestry. When returns from pastoral farming of marginal pastoral land were greater than the returns from carbon forestry, overall economic performance of the farm business declined, and vice versa.
7) Achieving a carbon neutral status of the farm business by integrating carbon forestry can be economically advantageous when 100% of total greenhouse gas emissions from pastoral farming practices are liable to be paid. Using the carbon stock change approach requires less land to be afforested than the averaging approach, and carbon forestry species that sequester CO_2 at greater rates are preferred over lower-growth carbon forestry species. However, the imposition of greenhouse gas emissions liabilities from pastoral farming significantly impacts profitability of pastoral farming enterprises, potentially rendering the pastoral farming enterprise uneconomic.

Overall, this study has concluded that many factors combine to determine the economic and environmental impacts of carbon forestry integration onto marginal pastoral land within sheep and beef hill country farms in New Zealand. Therefore, it is difficult to extrapolate results from one case study farm to another. As a result, if a farm owner is contemplating integrating carbon forestry onto marginal pastoral land, intensive modelling, such as undertaken within this research, would be required to fully inform the farmer of the economic and environmental impacts on the overall farm business.

Limitations

This dissertation has relied upon numerous assumptions to generate results from several modelling software, which have been outlined in Chapter Three. Although care has been taken to ensure the accuracy of assumptions made, modelling exercises are inherently flawed. Therefore, this research should not form the standalone basis of any investment decisions.

Due to various constraints, only two case study farms have been investigated within this research, one each for the 26 to 50% and the 51 to 75% categories of quantum of marginal pastoral land. Preferably, one case for each categorical variable (i.e. 0 to 25%, 26 to 50%, 51 to 75%, and 76 to 100%) would have been investigated, totalling four case studies. As a result of only two case studies being investigated, a full picture of how the quantum of marginal pastoral land within a farming business impacts upon the economic and environmental profitability of carbon forestry integration cannot be gained.

Within this study, it has been assumed for the various afforestation integration levels that the physical intensity and stock enterprises do not change on the balance pastoral land. However, this is unlikely to reflect what happens in reality, especially when larger areas of afforestation are integrated. Furthermore, no optimisation of the pastoral farming systems was modelled, which could have led to further reductions in greenhouse gas emissions and nutrient losses. Therefore, consideration needs to be given to the ability, and desire, of the case study farmer to adopt new livestock enterprises and farm management practices.

There are also several known benefits of carbon forestry that have not been captured within this research, such as timber harvest revenue from space-planted poplars and conifer-broadleaved native forests, increases in biodiversity from all afforestation types, revenue from Mānuka oil production, and reductions in soil erosion. Therefore, the entire suite of benefits of each carbon afforestation type has not been investigated, which has likely impacted the economic and environmental impacts of some afforestation types. An avenue for further research does exist to expand upon the results of this research by incorporating the aforementioned benefits of carbon forestry.

Another avenue for further research is a spatial analysis identifying marginal and non-marginal pastoral land within New Zealand using the NZLRI Land Use Capability shapefile (Landcare Research, 2010). A sample of case study farms would then be selected for an intensive modelling exercise to calculate the economic returns of pastoral farming from marginal and non-marginal pastoral land. This would allow for an investigation into whether there is a correlation between LUC Class and economic profitability of pastoral farming. Researching this avenue may also give rise to a new definition of marginal pastoral land than what has been adopted within this research, as this research has demonstrated how marginal pastoral land can be more physically and financially productive than land that has not been defined as marginal pastoral land.

Recommendations

Based on the economic results of this research, it is recommended that both case study farms should adopt the total afforestation integration level, in the absence of any greenhouse gas emissions liabilities. This integration level increases the economic and environmental performance of the overall farm business, which are two key metrics required to be met for farmers to adopt carbon forestry (Dominati, et al., 2019; Samarasinghe, et al., 2012). However, to further increase both economic and environmental performance of the Case Two farm at the total afforestation integration level, Pinus radiata should be the exclusive afforestation type established, not a mix of Pinus radiata and Mānuka.

In a scenario where 100% of total farm greenhouse gas emissions are liable to be paid for, it is recommended that Case One establishes 28 ha of Pinus radiata carbon forestry to generate NZUs through CO_2 sequestration, that can be surrendered to offset greenhouse gas emissions. In contrast, it is recommended that Case Two either exclusively establishes Pinus radiata, not a mix of Pinus radiata and Mānuka, or NZUs are purchased from the open market to offset emissions, instead of using carbon forestry integration.

From the literature reviewed within this research, it is clear that the New Zealand sheep and beef industry provides a valuable contribution to the GDP of the country (MPI, 2020), employs a fifth of all people within the agriculture sector (Statistics New Zealand, 2019b), and the industry is forecast to continue to grow with increases in demand for protein (Kim, et al., 2019). In contrast, Fogan and Pollard (2020) and Harrison and Bruce (2019) have modelled that carbon forestry has lower economic benefits to GDP and employment than pastoral farming. It was concluded by Fogan and Pollard (2020) that sheep and beef farms integrated with plantation forestry had the highest annual value-added, and highest annual total economic impact per 1,000 ha compared to standalone production forestry, carbon forestry, and pastoral farming. However, as modelled within this research, when the case study farms were liable to account for 100% of total gross greenhouse gas emissions from pastoral farming practices, the profitability of these farms was significantly reduced, and even caused Case One to become uneconomic, irrespective of whether or not carbon forestry was integrated to offset emissions. Therefore, careful consideration should be given by key stakeholders as to the economic impacts on the wider New Zealand economy of policies that promote wholesale carbon forestry in favour of sheep and beef pastoral farming.

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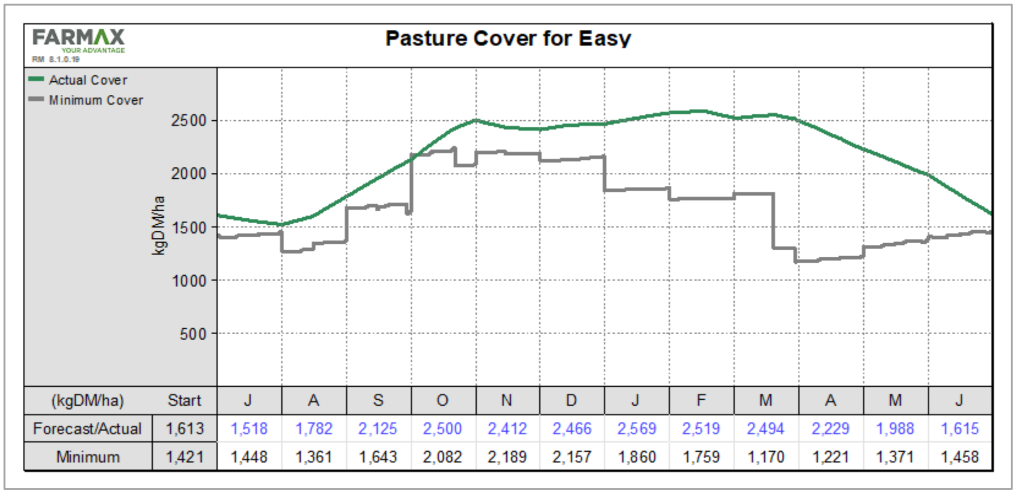
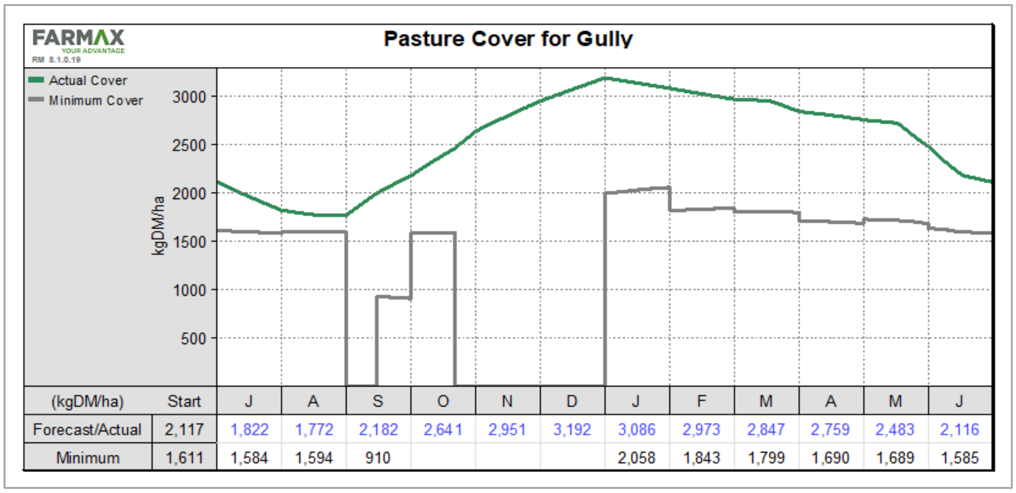
Appendices

Appendix A: Feasible Farmax Base Scenarios

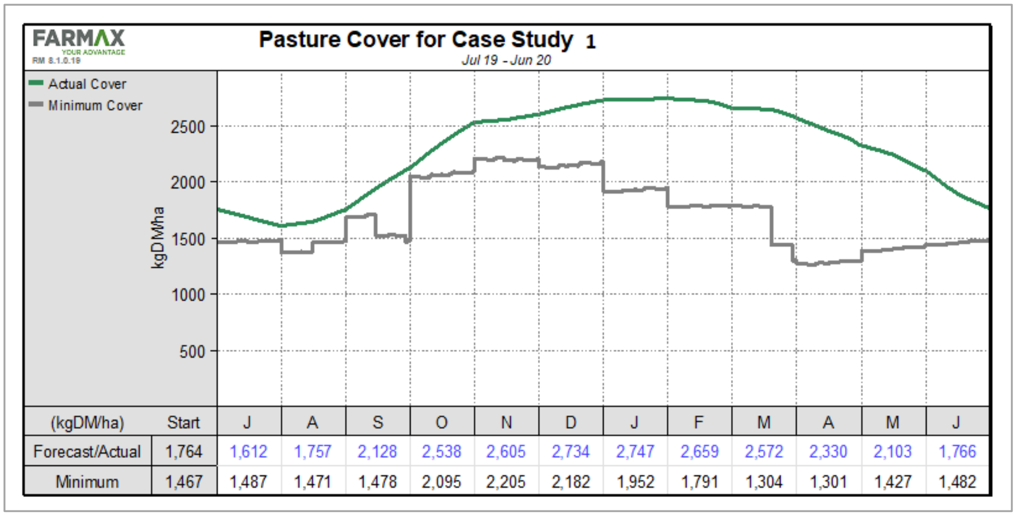
Appendix A1: Farmax Feed Budgets for Case One



(kgDM/ha)	Start	J	A	S	O	N	D	J	F	M	A	M	J
Forecast/Actual	1,613	1,518	1,782	2,125	2,500	2,412	2,466	2,569	2,519	2,494	2,229	1,988	1,615
Minimum	1,421	1,448	1,361	1,643	2,082	2,189	2,157	1,860	1,759	1,170	1,221	1,371	1,458

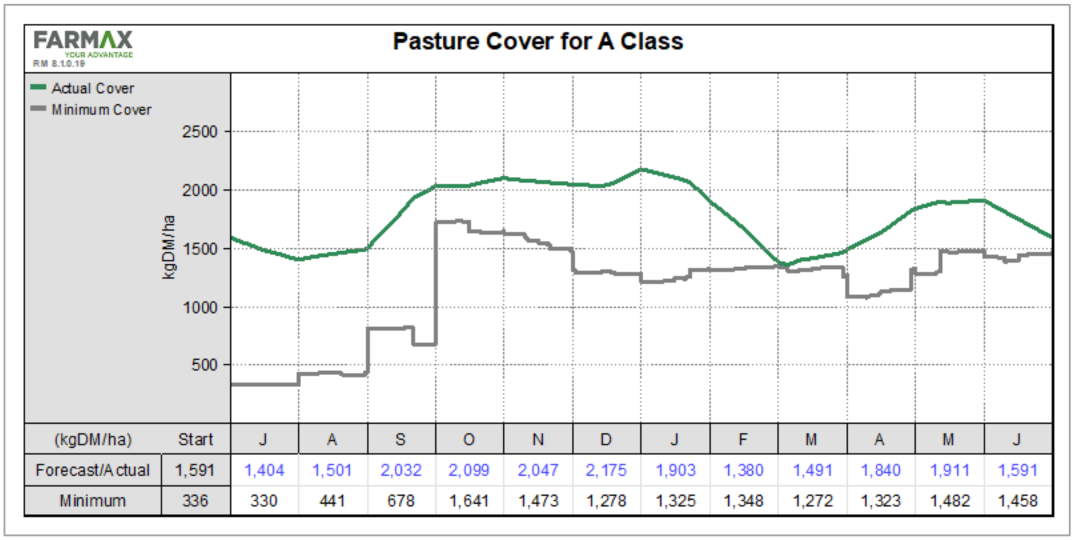


(kgDM/ha)	Start	J	A	S	O	N	D	J	F	M	A	M	J
Forecast/Actual	2,117	1,822	1,772	2,182	2,641	2,951	3,192	3,086	2,973	2,847	2,759	2,483	2,116
Minimum	1,611	1,584	1,594	910				2,058	1,843	1,799	1,690	1,689	1,585



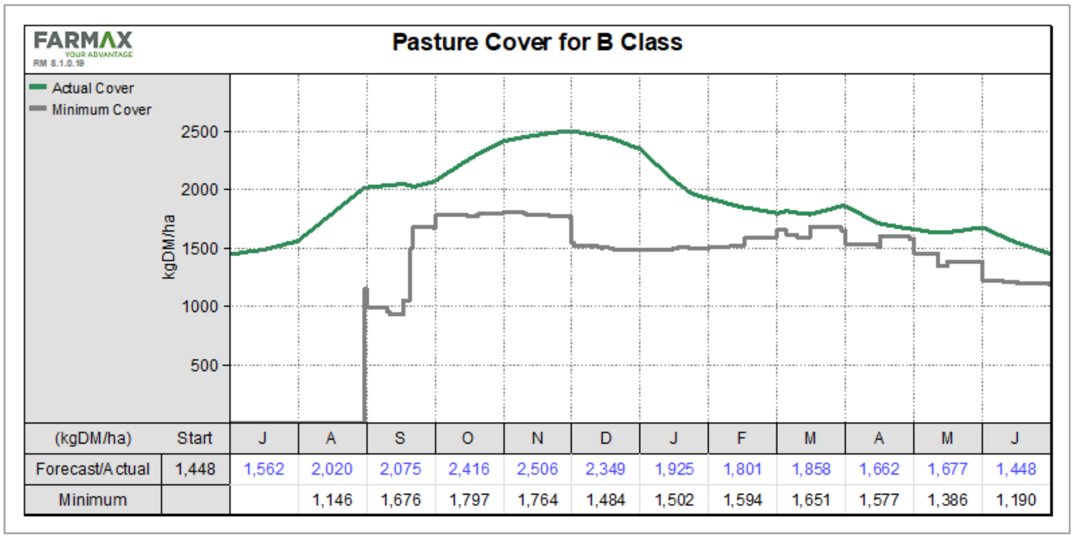
(kgDM/ha)	Start	J	A	S	O	N	D	J	F	M	A	M	J
Forecast/Actual	1,764	1,612	1,757	2,128	2,538	2,605	2,734	2,747	2,659	2,572	2,330	2,103	1,766
Minimum	1,467	1,487	1,471	1,478	2,095	2,205	2,182	1,952	1,791	1,304	1,301	1,427	1,482

Appendix A2: Farmax Feed Budgets for Case Two



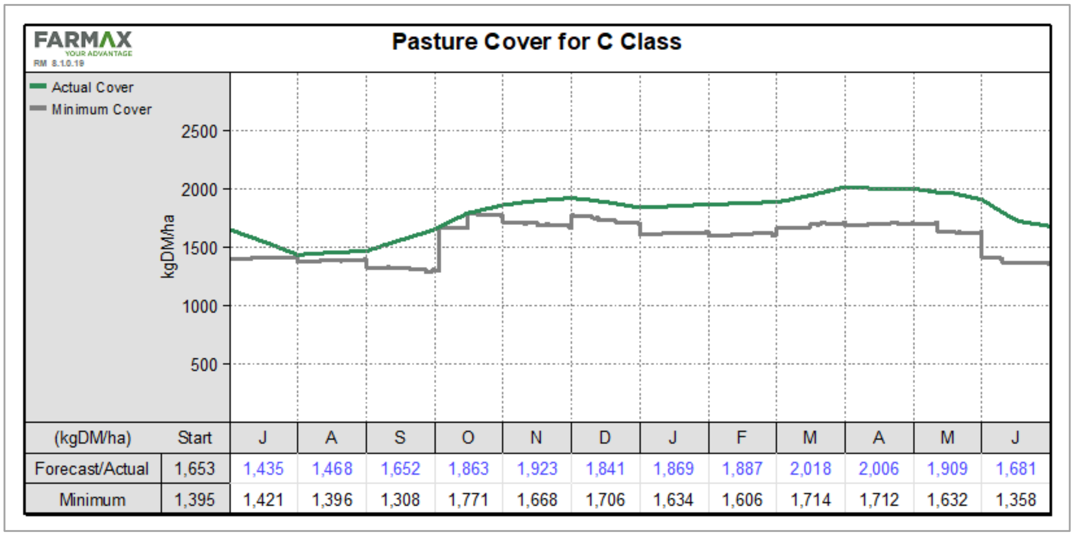
Pasture Cover for A Class

(kgDM/ha)	Start	J	A	S	O	N	D	J	F	M	A	M	J
Forecast/Actual	1,591	1,404	1,501	2,032	2,099	2,047	2,175	1,903	1,380	1,491	1,840	1,911	1,591
Minimum	336	330	441	678	1,641	1,473	1,278	1,325	1,348	1,272	1,323	1,482	1,458



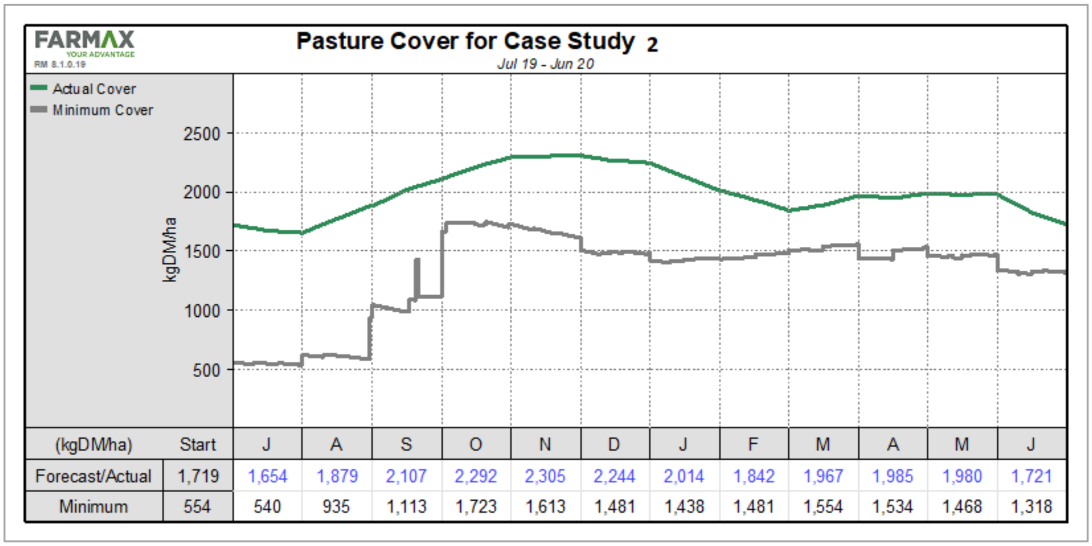
Pasture Cover for B Class

(kgDM/ha)	Start	J	A	S	O	N	D	J	F	M	A	M	J
Forecast/Actual	1,448	1,562	2,020	2,075	2,416	2,506	2,349	1,925	1,801	1,858	1,662	1,677	1,448
Minimum			1,146	1,676	1,797	1,764	1,484	1,502	1,594	1,651	1,577	1,386	1,190



Pasture Cover for C Class

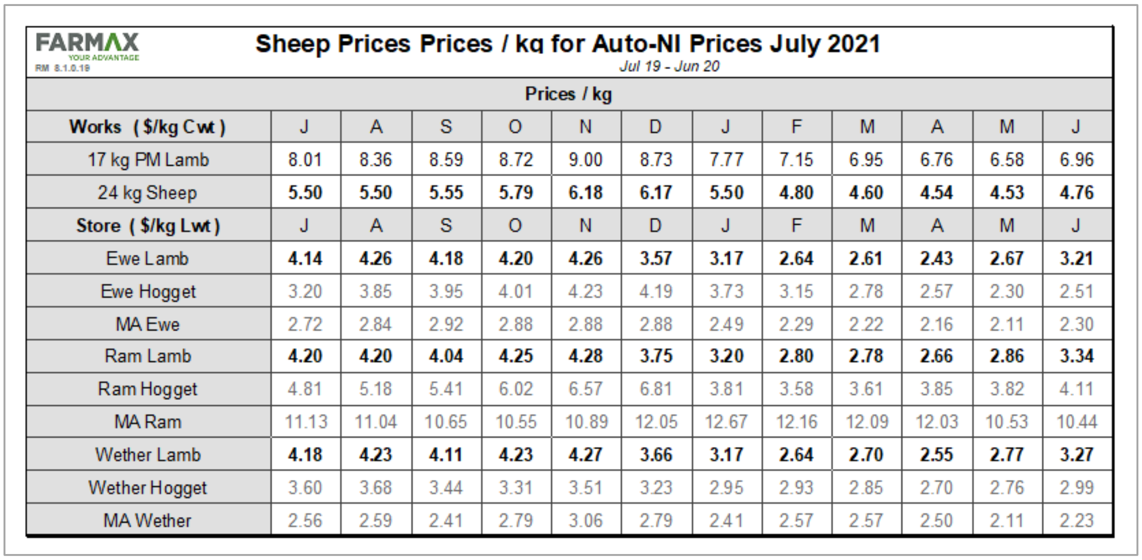
(kgDM/ha)	Start	J	A	S	O	N	D	J	F	M	A	M	J
Forecast/Actual	1,653	1,435	1,468	1,652	1,863	1,923	1,841	1,869	1,887	2,018	2,006	1,909	1,681
Minimum	1,395	1,421	1,396	1,308	1,771	1,668	1,706	1,634	1,606	1,714	1,712	1,632	1,358



(kgDM/ha)	Start	J	A	S	O	N	D	J	F	M	A	M	J
Forecast/Actual	1,719	1,654	1,879	2,107	2,292	2,305	2,244	2,014	1,842	1,967	1,985	1,980	1,721
Minimum	554	540	935	1,113	1,723	1,613	1,481	1,438	1,481	1,554	1,534	1,468	1,318

Appendix B: Farmax Revenue and Expense Inputs

Appendix B1: Sheep Schedule Prices Adopted for Both Case Studies



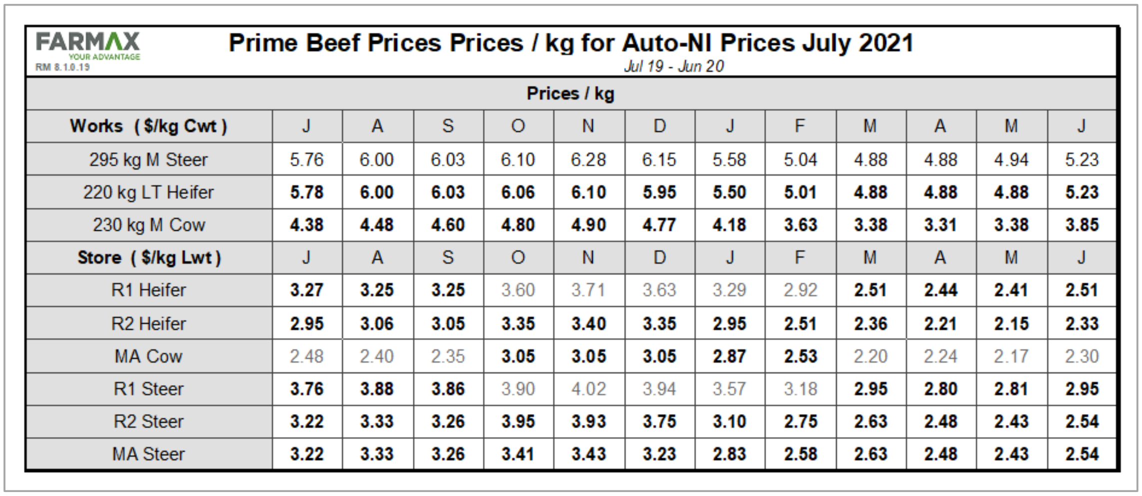
Sheep Prices Prices / kg for Auto-NI Prices July 2021

Jul 19 - Jun 20

Prices / kg

Works ($/kg Cwt)	J	A	S	O	N	D	J	F	M	A	M	J
17 kg PM Lamb	8.01	8.36	8.59	8.72	9.00	8.73	7.77	7.15	6.95	6.76	6.58	6.96
24 kg Sheep	5.50	5.50	5.55	5.79	6.18	6.17	5.50	4.80	4.60	4.54	4.53	4.76
Store ($/kg Lwt)	J	A	S	O	N	D	J	F	M	A	M	J
Ewe Lamb	4.14	4.26	4.18	4.20	4.26	3.57	3.17	2.64	2.61	2.43	2.67	3.21
Ewe Hogget	3.20	3.85	3.95	4.01	4.23	4.19	3.73	3.15	2.78	2.57	2.30	2.51
MA Ewe	2.72	2.84	2.92	2.88	2.88	2.88	2.49	2.29	2.22	2.16	2.11	2.30
Ram Lamb	4.20	4.20	4.04	4.25	4.28	3.75	3.20	2.80	2.78	2.66	2.86	3.34
Ram Hogget	4.81	5.18	5.41	6.02	6.57	6.81	3.81	3.58	3.61	3.85	3.82	4.11
MA Ram	11.13	11.04	10.65	10.55	10.89	12.05	12.67	12.16	12.09	12.03	10.53	10.44
Wether Lamb	4.18	4.23	4.11	4.23	4.27	3.66	3.17	2.64	2.70	2.55	2.77	3.27
Wether Hogget	3.60	3.68	3.44	3.31	3.51	3.23	2.95	2.93	2.85	2.70	2.76	2.99
MA Wether	2.56	2.59	2.41	2.79	3.06	2.79	2.41	2.57	2.57	2.50	2.11	2.23

Appendix B2: Prime Beef Schedule Prices Adopted for Both Case Studies



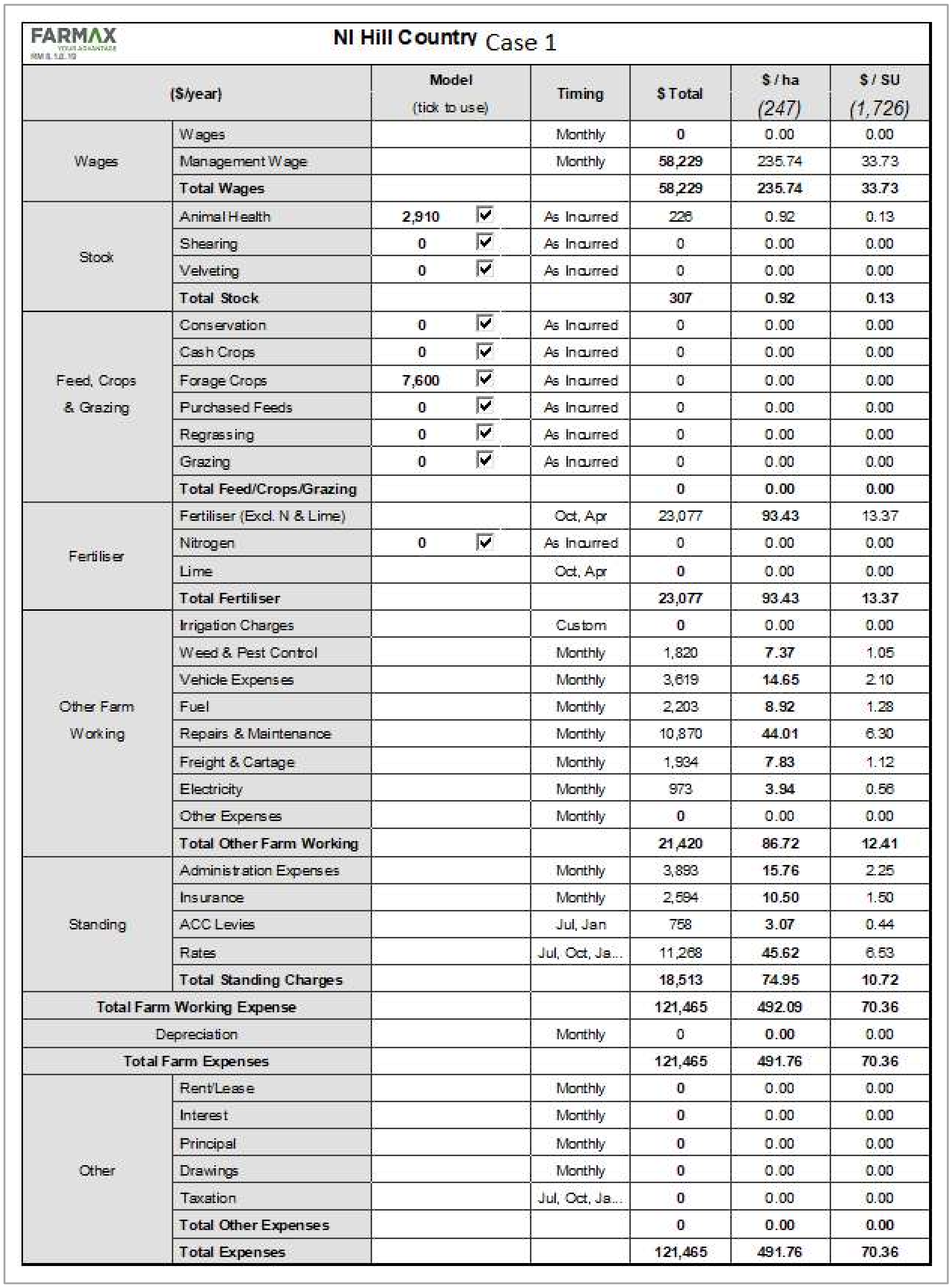
Prime Beef Prices Prices / kg for Auto-NI Prices July 2021

Jul 19 - Jun 20

Prices / kg

Works ($/kg Cwt)	J	A	S	O	N	D	J	F	M	A	M	J
295 kg M Steer	5.76	6.00	6.03	6.10	6.28	6.15	5.58	5.04	4.88	4.88	4.94	5.23
220 kg LT Heifer	5.78	6.00	6.03	6.06	6.10	5.95	5.50	5.01	4.88	4.88	4.88	5.23
230 kg M Cow	4.38	4.48	4.60	4.80	4.90	4.77	4.18	3.63	3.38	3.31	3.38	3.85
Store ($/kg Lwt)	J	A	S	O	N	D	J	F	M	A	M	J
R1 Heifer	3.27	3.25	3.25	3.60	3.71	3.63	3.29	2.92	2.51	2.44	2.41	2.51
R2 Heifer	2.95	3.06	3.05	3.35	3.40	3.35	2.95	2.51	2.36	2.21	2.15	2.33
MA Cow	2.48	2.40	2.35	3.05	3.05	3.05	2.87	2.53	2.20	2.24	2.17	2.30
R1 Steer	3.76	3.88	3.86	3.90	4.02	3.94	3.57	3.18	2.95	2.80	2.81	2.95
R2 Steer	3.22	3.33	3.26	3.95	3.93	3.75	3.10	2.75	2.63	2.48	2.43	2.54
MA Steer	3.22	3.33	3.26	3.41	3.43	3.23	2.83	2.58	2.63	2.48	2.43	2.54

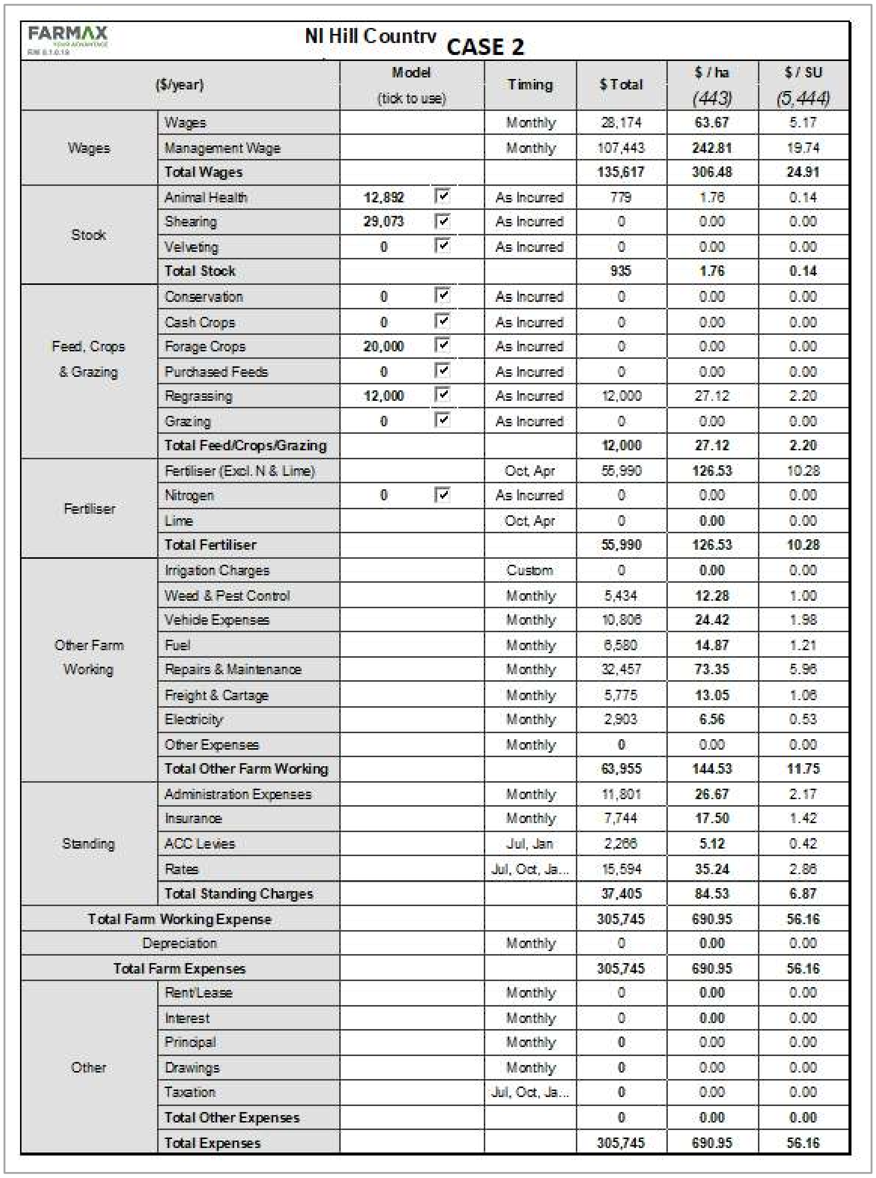
Appendix B3: Expense Inputs Adopted for Case One



NI Hill Country Case 1

($/year)		Model (tick to use)		Timing	$ Total	$ / ha (247)	$ / SU (1,726)
Wages	Wages			Monthly	0	0.00	0.00
	Management Wage			Monthly	58,229	235.74	33.73
	Total Wages				58,229	235.74	33.73
Stock	Animal Health	2,910	☑	As Incurred	226	0.92	0.13
	Shearing	0	☑	As Incurred	0	0.00	0.00
	Velveting	0	☑	As Incurred	0	0.00	0.00
	Total Stock				307	0.92	0.13
Feed, Crops & Grazing	Conservation	0	☑	As Incurred	0	0.00	0.00
	Cash Crops	0	☑	As Incurred	0	0.00	0.00
	Forage Crops	7,600	☑	As Incurred	0	0.00	0.00
	Purchased Feeds	0	☑	As Incurred	0	0.00	0.00
	Regrassing	0	☑	As Incurred	0	0.00	0.00
	Grazing	0	☑	As Incurred	0	0.00	0.00
	Total Feed/Crops/Grazing				0	0.00	0.00
Fertiliser	Fertiliser (Excl. N & Lime)			Oct, Apr	23,077	93.43	13.37
	Nitrogen	0	☑	As Incurred	0	0.00	0.00
	Lime			Oct, Apr	0	0.00	0.00
	Total Fertiliser				23,077	93.43	13.37
Other Farm Working	Irrigation Charges			Custom	0	0.00	0.00
	Weed & Pest Control			Monthly	1,820	7.37	1.05
	Vehicle Expenses			Monthly	3,619	14.65	2.10
	Fuel			Monthly	2,203	8.92	1.28
	Repairs & Maintenance			Monthly	10,870	44.01	6.30
	Freight & Cartage			Monthly	1,934	7.83	1.12
	Electricity			Monthly	973	3.94	0.56
	Other Expenses			Monthly	0	0.00	0.00
	Total Other Farm Working				21,420	86.72	12.41
Standing	Administration Expenses			Monthly	3,893	15.76	2.25
	Insurance			Monthly	2,594	10.50	1.50
	ACC Levies			Jul, Jan	758	3.07	0.44
	Rates			Jul, Oct, Ja...	11,268	45.62	6.53
	Total Standing Charges				18,513	74.95	10.72
Total Farm Working Expense					121,465	492.09	70.36
Depreciation				Monthly	0	0.00	0.00
Total Farm Expenses					121,465	491.76	70.36
Other	Rent/Lease			Monthly	0	0.00	0.00
	Interest			Monthly	0	0.00	0.00
	Principal			Monthly	0	0.00	0.00
	Drawings			Monthly	0	0.00	0.00
	Taxation			Jul, Oct, Ja...	0	0.00	0.00
	Total Other Expenses				0	0.00	0.00
	Total Expenses				121,465	491.76	70.36

Appendix B4: Expense Inputs Adopted for Case Two

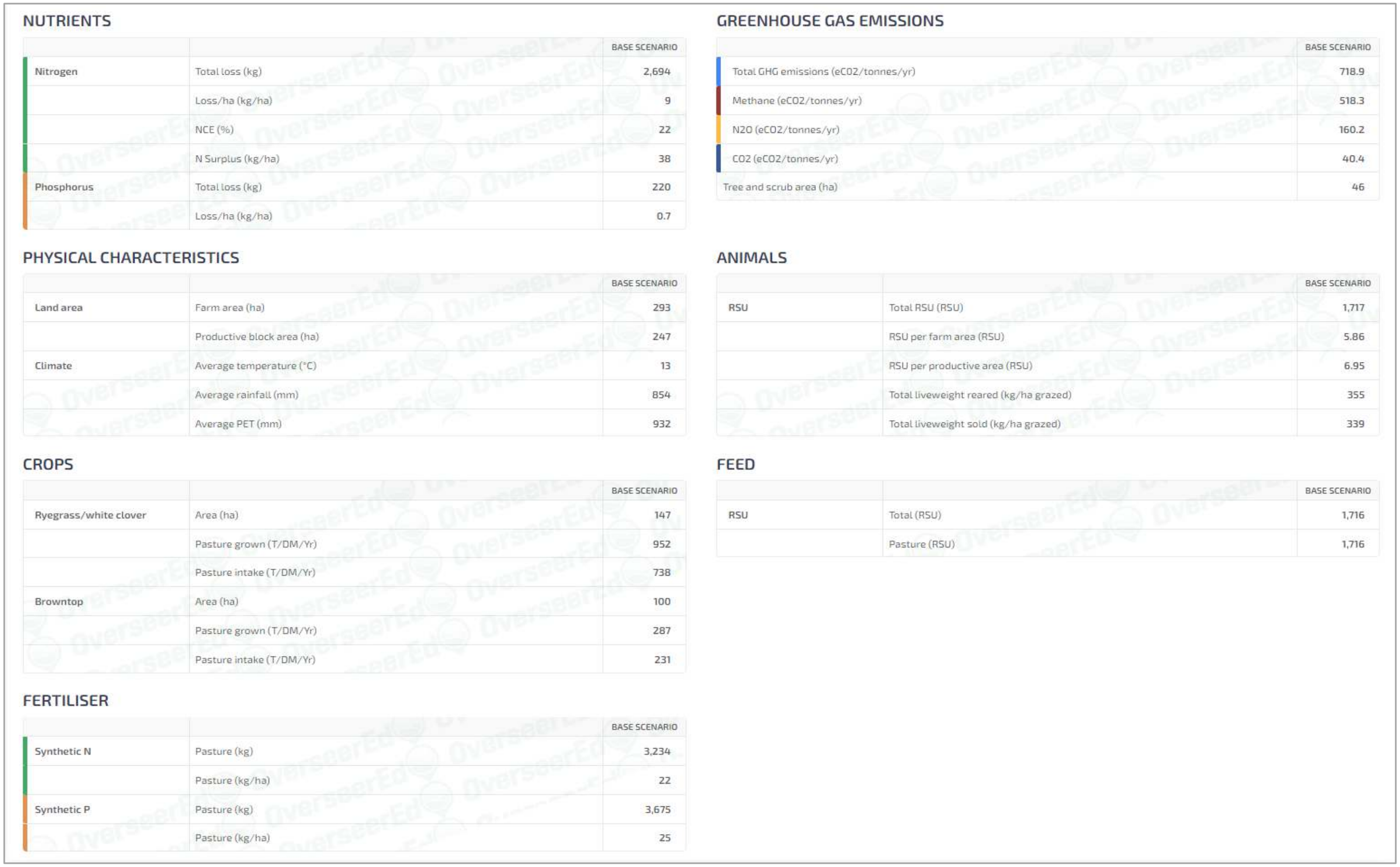


NI Hill Countrv **CASE 2**

($/year)		Model (tick to use)		Timing	$ Total	$ / ha (443)	$ / SU (5,444)
Wages	Wages			Monthly	28,174	**63.67**	5.17
	Management Wage			Monthly	107,443	**242.81**	19.74
	Total Wages				**135,617**	**306.48**	**24.91**
Stock	Animal Health	**12,892**	☑	As Incurred	779	1.76	0.14
	Shearing	**29,073**	☑	As Incurred	0	0.00	0.00
	Velveting	**0**	☑	As Incurred	0	0.00	0.00
	Total Stock				**935**	**1.76**	**0.14**
Feed, Crops & Grazing	Conservation	**0**	☑	As Incurred	0	0.00	0.00
	Cash Crops	**0**	☑	As Incurred	0	0.00	0.00
	Forage Crops	**20,000**	☑	As Incurred	0	0.00	0.00
	Purchased Feeds	**0**	☑	As Incurred	0	0.00	0.00
	Regrassing	**12,000**	☑	As Incurred	12,000	27.12	2.20
	Grazing	**0**	☑	As Incurred	0	0.00	0.00
	Total Feed/Crops/Grazing				**12,000**	**27.12**	**2.20**
Fertiliser	Fertiliser (Excl. N & Lime)			Oct, Apr	55,990	**126.53**	10.28
	Nitrogen	**0**	☑	As Incurred	0	0.00	0.00
	Lime			Oct, Apr	0	**0.00**	0.00
	Total Fertiliser				**55,990**	**126.53**	**10.28**
Other Farm Working	Irrigation Charges			Custom	0	**0.00**	0.00
	Weed & Pest Control			Monthly	5,434	**12.28**	1.00
	Vehicle Expenses			Monthly	10,806	**24.42**	1.98
	Fuel			Monthly	6,580	**14.87**	1.21
	Repairs & Maintenance			Monthly	32,457	**73.35**	5.96
	Freight & Cartage			Monthly	5,775	**13.05**	1.06
	Electricity			Monthly	2,903	**6.56**	0.53
	Other Expenses			Monthly	**0**	0.00	0.00
	Total Other Farm Working				**63,955**	**144.53**	**11.75**
Standing	Administration Expenses			Monthly	11,801	**26.67**	2.17
	Insurance			Monthly	7,744	**17.50**	1.42
	ACC Levies			Jul, Jan	2,266	**5.12**	0.42
	Rates			Jul, Oct, Ja...	15,594	**35.24**	2.86
	Total Standing Charges				**37,405**	**84.53**	**6.87**
Total Farm Working Expense					**305,745**	**690.95**	**56.16**
Depreciation				Monthly	0	**0.00**	0.00
Total Farm Expenses					**305,745**	**690.95**	**56.16**
Other	Rent/Lease			Monthly	0	**0.00**	0.00
	Interest			Monthly	0	**0.00**	0.00
	Principal			Monthly	**0**	0.00	0.00
	Drawings			Monthly	**0**	0.00	0.00
	Taxation			Jul, Oct, Ja...	**0**	0.00	0.00
	Total Other Expenses				**0**	**0.00**	**0.00**
	Total Expenses				**305,745**	**690.95**	**56.16**

Appendix C: Overseer Summaries for Base Scenario

Appendix C1: Overseer Summary of Base Scenario for Case One



NUTRIENTS

		BASE SCENARIO
Nitrogen	Total loss (kg)	2,694
	Loss/ha (kg/ha)	9
	NCE (%)	22
	N Surplus (kg/ha)	38
Phosphorus	Total loss (kg)	220
	Loss/ha (kg/ha)	0.7

GREENHOUSE GAS EMISSIONS

	BASE SCENARIO
Total GHG emissions (eCO2/tonnes/yr)	718.9
Methane (eCO2/tonnes/yr)	518.3
N2O (eCO2/tonnes/yr)	160.2
CO2 (eCO2/tonnes/yr)	40.4
Tree and scrub area (ha)	46

PHYSICAL CHARACTERISTICS

		BASE SCENARIO
Land area	Farm area (ha)	293
	Productive block area (ha)	247
Climate	Average temperature (°C)	13
	Average rainfall (mm)	854
	Average PET (mm)	932

ANIMALS

		BASE SCENARIO
RSU	Total RSU (RSU)	1,717
	RSU per farm area (RSU)	5.86
	RSU per productive area (RSU)	6.95
	Total liveweight reared (kg/ha grazed)	355
	Total liveweight sold (kg/ha grazed)	339

CROPS

		BASE SCENARIO
Ryegrass/white clover	Area (ha)	147
	Pasture grown (T/DM/Yr)	952
	Pasture intake (T/DM/Yr)	738
Browntop	Area (ha)	100
	Pasture grown (T/DM/Yr)	287
	Pasture intake (T/DM/Yr)	231

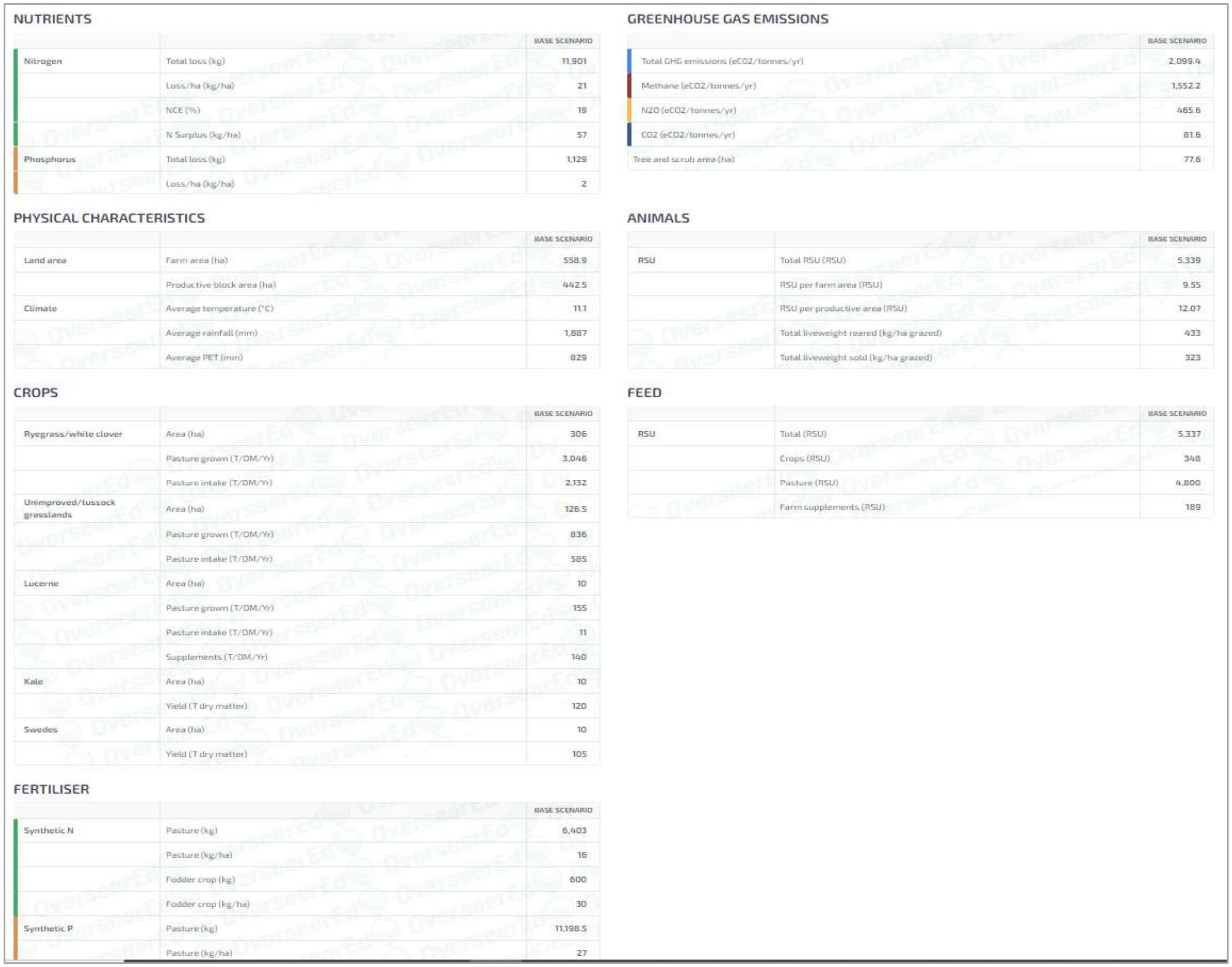
FEED

		BASE SCENARIO
RSU	Total (RSU)	1,716
	Pasture (RSU)	1,716

FERTILISER

		BASE SCENARIO
Synthetic N	Pasture (kg)	3,234
	Pasture (kg/ha)	22
Synthetic P	Pasture (kg)	3,675
	Pasture (kg/ha)	25

Appendix C2: Overseer Summary of Base Scenario for Case Two



NUTRIENTS

		BASE SCENARIO
Nitrogen	Total loss (kg)	11,901
	Loss/ha (kg/ha)	21
	NCE (%)	19
	N Surplus (kg/ha)	57
Phosphorus	Total loss (kg)	1,129
	Loss/ha (kg/ha)	2

PHYSICAL CHARACTERISTICS

		BASE SCENARIO
Land area	Farm area (ha)	558.9
	Productive block area (ha)	442.5
Climate	Average temperature (°C)	11.1
	Average rainfall (mm)	1,887
	Average PET (mm)	829

CROPS

		BASE SCENARIO
Ryegrass/white clover	Area (ha)	306
	Pasture grown (T/DM/Yr)	3,046
	Pasture intake (T/DM/Yr)	2,132
Unimproved/tussock grasslands	Area (ha)	126.5
	Pasture grown (T/DM/Yr)	836
	Pasture intake (T/DM/Yr)	585
Lucerne	Area (ha)	10
	Pasture grown (T/DM/Yr)	155
	Pasture intake (T/DM/Yr)	11
	Supplements (T/DM/Yr)	140
Kale	Area (ha)	10
	Yield (T dry matter)	120
Swedes	Area (ha)	10
	Yield (T dry matter)	105

FERTILISER

		BASE SCENARIO
Synthetic N	Pasture (kg)	6,403
	Pasture (kg/ha)	16
	Fodder crop (kg)	600
	Fodder crop (kg/ha)	30
Synthetic P	Pasture (kg)	11,198.5
	Pasture (kg/ha)	27

GREENHOUSE GAS EMISSIONS

	BASE SCENARIO
Total GHG emissions (eCO2/tonnes/yr)	2,099.4
Methane (eCO2/tonnes/yr)	1,552.2
N2O (eCO2/tonnes/yr)	465.6
CO2 (eCO2/tonnes/yr)	81.6
Tree and scrub area (ha)	77.6

ANIMALS

		BASE SCENARIO
RSU	Total RSU (RSU)	5,339
	RSU per farm area (RSU)	9.55
	RSU per productive area (RSU)	12.07
	Total liveweight reared (kg/ha grazed)	433
	Total liveweight sold (kg/ha grazed)	323

FEED

		BASE SCENARIO
RSU	Total (RSU)	5,337
	Crops (RSU)	348
	Pasture (RSU)	4,800
	Farm supplements (RSU)	189

Appendix D: Detailed Pinus Radiata Timber Harvest Costs and Revenue

Appendix D1: Harvest Costs and Revenue Adopted for Case One

P. rad	**Case Study 1**	STUMPAGE REVENUE			
		Preferred Afforestation		**Total Afforestation**	
Harvest Volume					
Grade	Price	Volume	%	Volume	%
Export AL	$113	310	40%	292	39%
Export AS	$113	50	6%	38	5%
Export KIL	$95	89	12%	104	14%
Export KIS	$95	41	5%	17	2%
Export KL	$101	121	16%	127	17%
Export KS	$101	22	3%	23	3%
Ex Pulp	$83	100	13%	107	14%
Dom Pulp	$51	39	5%	37	5%
TOTAL		**771**	100%	**744**	100%
Harvest Costs					
Ground Base %		48.1%		42.2%	
Harvest Age		27		27	
Road & Skid		$11.66		$9.20	
Log & Load	Ground	$ 38.00		$ 38.00	
	Hauler	$ 45.00		$ 45.00	
	Average	**$ 41.64**		**$ 42.04**	
Machinery Transport		$ 0.50		$ 0.50	
Log Transport		$ 15.26		$ 15.26	
Site cleanup/Fencing		$ 2.00		$ 2.00	
Forest Owner Commodity Levy		$ 0.27		$ 0.27	
Weighbridge		$ 0.50		$ 0.50	
Management & Marketing		$ 5.00		$ 5.00	
Contingency		$ 1.00		$ 1.00	
Cost per m3		**$ 77.82**		**$ 75.78**	
Gross Revenue		$ 77,778		$ 74,764	
Net Revenue		**$ 17,816**		**$ 18,366**	

Lead Distance	Preferred	Total
Internal	*1.8*	*1.8*
Pan Pac	52	52
Port	62	62

Info	Preferred	Total
Harvest Age	27	27
Ha	33.4	83.9

Roading - Preferred Afforestation

2,500	ha for GB roading	$ 70,000	per km for long roading
5,500	ha for HB roading	1.8	km of link road
4,058	Weighted Avg.	$ 126,000	Total roading
		$ 4.89	$/m3
$ 5.27	/m3		
$ 1.50	Maintenance	$ 11.66	33.4 ha + 1.8km of link road
$ 6.77	Total/m3		

Roading - Total Afforestation

2,500	ha for GB roading	$ 70,000	per km for long roading
5,500	ha for HB roading	1.8	km of link road
4,233	Weighted Avg.	$ 126,000	Total roading
		$ 2.02	$/m3
$ 5.69	/m3		
$ 1.50	Maintenance	$ 9.20	83.9 ha + 1.8km of link road
$ 7.19	Total/m3		

Cartage

20	km Limit for Flat Rate
$ 7.00	Charge for less than 20km lead distance
$ 0.20	Charge per km

Appendix D2: Harvest Costs and Revenue Adopted for Case Two

P. rad	**Case Study 2**	STUMPAGE REVENUE			
		Preferred Afforestation		**Total Afforestation**	
Harvest Volume					
Grade	Price	Volume	%	Volume	%
Export AL	$113	301	38%	365	43%
Export AS	$113	23	3%	38	5%
Export KIL	$95	101	13%	95	11%
Export KIS	$95	42	5%	38	4%
Export KL	$101	150	19%	132	16%
Export KS	$101	16	2%	29	3%
Ex Pulp	$83	116	15%	103	12%
Dom Pulp	$51	39	5%	42	5%
TOTAL		**788**	100%	**842**	100%
Harvest Costs					
Ground Base %		14.7%		43.9%	
Harvest Age		27		27	
Road & Skid		$9.42		$7.56	
Log & Load	Ground	$ 38.00		$ 38.00	
	Hauler	$ 45.00		$ 45.00	
	Average	**$ 43.97**		**$ 41.93**	
Machinery Transport		$ 0.50		$ 0.50	
Log Transport		$ 15.87		$ 15.58	
Site cleanup/Fencing		$ 2.00		$ 2.00	
Forest Owner Commodity Levy		$ 0.27		$ 0.27	
Weighbridge		$ 0.50		$ 0.50	
Management & Marketing		$ 5.00		$ 5.00	
Contingency		$ 1.00		$ 1.00	
Cost per m3		**$ 78.54**		**$ 74.34**	
Gross Revenue		$ 78,677		$ 85,287	
Net Revenue		**$ 16,811**		**$ 22,689**	

Lead Distance	Preferred	Total
Internal	*0.5*	*3.0*
Pan Pac	62	61
Port	65	63

Info	Preferred	Total
Harvest Age	27	27
Ha	29.6	227.8

Roading - Preferred Afforestation

	2,500	ha for GB roading	$	70,000	per km for long roading
	5,500	ha for HB roading		0.5	km of link road
	5,059	Weighted Avg.	$	35,000	Total roading
			$	1.50	$/m3
$	6.42	/m3			
$	1.50	Maintenance	$	9.42	30 ha + 0.5 km of link road
$	7.92	Total/m3			

Roading - Total Afforestation

	2,500	ha for GB roading	$	70,000	per km for long roading
	5,500	ha for HB roading		3	km of link road
	4,184	Weighted Avg.	$	210,000	Total roading
			$	1.10	$/m3
$	4.97	/m3			
$	1.50	Maintenance	$	7.56	228 ha + 3 km of link road
$	6.47	Total/m3			

Cartage

	20	km Limit for Flat Rate
$	7.00	Charge for less than 20km lead distance
$	0.20	Charge per km

Appendix E: Preferred, Total, and Permanent Afforestation Integration Level Discounted Cash Flows

Appendix E1: Preferred Afforestation Integration Level – Case One (years zero to 13)

PREFERRED AFFORESTATION **WHOLE FARM**

Project Area ha 247.0

0% % of Pastoral Emissions Liable for

0 No. of Plots

33.4 Total Afforested Area (ha)

Case Study One	Total	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Forest area (ha)		0.0	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4
Area planted (ha)		0.0	33.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Farm Area (ha)		207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0
Land Cost															
Purchase Land Value - Forestry	337,135	337,135													
Purchase Land Value - Pastoral	2,434,264	2,434,264													
Operation Costs															
P. rad	192,981	11,899	60,564	7,038	3,199	3,199	3,199	3,199	3,199	3,199	3,199	35,042	3,199	3,199	3,199
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**2,964,381**	**2,783,299**	**60,564**	**7,038**	**3,199**	**3,199**	**3,199**	**3,199**	**3,199**	**3,199**	**3,199**	**35,042**	**3,199**	**3,199**	**3,199**
Revenue															
1BT Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	28,968	28,968	-	-	-	-	-	-	-	-	-				
Terminal Land Value - Afforested Land	89,924														
Terminal Land Value - Waste Forestry Land	610														
Terminal Land Value - Pastoral	2,434,264														
Net Retained Pastoral Income	3,076,826	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P. rad Harvest	595,940														
Total Revenue	**6,226,532**	**138,855**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**3,262,152**	**- 2,644,444**	**49,323**	**102,849**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**74,844**	**106,688**	**106,688**	**106,688**
ETS Operation Costs															
FMA Plots	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annual	5,686	-	334	334	334	334	334	334	334	334	334	334	334	334	334
ETS Revenue															
Carbon Price	$ 35.00														
Carbon Sequestration (t CO2/ha)															
P. rad	14,584	-	17	84	201	836	1,238	1,405	1,405	1,003	401	435	769	903	1,037
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue ($)															
P. rad	510,439	-	585	2,927	7,024	29,268	43,317	49,171	49,171	35,122	14,049	15,219	26,927	31,610	36,293
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue ($)	510,439	-	585	2,927	7,024	29,268	43,317	49,171	49,171	35,122	14,049	15,219	26,927	31,610	36,293
Liability Created from Pastoral Enterprises															
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position (t CO2)	14,584	-	17	84	201	836	1,238	1,405	1,405	1,003	401	435	769	903	1,037
Net Carbon Revenue	504,752	-	251	2,592	6,690	28,934	42,983	48,836	48,836	34,787	13,714	14,885	26,592	31,275	35,958
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**3,766,904**	**- 2,644,444**	**49,574**	**105,441**	**113,378**	**135,622**	**149,671**	**155,524**	**155,524**	**141,475**	**120,402**	**89,729**	**133,280**	**137,963**	**142,646**
AVERAGE NET CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**$ 545**														

IRR OF PROJECT:		**TREE CROP, GRAZING & HONEY ONLY**	**4.21%**	**TREE CROP, GRAZING, HONEY & CARBON**	**4.96%**
NPV OF PROJECT: $/HA	**5%**	**TREE CROP, GRAZING & HONEY ONLY**	**-$674**	**TREE CROP, GRAZING, HONEY & CARBON**	**$627**
NPV OF PROJECT: TOTAL $		**TREE CROP, GRAZING & HONEY ONLY**	**-$166,355**	**TREE CROP, GRAZING, HONEY & CARBON**	**$154,747**

Appendix E1 (continued): Preferred Afforestation Integration Level – Case One (years 13 to 27)

PREFERRED AFFORESTATION	**WHOLE FARM**														
Project Area ha	247.0														
Case Study One	Total	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Forest area (ha)		33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.4
Area planted (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.4
Farm Area (ha)		207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0
Land Cost															
Purchase Land Value - Forestry	337,135														
Purchase Land Value - Pastoral	2,434,264														
Operation Costs															
P. rad	192,981	3,199	3,199	3,199	3,199	3,199	3,199	3,199	3,199	3,199	3,199	3,199	3,199	4,871	3,199
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**2,964,381**	**3,199**	**3,199**	**3,199**	**3,199**	**3,199**	**3,199**	**3,199**	**3,199**	**3,199**	**3,199**	**3,199**	**3,199**	**4,871**	**3,199**
Revenue															
1BT Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	28,968														
Terminal Land Value - Afforested Land	89,924														89,924
Terminal Land Value - Waste Forestry Land	610														610
Terminal Land Value - Pastoral	2,434,264														2,434,264
Net Retained Pastoral Income	3,076,826	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887	109,887
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P. rad Harvest	595,940														595,940
Total Revenue	**6,226,532**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**109,887**	**3,230,625**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**3,262,152**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**105,016**	**3,227,426**
ETS Operation Costs															
FMA Plots	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Annual	5,686	334	334	334	334	-	-	-	-	-	-	-	-	-	-
ETS Revenue															
Carbon Price	$ 35.00														
Carbon Sequestration (t CO2/ha)															
P. rad	14,584	1,137	1,204	1,238	1,271	-	-	-	-	-	-	-	-	-	
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue ($)															
P. rad	510,439	39,805	42,146	43,317	44,488	-	-	-	-	-	-	-	-	-	
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue ($)	510,439	39,805	42,146	43,317	44,488	-	-	-	-	-	-	-	-	-	-
Liability Created from Pastoral Enterprises															
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position (t CO2)	14,584	1,137	1,204	1,238	1,271	-	-	-	-	-	-	-	-	-	-
Net Carbon Revenue	504,752	39,470	41,812	42,983	44,153	-	-	-	-	-	-	-	-	-	-
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**3,766,904**	**146,158**	**148,500**	**149,671**	**150,841**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**106,688**	**105,016**	**3,227,426**

Appendix E2: Total Afforestation Integration Level – Case One (years zero to 13)

TOTAL AFFORESTATION **WHOLE FARM**

Project Area ha 247.0

0% % of Pastoral Emissions Liable for

0 No. of Plots

83.9 Total Afforested Area (ha)

Case Study One	Total	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Forest area (ha)		0.0	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9
Area planted (ha)		0.0	83.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Farm Area (ha)		147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0
Land Cost															
Purchase Land Value - Forestry	849,847	849,847													
Purchase Land Value - Pastoral	1,922,862	1,922,862													
Operation Costs															
P. rad	484,188	29,855	151,954	17,657	8,025	8,025	8,025	8,025	8,025	8,025	8,025	87,921	8,025	8,025	8,025
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**3,256,897**	**2,802,564**	**151,954**	**17,657**	**8,025**	**8,025**	**8,025**	**8,025**	**8,025**	**8,025**	**8,025**	**87,921**	**8,025**	**8,025**	**8,025**
Revenue															
1BT Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	72,421	72,421	-	-	-	-	-	-	-	-	-				
Terminal Land Value - Afforested Land	222,691														
Terminal Land Value - Waste Forestry Land	1,578														
Terminal Land Value - Pastoral	1,922,862														
Net Retained Pastoral Income	2,561,722	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P. rad Harvest	1,541,357														
Total Revenue	**6,322,631**	**163,911**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**3,065,734**	**- 2,638,654**	**- 60,463**	**73,833**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**3,569**	**83,465**	**83,465**	**83,465**
ETS Operation Costs															
FMA Plots	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annual	14,267	-	839	839	839	839	839	839	839	839	839	839	839	839	839
ETS Revenue															
Carbon Price	$ 35.00														
Carbon Sequestration (t CO2/ha)															
P. rad	36,591	-	42	210	504	2,098	3,105	3,525	3,525	2,518	1,007	1,091	1,930	2,266	2,602
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue ($)															
P. rad	1,280,687	-	1,469	7,343	17,624	73,434	108,682	123,369	123,369	88,121	35,248	38,186	67,559	79,309	91,058
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue ($)	1,280,687	-	1,469	7,343	17,624	73,434	108,682	123,369	123,369	88,121	35,248	38,186	67,559	79,309	91,058
Liability Created from Pastoral Enterprises															
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position (t CO2)	36,591	-	42	210	504	2,098	3,105	3,525	3,525	2,518	1,007	1,091	1,930	2,266	2,602
Net Carbon Revenue	1,266,420	-	629	6,504	16,785	72,595	107,843	122,530	122,530	87,281	34,409	37,346	66,720	78,469	90,219
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**4,332,154**	**- 2,638,654**	**- 59,834**	**80,337**	**100,250**	**156,060**	**191,308**	**205,995**	**205,995**	**170,746**	**117,874**	**40,915**	**150,185**	**161,934**	**173,684**
AVERAGE NET CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**$ 626**														

IRR OF PROJECT:		**TREE CROP, GRAZING & HONEY ONLY**	**3.60%**	**TREE CROP, GRAZING, HONEY & CARBON**	**5.35%**
NPV OF PROJECT: $/HA	5%	**TREE CROP, GRAZING & HONEY ONLY**	**-$1,888**	**TREE CROP, GRAZING, HONEY & CARBON**	**$1,373**
NPV OF PROJECT: TOTAL $		**TREE CROP, GRAZING & HONEY ONLY**	**-$466,418**	**TREE CROP, GRAZING, HONEY & CARBON**	**$339,224**

Appendix E2 (continued): Total Afforestation Integration Level – Case One (years 14 to 27)

TOTAL AFFORESTATION	WHOLE FARM
Project Area ha	247.0

Case Study One	Total	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Forest area (ha)		83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9	83.9
Area planted (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	83.9
Farm Area (ha)		147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0	147.0
Land Cost															
Purchase Land Value - Forestry	849,847														
Purchase Land Value - Pastoral	1,922,862														
Operation Costs															
P. rad	484,188	8,025	8,025	8,025	8,025	8,025	8,025	8,025	8,025	8,025	8,025	8,025	8,025	12,221	8,025
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**3,256,897**	**8,025**	**8,025**	**8,025**	**8,025**	**8,025**	**8,025**	**8,025**	**8,025**	**8,025**	**8,025**	**8,025**	**8,025**	**12,221**	**8,025**
Revenue															
1BT Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	72,421														
Terminal Land Value - Afforested Land	222,691														222,691
Terminal Land Value - Waste Forestry Land	1,578														1,578
Terminal Land Value - Pastoral	1,922,862														1,922,862
Net Retained Pastoral Income	2,561,722	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490	91,490
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P. rad Harvest	1,541,357														1,541,357
Total Revenue	**6,322,631**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**91,490**	**3,779,978**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**3,065,734**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**79,269**	**3,771,953**
ETS Operation Costs															
FMA Plots	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Annual	14,267	839	839	839	839	-	-	-	-	-	-	-	-	-	-
ETS Revenue															
Carbon Price	$ 35.00														
Carbon Sequestration (t CO2/ha)															
P. rad	36,591	2,853	3,021	3,105	3,189	-	-	-	-	-	-	-	-	-	
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue ($)															
P. rad	1,280,687	99,870	105,745	108,682	111,620	-	-	-	-	-	-	-	-	-	
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue ($)	1,280,687	99,870	105,745	108,682	111,620	-	-	-	-	-	-	-	-	-	-
Liability Created from Pastoral Enterprises															
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position (t CO2)	36,591	2,853	3,021	3,105	3,189	-	-	-	-	-	-	-	-	-	-
Net Carbon Revenue	1,266,420	99,031	104,906	107,843	110,780	-	-	-	-	-	-	-	-	-	-
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**4,332,154**	**182,496**	**188,370**	**191,308**	**194,245**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**83,465**	**79,269**	**3,771,953**

Appendix E3: Permanent Afforestation Integration Level – Case One (years zero to 25)

PERMANENT AFFORESTATION **WHOLE FARM**

Project Area ha 247.0 0 No. of Plots 27.5 Total Afforested Area (ha)

0% % of Pastoral Emissions Liable for

Case Study One	Total	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Forest area (ha)		0.0	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5
Area planted (ha)		0.0	27.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Farm Area (ha)		219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0
Land Cost																											
Purchase Land Value - Forestry	234,224	234,224																									
Purchase Land Value - Pastoral	2,536,544	2,536,544																									
Operation Costs																											
P. rad	154,920	9,776	48,502	4,528	1,374	1,374	1,374	1,374	1,374	1,374	1,374	27,535	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**2,925,688**	**2,780,544**	**48,502**	**4,528**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**27,535**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**
Revenue																											
1BT Funding																											
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding																											
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	20,278	20,278	-	-	-	-	-	-	-	-	-																
Terminal Land Value - Afforested Land	73,877																										
Terminal Land Value - Waste Forestry Land	-																										
Terminal Land Value - Pastoral	2,536,544																										
Net Retained Pastoral Income	5,791,863	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P. rad Harvest	-																										
Total Revenue	**8,422,562**	**133,844**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**5,496,874**	**- 2,646,700**	**65,064**	**109,038**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**86,031**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**
ETS Operation Costs																											
FMA Plots	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annual	13,740	-	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275
ETS Revenue																											
Carbon Price	$ 35.00																										
Carbon Sequestration (t CO2/ha)																											
P. rad	35,587	-	14	69	14	69	165	687	1,017	1,154	1,154	824	330	357	632	742	852	934	989	1,017	1,044	1,017	1,017	1,017	962	962	907
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue																											
P. rad	1,245,542	-	481	2,405	481	2,405	5,771	24,045	35,587	40,396	40,396	28,854	11,542	12,504	22,122	25,969	29,816	32,701	34,625	35,587	36,549	35,587	35,587	35,587	33,663	33,663	31,740
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue	1,245,542	-	481	2,405	481	2,405	5,771	24,045	35,587	40,396	40,396	28,854	11,542	12,504	22,122	25,969	29,816	32,701	34,625	35,587	36,549	35,587	35,587	35,587	33,663	33,663	31,740
Liability Created from Pastoral Enterprises																											
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position	35,587	-	14	69	14	69	165	687	1,017	1,154	1,154	824	330	357	632	742	852	934	989	1,017	1,044	1,017	1,017	1,017	962	962	907
Net Carbon Revenue	1,231,802	-	206	2,130	206	2,130	5,496	23,770	35,312	40,121	40,121	28,579	11,267	12,229	21,847	25,694	29,541	32,427	34,350	35,312	36,274	35,312	35,312	35,312	33,388	33,388	31,465
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**6,728,676**	**- 2,646,700**	**65,270**	**111,168**	**112,398**	**114,322**	**117,688**	**135,962**	**147,504**	**152,313**	**152,313**	**114,610**	**123,459**	**124,421**	**134,039**	**137,886**	**141,733**	**144,619**	**146,542**	**147,504**	**148,466**	**147,504**	**147,504**	**147,504**	**145,580**	**145,580**	**143,657**
AVERAGE NET CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**$ 534**																										

IRR OF PROJECT:		**TREE CROP, GRAZING & HONEY ONLY**	**4.11%**	**TREE CROP, GRAZING, HONEY & CARBON**	**4.94%**
NPV OF PROJECT: $/HA	**5%**	**TREE CROP, GRAZING & HONEY ONLY**	**-$1,029**	**TREE CROP, GRAZING, HONEY & CARBON**	**$740**
NPV OF PROJECT: TOTAL $		**TREE CROP, GRAZING & HONEY ONLY**	**-$254,273**	**TREE CROP, GRAZING, HONEY & CARBON**	**$182,903**

Appendix E3 (continued): Permanent Afforestation Integration Level – Case One (years 26 to 50)

PERMANENT AFFORESTATION	**WHOLE FARM**																									
Project Area ha	247.0																									
Case Study One	Total	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Forest area (ha)		27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5
Area planted (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Farm Area (ha)		219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0	219.0
Land Cost																										
Purchase Land Value - Forestry	234,224																									
Purchase Land Value - Pastoral	2,536,544																									
Operation Costs																										
P. rad	154,920	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**2,925,688**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**	**1,374**
Revenue																										
1BT Funding																										
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding																										
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	20,278																									
Terminal Land Value - Afforested Land	73,877																									73,877
Terminal Land Value - Waste Forestry Land	-																									-
Terminal Land Value - Pastoral	2,536,544																									2,536,544
Net Retained Pastoral Income	5,791,863	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566	113,566
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P. rad Harvest	-																									-
Total Revenue	**8,422,562**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**113,566**	**2,723,987**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**5,496,874**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**112,192**	**2,722,613**
ETS Operation Costs																										
FMA Plots	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annual	13,740	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275	275
ETS Revenue																										
Carbon Price	$ 35.00																									
Carbon Sequestration (t CO2/ha)																										
P. rad	35,587	852	852	797	769	769	769	742	714	687	714	660	687	660	660	660	632	660	660	632	660	660	687	687	687	687
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue																										
P. rad	1,245,542	29,816	29,816	27,892	26,931	26,931	26,931	25,969	25,007	24,045	25,007	23,083	24,045	23,083	23,083	23,083	22,122	23,083	23,083	22,122	23,083	23,083	24,045	24,045	24,045	24,045
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue	1,245,542	29,816	29,816	27,892	26,931	26,931	26,931	25,969	25,007	24,045	25,007	23,083	24,045	23,083	23,083	23,083	22,122	23,083	23,083	22,122	23,083	23,083	24,045	24,045	24,045	24,045
Liability Created from Pastoral Enterprises																										
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position	35,587	852	852	797	769	769	769	742	714	687	714	660	687	660	660	660	632	660	660	632	660	660	687	687	687	687
Net Carbon Revenue	1,231,802	29,541	29,541	27,618	26,656	26,656	26,656	25,694	24,732	23,770	24,732	22,809	23,770	22,809	22,809	22,809	21,847	22,809	22,809	21,847	22,809	22,809	23,770	23,770	23,770	23,770
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**6,728,676**	**141,733**	**141,733**	**139,810**	**138,848**	**138,848**	**138,848**	**137,886**	**136,924**	**135,962**	**136,924**	**135,001**	**135,962**	**135,001**	**135,001**	**135,001**	**134,039**	**135,001**	**135,001**	**134,039**	**135,001**	**135,001**	**135,962**	**135,962**	**135,962**	**2,746,383**

Appendix E4: Preferred Afforestation Integration Level – Case Two (years zero to 13)

PREFERRED AFFORESTATION **WHOLE FARM**

Project Area ha 442.5 0 No. of Plots 75.3 Total Afforested Area (ha)

0% % of Pastoral Emissions Liable for

Case Study Two	Total	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Forest area (ha)		0.0	44.8	60.0	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3
Area planted (ha)		0.0	44.8	15.2	15.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Farm Area (ha)		361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7
Land Cost															
Purchase Land Value - Forestry	481,435	481,435													
Purchase Land Value - Pastoral	3,198,824	3,198,824													
Operation Costs															
P. rad	162,322	10,520	53,236	5,915	2,521	2,521	2,521	2,521	2,521	2,521	2,521	30,674	2,521	2,521	2,521
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	418,092	5,418	68,035	116,428	111,928	50,228	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**4,260,673**	**3,696,197**	**121,271**	**122,343**	**114,448**	**52,749**	**5,273**	**5,273**	**5,273**	**5,273**	**5,273**	**33,426**	**5,273**	**5,273**	**5,273**
Revenue															
1BT Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	107,776	64,158	21,809	21,809	-	-	-	-	-	-	-				
Terminal Land Value - Afforested Land	187,261														
Terminal Land Value - Waste Forestry Land	552														
Terminal Land Value - Pastoral	3,198,824														
Net Retained Pastoral Income	7,713,412	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	190,322	-	-	-	-	-	26	231	925	2,239	4,569	7,427	9,606	10,280	10,280
P. rad Harvest	497,153														
Total Revenue	**11,895,301**	**321,272**	**278,923**	**278,923**	**257,114**	**257,114**	**257,139**	**257,345**	**258,039**	**259,352**	**261,683**	**264,541**	**266,720**	**267,394**	**267,394**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**7,634,627**	**- 3,374,925**	**157,652**	**156,580**	**142,665**	**204,365**	**251,866**	**252,072**	**252,766**	**254,079**	**256,409**	**231,115**	**261,447**	**262,121**	**262,121**
ETS Operation Costs															
FMA Plots	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annual	16,449	-	448	600	753	753	753	753	753	753	753	753	753	753	753
ETS Revenue															
Carbon Price	$ 35.00														
Carbon Sequestration (t CO2/ha)															
P. rad	12,893	-	15	74	177	739	1,094	1,242	1,242	887	355	384	680	798	917
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	10,677	-	9	18	38	61	101	146	196	247	297	346	393	437	477
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue ($)															
P. rad	451,272	-	518	2,588	6,210	25,876	38,296	43,471	43,471	31,051	12,420	13,455	23,806	27,946	32,086
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	373,711	-	320	640	1,333	2,132	3,518	5,117	6,876	8,635	10,394	12,100	13,752	15,298	16,684
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue ($)	824,983	-	837	3,227	7,543	28,008	41,814	48,588	50,347	39,686	22,815	25,555	37,558	43,244	48,770
Liability Created from Pastoral Enterprises															
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position (t CO2)	23,571	-	24	92	216	800	1,195	1,388	1,438	1,134	652	730	1,073	1,236	1,393
Net Carbon Revenue	808,534	-	389	2,627	6,790	27,255	41,061	47,836	49,595	38,933	22,062	24,803	36,805	42,491	48,017
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**8,443,161**	**- 3,374,925**	**158,041**	**159,207**	**149,456**	**231,620**	**292,928**	**299,908**	**302,361**	**293,013**	**278,471**	**255,918**	**298,252**	**304,612**	**310,138**
AVERAGE NET CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**$ 636**														

IRR OF PROJECT:		**TREE CROP, GRAZING & HONEY ONLY**	**7.05%**	**TREE CROP, GRAZING, HONEY & CARBON**	**7.81%**
NPV OF PROJECT: $/HA	**5%**	**TREE CROP, GRAZING & HONEY ONLY**	**$3,256**	**TREE CROP, GRAZING, HONEY & CARBON**	**$4,275**
NPV OF PROJECT: TOTAL $		**TREE CROP, GRAZING & HONEY ONLY**	**$1,440,424**	**TREE CROP, GRAZING, HONEY & CARBON**	**$1,891,682**

Appendix E4 (continued): Preferred Afforestation Integration Level – Case Two (years 14 to 27)

PREFERRED AFFORESTATION	**WHOLE FARM**																
Project Area ha	442.5																
Case Study Two	Total	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Forest area (ha)		75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	30.5	15.2
Area planted (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.6	15.2	15.2
Farm Area (ha)		361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7	361.7
Land Cost																	
Purchase Land Value - Forestry	481,435																
Purchase Land Value - Pastoral	3,198,824																
Operation Costs																	
P. rad	162,322	2,521	2,521	2,521	2,521	2,521	2,521	2,521	2,521	2,521	2,521	2,521	2,521	3,999	2,521	-	-
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	418,092	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	1,835	917
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**4,260,673**	**5,273**	**5,273**	**5,273**	**5,273**	**5,273**	**5,273**	**5,273**	**5,273**	**5,273**	**5,273**	**5,273**	**5,273**	**6,752**	**5,273**	**1,835**	**917**
Revenue																	
1BT Funding																	
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding																	
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	107,776																
Terminal Land Value - Afforested Land	187,261														73,581	-	113,681
Terminal Land Value - Waste Forestry Land	552														276	-	276
Terminal Land Value - Pastoral	3,198,824														-	-	3,198,824
Net Retained Pastoral Income	7,713,412	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114	257,114
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	190,322	10,280	10,280	10,280	10,280	10,280	10,280	10,280	10,280	10,280	10,280	10,280	10,280	9,606	8,021	3,110	642
P. rad Harvest	497,153														497,153	-	-
Total Revenue	**11,895,301**	**267,394**	**267,394**	**267,394**	**267,394**	**267,394**	**267,394**	**267,394**	**267,394**	**267,394**	**267,394**	**267,394**	**267,394**	**266,720**	**836,144**	**260,223**	**3,570,537**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**7,634,627**	**262,121**	**262,121**	**262,121**	**262,121**	**262,121**	**262,121**	**262,121**	**262,121**	**262,121**	**262,121**	**262,121**	**262,121**	**259,968**	**830,871**	**258,389**	**3,569,620**
ETS Operation Costs																	
FMA Plots	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Annual	16,449	753	753	753	753	457	457	457	457	457	457	457	457	457	-	-	-
ETS Revenue																	
Carbon Price	$ 35.00																
Carbon Sequestration (t CO2/ha)																	
P. rad	12,893	1,005	1,065	1,094	1,124	-	-	-	-	-	-	-	-	-			
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Native - Manuka	10,677	510	536	557	571	580	582	577	568	553	536	515	493	468	442	285	139
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue ($)																	
P. rad	451,272	35,191	37,261	38,296	39,331	-	-	-	-	-	-	-	-	-			
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Native - Manuka	373,711	17,857	18,763	19,509	19,989	20,309	20,362	20,202	19,882	19,349	18,763	18,017	17,270	16,364	15,458	9,968	4,851
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue ($)	824,983	53,048	56,024	57,805	59,320	20,309	20,362	20,202	19,882	19,349	18,763	18,017	17,270	16,364	15,458	9,968	4,851
Liability Created from Pastoral Enterprises																	
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position (t CO2)	23,571	1,516	1,601	1,652	1,695	580	582	577	568	553	536	515	493	468	442	285	139
Net Carbon Revenue	808,534	52,295	55,271	57,053	58,567	19,852	19,905	19,745	19,425	18,892	18,306	17,560	16,813	15,907	15,458	9,968	4,851
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**8,443,161**	**314,416**	**317,392**	**319,173**	**320,688**	**281,972**	**282,026**	**281,866**	**281,546**	**281,013**	**280,427**	**279,680**	**278,934**	**275,875**	**846,329**	**268,356**	**3,574,470**

Appendix E5: Total Afforestation Integration Level – Case Two (years zero to 13)

TOTAL AFFORESTATION **WHOLE FARM**

Project Area ha 442.5 37 No. of Plots 273.5 Total Afforested Area (ha)

0% % of Pastoral Emissions Liable for

Case Study Two	Total	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Forest area (ha)		0.0	91.2	182.3	273.5	273.5	273.5	273.5	273.5	273.5	273.5	273.5	273.5	273.5	273.5
Area planted (ha)		0.0	91.2	91.2	91.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Farm Area (ha)		142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5
Land Cost															
Purchase Land Value - Forestry	2,278,553	2,278,553													
Purchase Land Value - Pastoral	1,401,697	1,401,697													
Operation Costs															
P. rad	1,250,193	27,008	163,683	178,868	158,331	28,128	19,415	19,415	19,415	19,415	19,415	91,692	91,692	91,692	19,415
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	418,092	5,418	68,035	116,428	111,928	50,228	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**5,348,536**	**3,712,677**	**231,717**	**295,296**	**270,259**	**78,356**	**22,167**	**22,167**	**22,167**	**22,167**	**22,167**	**94,444**	**94,444**	**94,444**	**22,167**
Revenue															
1BT Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding															
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	519,747	173,249	173,249	173,249	-	-	-	-	-	-	-				
Terminal Land Value - Afforested Land	606,565														
Terminal Land Value - Waste Forestry Land	1,324														
Terminal Land Value - Pastoral	1,401,697														
Net Retained Pastoral Income	3,106,880	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	190,322	-	-	-	-	-	26	231	925	2,239	4,569	7,427	9,606	10,280	10,280
P. rad Harvest	5,167,762														
Total Revenue	**10,994,298**	**276,812**	**276,812**	**276,812**	**103,563**	**103,563**	**103,588**	**103,794**	**104,488**	**105,801**	**108,132**	**110,990**	**113,169**	**113,843**	**113,843**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**5,645,762**	**- 3,435,865**	**45,094**	**- 18,484**	**- 166,696**	**25,206**	**81,421**	**81,627**	**82,321**	**83,634**	**85,964**	**16,546**	**18,725**	**19,399**	**91,675**
ETS Operation Costs															
FMA Plots	22,200	-	-	-	5,550	-	-	-	-	5,550	-	-	-	-	5,550
Annual	52,876	-	912	1,823	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735	2,735
ETS Revenue															
Carbon Price	$ 35.00														
Carbon Sequestration (t CO2/ha)															
P. rad	150,771	-	38	228	423	1,399	3,075	5,797	8,595	11,204	13,106	13,892	11,762	9,666	8,156
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	10,677	-	9	18	38	61	101	146	196	247	297	346	393	437	477
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue ($)															
P. rad	5,276,999	-	1,329	7,972	14,813	48,974	107,639	202,887	300,822	392,128	458,696	486,234	411,661	338,298	285,459
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	373,711	-	320	640	1,333	2,132	3,518	5,117	6,876	8,635	10,394	12,100	13,752	15,298	16,684
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue ($)	5,650,710	-	1,648	8,611	16,146	51,106	111,157	208,004	307,698	400,763	469,090	498,334	425,414	353,596	302,143
Liability Created from Pastoral Enterprises															
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position (t CO2)	161,449	-	47	246	461	1,460	3,176	5,943	8,791	11,450	13,403	14,238	12,155	10,103	8,633
Net Carbon Revenue	5,575,634	-	737	6,788	7,861	48,372	108,422	205,269	304,963	392,479	466,356	495,599	422,679	350,861	293,859
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**11,221,396**	**- 3,435,865**	**45,831**	**- 11,696**	**- 158,835**	**73,578**	**189,843**	**286,896**	**387,284**	**476,113**	**552,320**	**512,145**	**441,404**	**370,260**	**385,534**
AVERAGE NET CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**$ 845**														

IRR OF PROJECT:		**TREE CROP, GRAZING & HONEY ONLY**	**3.85%**	**TREE CROP, GRAZING, HONEY & CARBON**	**8.19%**
NPV OF PROJECT: $/HA	**5%**	**TREE CROP, GRAZING & HONEY ONLY**	**-$1,280**	**TREE CROP, GRAZING, HONEY & CARBON**	**$5,954**
NPV OF PROJECT: TOTAL $		**TREE CROP, GRAZING & HONEY ONLY**	**-$566,417**	**TREE CROP, GRAZING, HONEY & CARBON**	**$2,634,511**

Appendix E5 (continued): Total Afforestation Integration Level – Case Two (years 14 to 29)

TOTAL AFFORESTATION	**WHOLE FARM**																
Project Area ha	442.5																
Case Study Two	Total	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Forest area (ha)		273.5	273.5	273.5	273.5	273.5	273.5	273.5	273.5	273.5	273.5	273.5	273.5	273.5	273.5	182.3	91.2
Area planted (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	75.9	91.2	91.2
Farm Area (ha)		142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5
Land Cost																	
Purchase Land Value - Forestry	2,278,553																
Purchase Land Value - Pastoral	1,401,697																
Operation Costs																	
P. rad	1,250,193	19,415	19,415	19,415	19,415	19,415	19,415	19,415	19,415	19,415	19,415	19,415	19,415	23,211	23,211	16,739	6,472
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	418,092	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	2,752	1,835	917
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**5,348,536**	**22,167**	**22,167**	**22,167**	**22,167**	**22,167**	**22,167**	**22,167**	**22,167**	**22,167**	**22,167**	**22,167**	**22,167**	**25,963**	**25,963**	**18,574**	**7,389**
Revenue																	
1BT Funding																	
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding																	
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	519,747																
Terminal Land Value - Afforested Land	606,565														-	-	606,565
Terminal Land Value - Waste Forestry Land	1,324														-	-	1,324
Terminal Land Value - Pastoral	1,401,697														-	-	1,401,697
Net Retained Pastoral Income	3,106,880	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563	103,563
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	190,322	10,280	10,280	10,280	10,280	10,280	10,280	10,280	10,280	10,280	10,280	10,280	10,280	9,606	8,021	3,110	642
P. rad Harvest	5,167,762														1,722,587	1,722,587	1,722,587
Total Revenue	**10,994,298**	**113,843**	**113,843**	**113,843**	**113,843**	**113,843**	**113,843**	**113,843**	**113,843**	**113,843**	**113,843**	**113,843**	**113,843**	**113,169**	**1,834,171**	**1,829,260**	**3,836,379**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**5,645,762**	**91,675**	**91,675**	**91,675**	**91,675**	**91,675**	**91,675**	**91,675**	**91,675**	**91,675**	**91,675**	**91,675**	**91,675**	**87,206**	**1,808,208**	**1,810,685**	**3,828,990**
ETS Operation Costs																	
FMA Plots	22,200	-	-	-	-	5,550	-	-	-	-	-	-	-	-			
Annual	52,876	2,735	2,735	2,735	2,735	2,735	2,735	457	457	457	457	457	457	457	457	-	-
ETS Revenue																	
Carbon Price	$ 35.00																
Carbon Sequestration (t CO2/ha)																	
P. rad	150,771	9,160	9,991	10,597	11,047	11,241	11,395	-	-	-	-	-	-	-			
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Native - Manuka	10,677	510	536	557	571	580	582	577	568	553	536	515	493	468	442	285	139
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue ($)																	
P. rad	5,276,999	320,611	349,676	370,900	386,647	393,432	398,822	-	-	-	-	-	-	-			
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
Native - Manuka	373,711	17,857	18,763	19,509	19,989	20,309	20,362	20,202	19,882	19,349	18,763	18,017	17,270	16,364	15,458	9,968	4,851
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue ($)	5,650,710	338,468	368,439	390,409	406,636	413,741	419,184	20,202	19,882	19,349	18,763	18,017	17,270	16,364	15,458	9,968	4,851
Liability Created from Pastoral Enterprises																	
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position (t CO2)	161,449	9,671	10,527	11,155	11,618	11,821	11,977	577	568	553	536	515	493	468	442	285	139
Net Carbon Revenue	5,575,634	335,733	365,705	387,675	403,902	405,456	416,449	19,745	19,425	18,892	18,306	17,560	16,813	15,907	15,001	9,968	4,851
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**11,221,396**	**427,409**	**457,380**	**479,350**	**495,577**	**497,132**	**508,125**	**111,421**	**111,101**	**110,568**	**109,981**	**109,235**	**108,489**	**103,113**	**1,823,209**	**1,820,653**	**3,833,841**

Appendix E6: Preferred Afforestation Integration Level – Case Two (years zero to 25)

PERMANENT AFFORESTATION **WHOLE FARM**

Project Area ha 442.5 30 No. of Plots 135.8 Total Afforested Area (ha)

0% % of Pastoral Emissions Liable for

Case Study Two	Total	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Forest area (ha)		0.0	69.9	86.4	102.9	119.4	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8
Area planted (ha)		0.0	69.9	16.5	16.5	16.5	16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Farm Area (ha)		306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6
Land Cost																											
Purchase Land Value - Forestry	836,218	836,218																									
Purchase Land Value - Pastoral	2,844,023	2,844,023																									
Operation Costs																											
P. rad	300,920	18,989	94,211	8,795	2,669	2,669	2,669	2,669	2,669	2,669	2,669	53,485	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	868,928	5,867	73,682	126,093	127,086	128,080	123,206	56,385	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**4,850,088**	**3,705,097**	**167,894**	**134,888**	**129,755**	**130,749**	**125,875**	**59,053**	**7,637**	**7,637**	**7,637**	**58,453**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**
Revenue																											
1BT Funding																											
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding																											
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	187,966	96,679	22,822	22,822	22,822	22,822	-	-	-	-	-																
Terminal Land Value - Afforested Land	338,010																										
Terminal Land Value - Waste Forestry Land	- 0																										
Terminal Land Value - Pastoral	2,844,023																										
Net Retained Pastoral Income	12,710,342	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	348,543	-	-	-	-	-	17	150	601	1,783	4,455	8,083	11,876	15,366	17,821	18,555	18,555	18,555	18,555	18,555	18,555	18,555	18,555	18,555	18,555	18,555	18,555
P. rad Harvest	-																										
Total Revenue	**16,428,883**	**327,776**	**253,919**	**253,919**	**253,919**	**253,919**	**231,114**	**231,247**	**231,698**	**232,880**	**235,552**	**239,180**	**242,973**	**246,463**	**248,918**	**249,653**	**249,653**	**249,653**	**249,653**	**249,653**	**249,653**	**249,653**	**249,653**	**249,653**	**249,653**	**249,653**	**249,653**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**11,578,795**	**- 3,377,321**	**86,025**	**119,031**	**124,164**	**123,170**	**105,239**	**172,194**	**224,061**	**225,243**	**227,915**	**180,727**	**235,336**	**238,826**	**241,281**	**242,016**	**242,016**	**242,016**	**242,016**	**242,016**	**242,016**	**242,016**	**242,016**	**242,016**	**242,016**	**242,016**	**242,016**
ETS Operation Costs																											
FMA Plots	49,500	-	-	-	4,500	-	-	-	-	4,500	-	-	-	-	4,500	-	-	-	-	4,500	-	-	-	-	4,500	-	-
Annual	67,924	-	699	864	1,029	1,194	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358
ETS Revenue																											
Carbon Price	$ 35.00																										
Carbon Sequestration (t CO2/ha)																											
P. rad	71,794	-	27	133	320	1,334	1,975	2,242	2,242	1,601	641	694	1,228	1,441	1,655	1,815	1,922	1,975	2,028	1,975	1,975	1,975	1,868	1,868	1,761	1,655	1,655
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	26,670	-	10	20	41	76	129	190	269	355	445	534	622	706	783	853	912	962	998	1,024	1,039	1,042	1,036	1,019	995	963	929
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue																											
P. rad	2,512,786	-	934	4,671	11,209	46,706	69,125	78,466	78,466	56,047	22,419	24,287	42,970	50,443	57,916	63,520	67,257	69,125	70,993	69,125	69,125	69,125	65,388	65,388	61,652	57,916	57,916
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	933,465	-	346	693	1,443	2,655	4,503	6,639	9,410	12,412	15,587	18,704	21,764	24,708	27,421	29,845	31,924	33,656	34,926	35,849	36,369	36,484	36,253	35,676	34,810	33,713	32,501
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue	3,446,251	-	1,280	5,363	12,653	49,362	73,628	85,105	87,876	68,459	38,006	42,991	64,733	75,150	85,336	93,366	99,180	102,780	105,919	104,974	105,494	105,609	101,642	101,065	96,462	91,629	90,416
Liability Created from Pastoral Enterprises																											
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position	98,464	-	37	153	362	1,410	2,104	2,432	2,511	1,956	1,086	1,228	1,850	2,147	2,438	2,668	2,834	2,937	3,026	2,999	3,014	3,017	2,904	2,888	2,756	2,618	2,583
Net Carbon Revenue	3,328,827	-	582	4,500	7,124	48,168	72,269	83,746	86,517	62,600	36,647	41,633	63,375	73,792	79,478	92,007	97,822	101,422	104,560	99,116	104,135	104,251	100,283	99,706	90,604	90,270	89,058
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**14,907,622**	**- 3,377,321**	**86,607**	**123,531**	**131,288**	**171,338**	**177,508**	**255,940**	**310,579**	**287,844**	**264,562**	**222,359**	**298,710**	**312,618**	**320,759**	**334,023**	**339,838**	**343,438**	**346,576**	**341,131**	**346,151**	**346,266**	**342,299**	**341,722**	**332,619**	**332,286**	**331,074**
AVERAGE NET CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**$ 613**																										

IRR OF PROJECT:		**TREE CROP, GRAZING & HONEY ONLY**	**5.84%**	**TREE CROP, GRAZING, HONEY & CARBON**	**7.44%**
NPV OF PROJECT: $/HA	**5%**	**TREE CROP, GRAZING & HONEY ONLY**	**$2,084**	**TREE CROP, GRAZING, HONEY & CARBON**	**$4,916**
NPV OF PROJECT: TOTAL $		**TREE CROP, GRAZING & HONEY ONLY**	**$922,195**	**TREE CROP, GRAZING, HONEY & CARBON**	**$2,175,260**

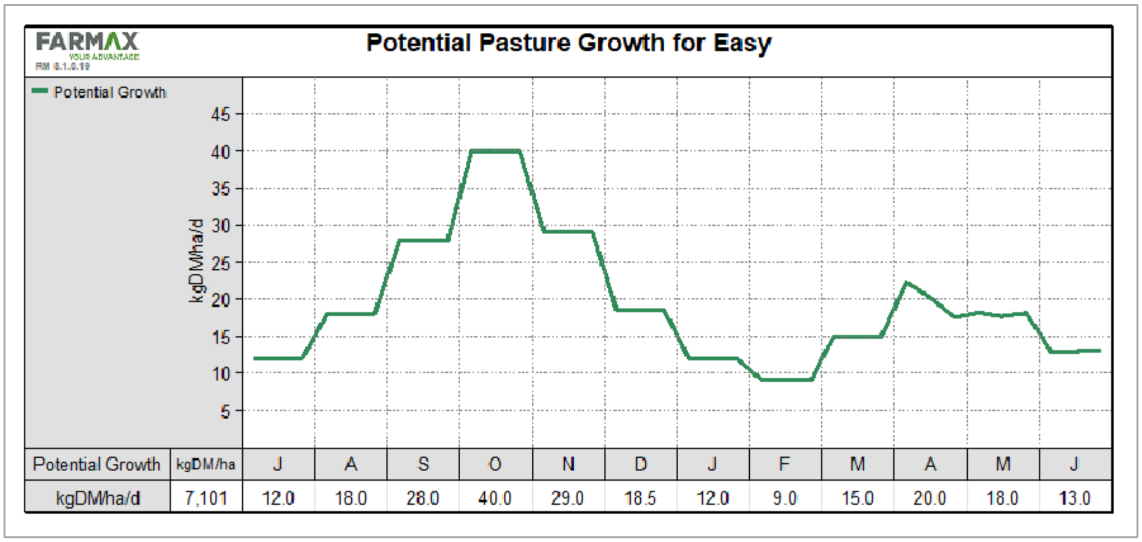
Appendix E6 (continued): Preferred Afforestation Integration Level – Case Two (years 26 to 50)

PERMANENT AFFORESTATION	**WHOLE FARM**
Project Area ha	442.5

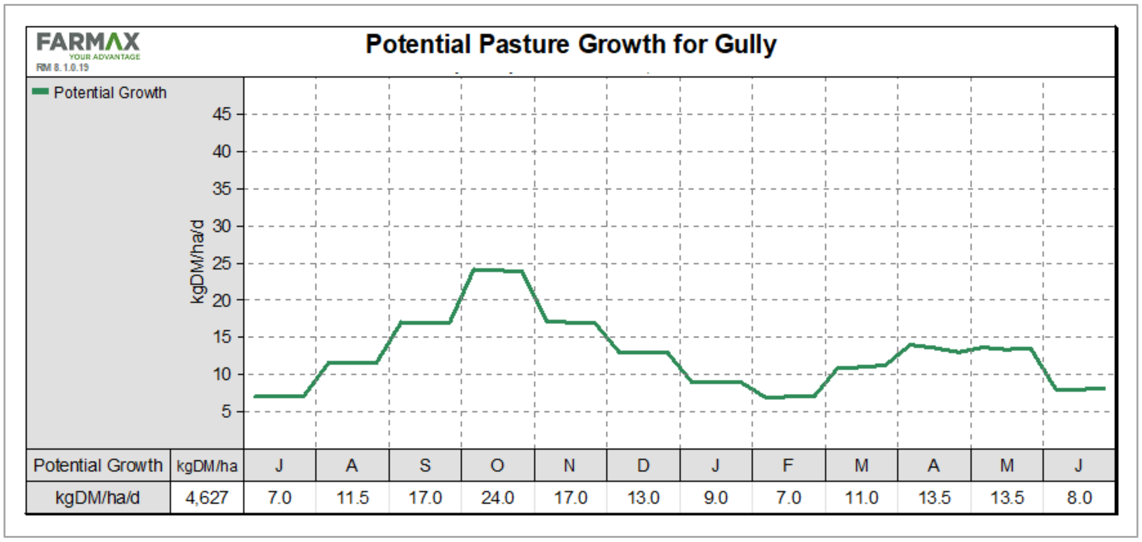
Case Study Two	Total	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Forest area (ha)		135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	135.8	66.0	49.5	33.0	16.5
Area planted (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Area clearfelled (ha)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	69.9	16.5	16.5	16.5
Farm Area (ha)		306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6	306.6
Land Cost																														
Purchase Land Value - Forestry	836,218																													
Purchase Land Value - Pastoral	2,844,023																													
Operation Costs																														
P. rad	300,920	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	2,669	-	-	-	-
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	868,928	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	4,968	3,974	2,981	1,987	994
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Expenditure	**4,850,088**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**7,637**	**3,974**	**2,981**	**1,987**	**994**
Revenue																														
1BT Funding																														
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HBRC Funding																														
Establishment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maturity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Livestock Sales	187,966																													
Terminal Land Value - Afforested Land	338,010																									132,814	-	-	-	205,196
Terminal Land Value - Waste Forestry Land	- 0																									- 0	-	-	-	- 0
Terminal Land Value - Pastoral	2,844,023																									-	-	-	-	2,844,023
Net Retained Pastoral Income	12,710,342	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097	231,097
Net Grazing - Intensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Grazing - Extensive Poplars	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manuka Honey	348,543	17,821	16,049	13,093	9,092	5,212	2,405	898	267	91	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	30	17	7	2
P. rad Harvest	-																									-	-	-	-	-
Total Revenue	**16,428,883**	**248,918**	**247,146**	**244,190**	**240,189**	**236,309**	**233,502**	**231,995**	**231,364**	**231,188**	**231,144**	**231,144**	**231,144**	**231,144**	**231,144**	**231,144**	**231,144**	**231,144**	**231,144**	**231,144**	**231,144**	**231,144**	**231,144**	**231,144**	**231,144**	**363,958**	**231,127**	**231,114**	**231,105**	**3,280,317**
NET PRE TAX CASHFLOW (TREE CROP, GRAZING & MANUKA HONEY ONLY)	**11,578,795**	**241,281**	**239,509**	**236,553**	**232,552**	**228,672**	**225,865**	**224,358**	**223,727**	**223,551**	**223,507**	**223,507**	**223,507**	**223,507**	**223,507**	**223,507**	**223,507**	**223,507**	**223,507**	**223,507**	**223,507**	**223,507**	**223,507**	**223,507**	**223,507**	**356,321**	**227,152**	**228,133**	**229,117**	**3,279,324**
ETS Operation Costs																														
FMA Plots	49,500	-	-	4,500	-	-	-	-	4,500	-	-	-	-	4,500	-	-	-	-	4,500	-	-	-	-	4,500	-	-	-	-	4,500	-
Annual	67,924	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	1,358	660	495	330	165
ETS Revenue																														
Carbon Price	$ 35.00																													
Carbon Sequestration (t CO2/ha)																														
P. rad	71,794	1,548	1,495	1,495	1,495	1,441	1,388	1,334	1,388	1,281	1,334	1,281	1,281	1,281	1,228	1,281	1,281	1,228	1,281	1,281	1,334	1,334	1,334	1,334	1,441	1,388	-	-	-	-
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	26,670	886	843	797	749	701	655	609	562	520	478	439	402	369	336	307	279	254	229	209	188	172	153	140	125	114	86	61	38	18
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Sequestration Revenue																														
P. rad	2,512,786	54,179	52,311	52,311	52,311	50,443	48,574	46,706	48,574	44,838	46,706	44,838	44,838	44,838	42,970	44,838	44,838	42,970	44,838	44,838	46,706	46,706	46,706	46,706	50,443	48,574	-	-	-	-
Poplars - Intensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poplars - Extensive	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Native - Manuka	933,465	31,000	29,499	27,883	26,209	24,534	22,918	21,302	19,685	18,184	16,741	15,356	14,086	12,931	11,777	10,737	9,756	8,890	8,024	7,331	6,581	6,004	5,369	4,907	4,387	3,983	3,002	2,136	1,328	635
Native - Mix	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon Sequestration Revenue	3,446,251	85,179	81,810	80,193	78,519	74,977	71,492	68,008	68,260	63,022	63,447	60,194	58,923	57,769	54,746	55,575	54,594	51,860	52,862	52,169	53,287	52,710	52,075	51,613	54,830	52,558	3,002	2,136	1,328	635
Liability Created from Pastoral Enterprises																														
Pastoral CO2 equivalents (t/year)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pastoral Emissions Liability @ 0.00%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net NZU Position	98,464	2,434	2,337	2,291	2,243	2,142	2,043	1,943	1,950	1,801	1,813	1,720	1,684	1,651	1,564	1,588	1,560	1,482	1,510	1,491	1,522	1,506	1,488	1,475	1,567	1,502	86	61	38	18
Net Carbon Revenue	3,328,827	83,821	80,451	74,335	77,161	73,619	70,134	66,649	62,401	61,664	62,089	58,835	57,565	51,910	53,388	54,217	53,235	50,501	47,004	50,811	51,929	51,351	50,716	45,754	53,471	51,199	2,342	1,641	- 3,502	470
NET PRE TAX CASHFLOW (TREE CROP, GRAZING, HONEY & CARBON)	**14,907,622**	**325,101**	**319,960**	**310,888**	**309,713**	**302,291**	**295,999**	**291,008**	**286,129**	**285,215**	**285,595**	**282,342**	**281,072**	**275,417**	**276,894**	**277,723**	**276,742**	**274,008**	**270,510**	**274,317**	**275,435**	**274,858**	**274,223**	**269,261**	**276,978**	**407,520**	**229,495**	**229,774**	**225,615**	**3,279,794**

Appendix F: Farmax Pasture Growth Rates

Appendix F1: Pasture Growth Rates for Case One

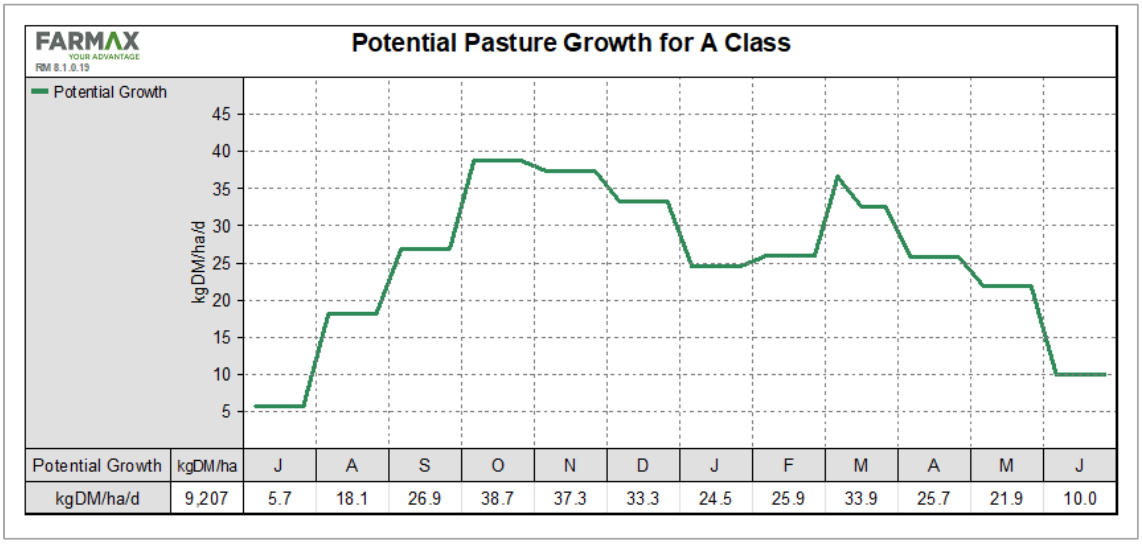


Potential Growth	kgDM/ha	J	A	S	O	N	D	J	F	M	A	M	J
kgDM/ha/d	7,101	12.0	18.0	28.0	40.0	29.0	18.5	12.0	9.0	15.0	20.0	18.0	13.0

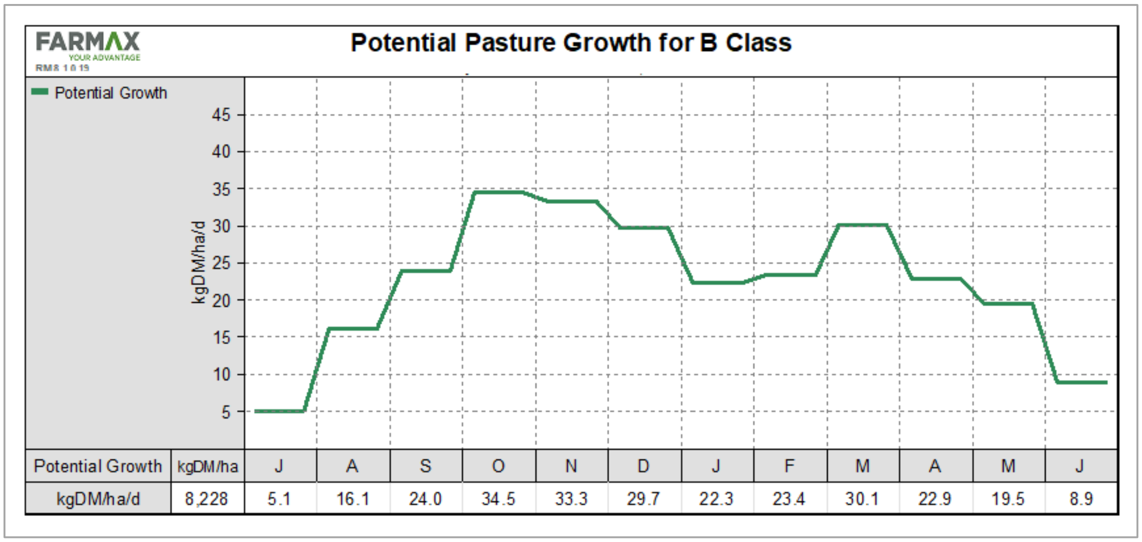


Potential Growth	kgDM/ha	J	A	S	O	N	D	J	F	M	A	M	J
kgDM/ha/d	4,627	7.0	11.5	17.0	24.0	17.0	13.0	9.0	7.0	11.0	13.5	13.5	8.0

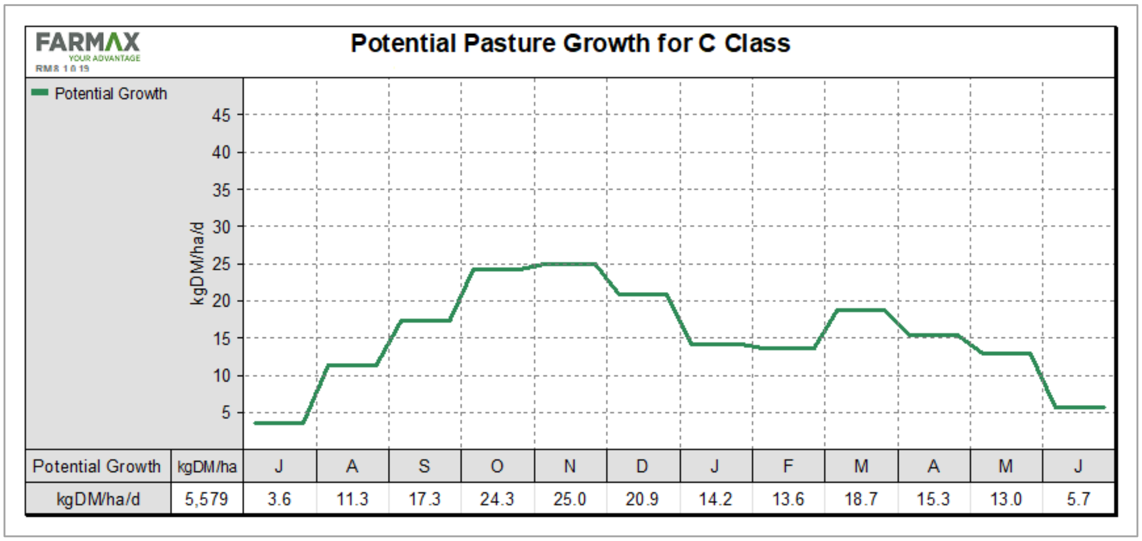
Appendix F2: Pasture Growth Rates for Case Two



Potential Growth	kgDM/ha	J	A	S	O	N	D	J	F	M	A	M	J
kgDM/ha/d	9,207	5.7	18.1	26.9	38.7	37.3	33.3	24.5	25.9	33.9	25.7	21.9	10.0



Potential Growth	kgDM/ha	J	A	S	O	N	D	J	F	M	A	M	J
kgDM/ha/d	8,228	5.1	16.1	24.0	34.5	33.3	29.7	22.3	23.4	30.1	22.9	19.5	8.9



Potential Growth	kgDM/ha	J	A	S	O	N	D	J	F	M	A	M	J
kgDM/ha/d	5,579	3.6	11.3	17.3	24.3	25.0	20.9	14.2	13.6	18.7	15.3	13.0	5.7