Net emissions and removals from vegetation and soils on sheep and beef farmland

Ministry for the Environment
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Summary

1. There is an increasing amount of interest in understanding how to recognise and encourage carbon sequestration on farmland. To do this effectively, an accurate and comprehensive estimate of net emissions and removals from vegetation and soils on farmland is required.
2. This report estimates the net emissions and removals from vegetation and soils on New Zealand sheep and beef farmland, using methods consistent with New Zealand's Greenhouse Gas Inventory (MfE, 2020) and the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines for reporting (IPCC, 2006b).
3. Woody vegetation and drained organic soils on sheep and beef farms are estimated to be a net sink, removing **5487 kt CO_2-e** from the atmosphere in 2018.
4. Carbon dioxide (CO_2) removals were driven by large areas of natural (indigenous) forest and planted (exotic) forests. Emissions from vegetation were driven by deforestation and harvesting of planted forests. The overall net removals from existing vegetation on sheep and beef farms are projected to decrease over the next decade as the harvesting of planted forests increases.
5. A recent report prepared by Auckland University of Technology, funded by Beef + Lamb New Zealand, estimated woody vegetation on sheep and beef farms may be removing between **10,394 kt CO_2-e** and **19,655 kt CO_2-e** per year, suggested to be offsetting **63 to 118** per cent of the gross agricultural emissions from this sector (Case and Ryan, 2020).
6. In contrast, the findings of this present report indicate net carbon dioxide removals are **63 per cent** lower than the midpoint estimate of Case and Ryan (2020), equivalent to **33 per cent** of the on-farm agricultural emissions.
7. These lower net carbon dioxide removals are mainly due to the inclusion of emissions from forest harvest, scrub clearance and deforestation, and the application of more appropriate sequestration rates for natural forest and scrub/shrub classes which better reflect vegetation age and management practices.
8. This present report provides a robust and up-to-date estimate of net carbon dioxide removals occurring on sheep and beef farmland. Future research could focus on improving the methods to estimate carbon stock change in vegetation and soils on farmland, and identify where sequestration could be increased.

Net emissions, removals and carbon sequestration

The terms net emissions, removals and carbon sequestration describe how greenhouse gases may be increasing or decreasing in the atmosphere. They are expressed as carbon dioxide equivalents (CO_2-e).

An **emission** represents a release of CO_2-e to the atmosphere. This can be due to a loss of carbon in vegetation or soil, for example through respiration, decay or burning.

A **removal** represents a withdrawal of carbon dioxide from the atmosphere, usually due to an increase in carbon stored in vegetation or soil.

Net emissions represent the overall sum of emissions and removals occurring, expressed as CO_2-e. This includes carbon gains from vegetation growth; carbon losses due to harvesting, vegetation clearance, and deforestation; and carbon gains and losses in soils.

Carbon sequestration is the process of capturing and storing carbon dioxide. Usually, this refers to increasing carbon stocks in vegetation or soil. It represents a removal from the atmosphere.

Gross sequestration, in the context of this report, refers to the carbon sequestration that occurs before human-induced losses are accounted for (ie, excludes the emissions from harvesting and deforestation).

Net sequestration refers to carbon sequestration that includes all sources and sinks. It is the overall net change in carbon from the land. Net sequestration is the standard approach to measure and report net CO_2-e removals from the atmosphere.

Harvesting, deforestation and clearance of vegetation

Harvesting refers to the harvest of planted production forests for timber, which are then replanted.

Deforestation occurs when forest land is cleared for another land use.

Clearance of vegetation, in this report, refers to land use change from grassland with woody biomass to a new land use (usually pasture). It involves the removal of the existing woody vegetation. Note that the partial removal of vegetation, which does not result in a detected land use change, is not included in this definition.

Introduction

The purpose of this report is to estimate the net emissions and removals from woody vegetation and drained organic soils occurring on sheep and beef farmland in New Zealand. The approach takes into account carbon gains and losses, and applies measurement principles consistent with New Zealand's Greenhouse Gas Inventory (MfE, 2020) and the Intergovernmental Panel on Climate Change (IPCC) guidelines for reporting (IPCC, 2006a).

In September 2020, Auckland University of Technology (AUT) published 'An analysis of carbon stocks and net carbon position for New Zealand sheep and beef farmland' (Case and Ryan, 2020). This study assesses the carbon stocks, carbon sequestration and net emissions on sheep and beef farms. It takes a spatial approach using existing map data to identify vegetation types on this farmland across New Zealand. Various data sources were then compiled to derive estimates of carbon stocks and stock change (ie, carbon sequestration) for these vegetation types.

This provided:

- an assessment of vegetation carbon stocks, the vegetation types they are stored in, and their distribution across New Zealand
- an estimate of the overall carbon sequestration occurring on sheep and beef farmland.

A key finding was that woody vegetation on these farms may be removing between 10,394 kt CO_2-e and 19,655 kt CO_2-e per year. These removals were compared to the gross emissions from agriculture, leading to suggestions that sheep and beef farmland may already be close to carbon neutral (Beef + Lamb, 2020).

Case and Ryan (2020) take a promising approach to developing a sector-based estimate of the vegetation area and carbon stocks. However, there are some fundamental limitations in how the estimates of carbon sequestration were derived. As a result, the net removals have been overestimated (for both the upper and lower estimates in their report).

The main reasons for these overestimations are:

- excluding carbon losses from clearing vegetation, such as forest harvesting, deforestation and scrub clearance
- using inconsistent or inappropriate emissions factors for some types of vegetation
- not considering vegetation age, or that the further growth of much on-farm scrub and shrubland is likely to be constrained by management or environmental factors
- excluding emissions from soils.

For more details, see the appendix.

Recognising sequestration

The He Waka Eke Noa primary sector climate action partnership between government, industry and iwi/Māori was agreed in 2019, with a focus on collaborating to reduce primary sector emissions. One of the goals is to explore how to recognise on-farm sequestration (He Waka Eke Noa, 2020).

Understanding the magnitude of net sequestration on farmland, and how we may recognise this in the context of reducing overall emissions, has sparked much interest in sector-based on-farm net emissions estimates, such as in Case and Ryan (2020).

Effectively informing policy on how to recognise sequestration requires an accurate and comprehensive estimate of net emissions and removals from vegetation and soils on farmland. Such estimates should ideally use approaches consistent with those used for New Zealand's national emissions (MfE, 2020), in order to draw like-for-like comparisons and identify areas of improvement.

Estimating net emissions and removals

Net emissions from vegetation and soils are reported each year in the land use, land use change and forestry sector (LULUCF) of New Zealand's Greenhouse Gas Inventory (MfE, 2020). Net emissions from New Zealand's LULUCF sector are estimated by mapping land use and land use change, and then determining the net emissions and removals associated with each activity. This approach is underpinned by wall-to-wall spatial mapping of all land uses at a national scale. It is possible to intersect this information with other spatial data on land use, management or ownership. This can allow for an estimate of net emissions and removals from the land for a specific sector, such as sheep and beef farming, that is consistent in approach with New Zealand's national estimate for the LULUCF sector.

This report aims to estimate the net emissions and removals from woody vegetation and drained organic soils occurring on sheep and beef farms in New Zealand. Using approaches consistent with New Zealand's Greenhouse Gas Inventory (MfE, 2020) it is possible to determine a robust and comprehensive estimate.

Methods

Determining vegetation area

We assessed the area of woody vegetation, vegetation clearance and vegetation age, by intersecting land classed as sheep and beef farmland using AgriBase™ (AsureQuality, 2019), the land cover database (LCDBv5) and the Land Use and Carbon Analysis System (LUCAS) land use map (LUCAS LUM 2016 v8).

The area of sheep and beef farmland was determined as the area of land classified as 'beef cattle farming', 'sheep farming', and 'mixed sheep and beef farming' in AgriBase™. The total estimate was 10.4 million hectares (ha), slightly higher than the 10.2 million hectares estimated in Case and Ryan (2020). The categories for classifying the farmland from AgriBase™ were not specified in Case and Ryan (2020).

We used the LUCAS LUM 2016 v8 to assign the area and area change (ie, deforestation) of woody vegetation land use classes. The 2016 map year was used to determine the area of each land use class present on the farms. This was combined with previous map years (1990, 2007, 2012), to determine how the age and clearance of vegetation has changed through time.

We favoured the LUCAS LUM classes over the LCDB classes to estimate carbon stock and stock change, as the LUCAS LUM was created specifically for this purpose. The land use classes consider age and management activity which are expected to influence the carbon stock and stock change of key vegetation types. Consequently, it is possible to obtain more accurate and robust estimates of net carbon emissions and removals that are representative of each land use class. The LUCAS land use classes are also consistent with New Zealand's national reporting obligations and accounting for emissions reduction targets, as well as domestic climate change policy.

Estimating carbon stock change

The area of each land use and land use change category from LUCAS LUM 2016 v8 was assigned an emission factor, associated with that land use type. Emissions factors in the LULUCF sector are used to represent the net emissions or removals per unit area of land. Emissions factors can represent the rate of sequestration per unit area, expressed as t CO_2-e ha^{-1} $year^{-1}$. These methods and carbon accounting principles are consistent with the IPCC guidelines for greenhouse gas measurement and reporting (IPCC, 2006b).

We estimated an average emissions factor for each land use type and associated activity, using either:

- a bespoke, plot-based estimate for vegetation on the farmland (for pre-1990 natural forest), or
- data from New Zealand's 1990–2018 Greenhouse Gas Inventory (MfE, 2020).

Each emissions factor was then applied to the area of a given land use type, to estimate total net emissions and removals.

This approach enables estimates of net emissions and removals to be consistent with New Zealand's national estimate (MfE, 2020). As there are no nationally representative estimates of carbon stock and stock change for vegetation on sheep and beef farmland, assuming similar values to those used at the national level was considered the most viable approach. The emissions factors used in New Zealand's Greenhouse Gas Inventory undergo robust quality assurance and represent the best current available estimate for each land use category (MfE, 2020). They are continually updated as the data improves or as changes are detected through time.

Classifying woody vegetation

The LUCAS LUM has three main categories for woody vegetation:

- natural forest (pre-1990 and post-1989)
- planted forest (pre-1990 and post-1989)
- grassland with woody biomass.

Forest land

Forests are divided into:

- forest land before 31 January 1990 (pre-1990)
- those which became forest after this date (post-1989).

This split allows for a comparison of new and existing forests to a 1990 base year (determining how these forests will be treated in international target accounting and domestic policies). It also gives more accurate estimates of carbon stock and stock change, specific to each of these strata.

To be classed as forest land, mapped areas of woody vegetation must meet these criteria:

- have at least 30 per cent woody vegetation cover
- be at least 1 hectare in size, and 30 metres wide
- have the potential to reach 5 metres in height in 30 to 40 years under current land management.

Grassland with woody biomass

This consists of land covered by woody vegetation that does not meet the forest definition and is not expected to do so under current ecological, management or environmental conditions.

This vegetation type may not meet the forest definition because it is already growing at its environmental limits, or biotic pressure such as grazing may be preventing the successful transition into forest.

Natural forest

Carbon dioxide removals from biomass in **pre-1990 natural forest** were derived from the LUCAS natural forest plot network and plot level carbon stock change calculations from Paul et al (2019a). To determine the natural forest plots on sheep and beef farmland, the LUCAS network was intersected with land classified as sheep and beef farmland in AgriBase^{TM}. The carbon stock change estimate for these plots was taken from the plot level calculations from the analysis in Paul et al (2019a). This gave 120 pre-1990 natural forest plots, with at least one measurement to calculate carbon stock and stock change. The average carbon stock change of these 120 plots was used to determine an emissions factor for pre-1990 natural forest on sheep and beef farmland.

Biomass removals from **post-1989 natural forest** were estimated as the average net removals per hectare occurring on this forest type across all New Zealand in 2018. This was calculated using estimates of carbon stocks and yield table values for post-1989 natural forest (Beets et al, 2014), combined with forest age to determine net emissions per year.

Subdividing natural forests into pre-1990 and post-1989 strata allows for a more accurate representation of the successional stage of each forest type, and a more accurate rate of sequestration. Younger, early successional forests tend to sequester carbon at a faster rate than older forests (Carswell et al, 2012). For reporting purposes, the post-1989 natural forest area was divided into further categories of wildling pines and natural regenerating forest. These were both assigned the same sequestration rate.

Grassland with woody biomass

Grassland with woody biomass was divided into two subcategories based on age since establishment. This is to reflect that land recently converted to this category is considered to result in sequestration up to the long-term average carbon stock. Land that has remained grassland with woody biomass, without transitioning into forest, is assumed to have its further growth limited by the environment (eg, altitude) or management (eg, grazing) and therefore not sequestering any additional carbon. The classifications were:

- **in transition:** land mapped as grassland with woody biomass in 2016 that had been newly established since 1990
- **steady:** land classed as grassland with woody biomass in 1990 that remained in that class in 2016.

This assumes a 26-year transition based on map years, similar to the 28-year transition used in the greenhouse gas inventory (MfE, 2020).

Grassland with woody biomass in transition was considered to be sequestering carbon over a 28-year period, starting at the carbon stock value for low-producing grassland (2.87 t C ha^{-1}) up to an average carbon stock value of 13.05 t C ha^{-1} (Wakelin and Beets, 2013).

Steady grassland with woody biomass (existing for more than 26 years) was assumed to not be sequestering any additional carbon. This approach assumes a linear increase in carbon after vegetation is established, up to the national average carbon stock. Any other fluctuations in carbon stocks (eg, burning or clearance resulting in the loss and subsequent regrowth of vegetation) result in no long-term net change in carbon and are therefore not included.

If areas of scrub are expected to transition into forest (under current management or environmental factors), they are reported in the forest category with the corresponding rate of sequestration.

Planted forest

Carbon dioxide removals from forest growth and emissions from harvesting in **pre-1990** and **post-1989 planted forest** were estimated by pro-rating the net emissions and removals per hectare for all of New Zealand's planted forest (MfE, 2020), to the area of that forest type on sheep and beef farmland. Removals from forest growth include the net increase in carbon stocks as the forest grows. Emissions from harvesting include carbon losses from timber removed at the time of harvest and the subsequent losses from deadwood decay.

This approach assumes that the management, age profile and harvesting activity for these forest types on sheep and beef farmland is equivalent to New Zealand's national estimate. An advantage of this approach is that planted forest can be divided into the two strata with different age profiles (pre-1990 and post-1989).

Accounting for the age and expected harvesting of planted forest allows for a more accurate point-in-time estimate of net emissions from planted forests, and a more accurate projection of what future emissions may look like. This approach also accounts for the emissions from decaying deadwood from previous harvesting.

To validate the approach, we compared the modelled harvest area estimate (based on New Zealand's national activity data from MfE (2020)) to the harvest area detected on sheep and beef farmland in the LUCAS LUM for the 2016 map year (LUCAS LUM 2016 v8).

Pre-1990 and **post-1989 planted forests** were further split into two subcategories:

- **Production forest** (also known as net-stocked area)
- **Non-production forest** – representing unstocked skid sites and older riparian forests, which are not considered to contribute to additional sequestration.

For both these forest types, carbon sequestration is estimated from plot-based samples from New Zealand's national forest inventory. This is then used to create yield tables representative of pre-1990 (Paul et al, 2016) and post-1989 planted forest (Paul et al, 2019b).

Deforestation and clearance of grassland with woody biomass

The area of **deforestation** and **clearance of grassland with woody biomass** for 2018 was estimated from the average annual land use change for each category between 2013 and 2016 (as detected in the LUCAS LUM (LUCAS LUM 2016 v8)) and projected to 2018. This yearly estimate was then multiplied by an emissions factor.

The emissions factor for each forest type was estimated as the average emissions per hectare associated with the deforestation of that forest type in 2018 (MfE, 2020).

The emissions factor for the clearance of grassland with woody biomass was estimated from the carbon stock change per hectare for the conversion of grassland with woody biomass (13.05 t C ha^{-1}) into low-producing grassland (2.87 t C ha^{-1}). Non-CO_2 emissions from vegetation burning, such as controlled burning to clear scrub or forest wildfires, were not included. There is limited data to assign this activity to sheep and beef farmland, and these emissions only contribute a relatively small amount to New Zealand's national emissions estimate (MfE, 2020).

Drained organic soils

Emissions from **drained organic soils** were estimated for the area of organic soils occurring on grassland. Total emissions were calculated by applying the emissions factors for areas in each climate zone, as specified in the IPCC guidelines (IPCC, 2006b).

Uncertainty

The uncertainty estimate for the emissions factor and area for each land use was determined from the estimates used in New Zealand's Greenhouse Gas Inventory (MfE, 2020). A further adjustment was made to these uncertainties to account for scaling this estimate to sheep and beef farms. The uncertainty in the emissions factors and area for each land use was combined using the approaches outlined for error propagation in the IPCC guidelines (IPCC, 2006b). In this report, the uncertainty represents the 95 per cent confidence interval, expressed as a percentage.

Emissions projections for planted forests

The projected future emissions from planted forests on sheep and beef farmland were estimated by determining the net emissions per hectare for post-1989 and pre-1990 planted forests (MPI, 2020). The net emissions per hectare were then applied to the area of pre-1990 and post-1989 planted production forest present on sheep and beef land in 2016. This gives some insight into the year-to-year variation in net emissions from existing planted forests, and how they may be expected to change over the next decade.

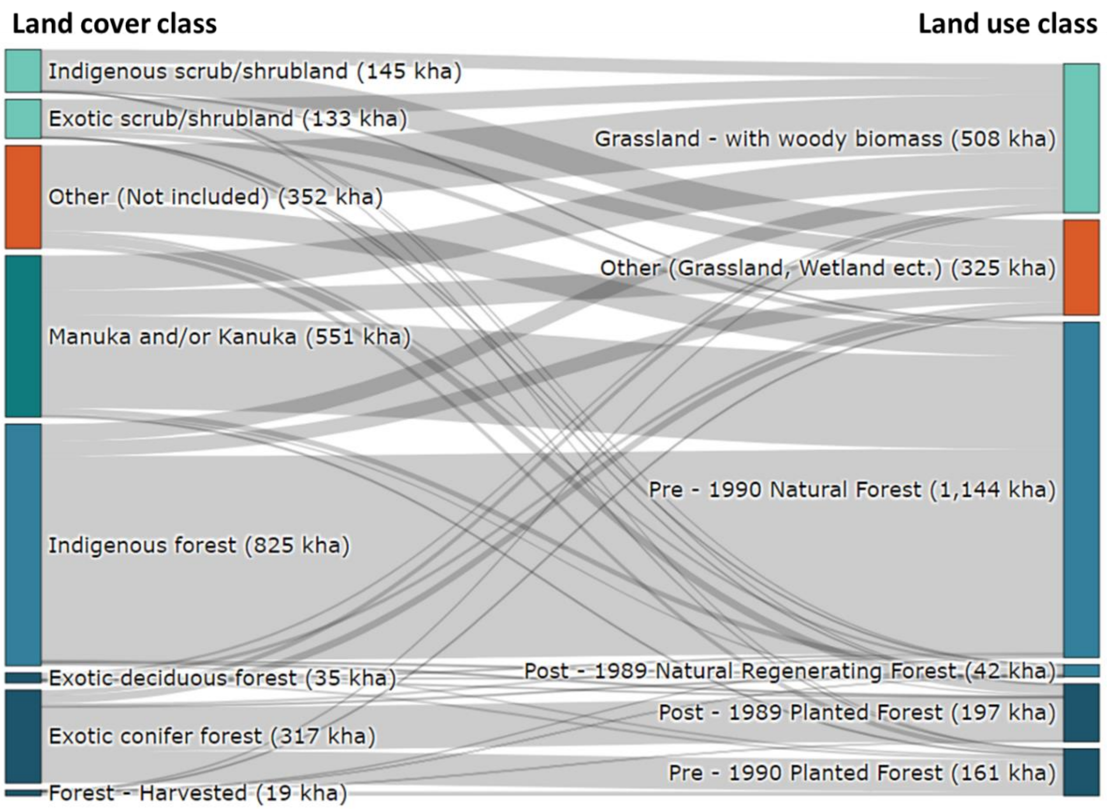
Results

A total area of 2056 kilohectares (kha) of woody vegetation is included in the assessment of biomass removals from mapped land use classes in this report. This is slightly higher (by 1.4 per cent) than the 2028 kilohectares of land cover with woody vegetation used in Case and Ryan (2020).

Figure 1 shows the concordance in area between the land cover classes used in Case and Ryan (2020) and the land use classes used in this report, as at 2012. The 2012 map year is used to show this concordance because it is used in Case and Ryan. A 2012 map is available for both the LUM and LCDB, allowing for a more accurate comparison.

The area estimate for woody vegetation on sheep and beef farmland in this report uses the 2016 map year in the LUM (LUCAS LUM 2016 v8), the most recent mapping data available.

Figure 1: The concordance of area between the land cover classes used in Case and Ryan (2020, derived from LCDB v. 4.1) and the land use classes (derived from LUCAS LUM 2016 v8) used in this report (as at the 2012 map year)



Note: The height of the bars are proportional to the land use or land cover area (kha). The orange bars represent land cover or land use classes that were not included in these analyses.

Using the methods outlined above, net removals on sheep and beef farmland are estimated to be 5487 kt CO_2-e in 2018 (table 1). This net figure is calculated as the difference between 12,623 kt CO_2-e of biomass removals and 7137 kt CO_2-e of emissions from biomass and drained organic soils.

Table 1: Net emissions and removals from vegetation biomass and organic soils on sheep and beef farmland in 2018

Land use	Land use subcategory	Area (ha)	Mean emission factor (t CO_2-e ha^{-1} yr^{-1})	Emissions (kt CO_2-e)	Uncertainty (%)	Source
Biomass removals						
Pre-1990 natural forest		1,143,088	–1.57	–1,796	68	This report (derived from Paul et al, 2019a)
Post-89 natural forest	Wilding pines	8,540	–7.75	–66	37	MfE, 2020; Beets et al, 2014
	Natural regenerating	38,346	–7.75	–297	37	MfE, 2020; Beets et al, 2014
Grassland with woody biomass	In transition	61,520	–1.33	–82	112	MfE, 2020; Wakelin & Beets, 2013
	Steady	439,293	0	0	112	MfE, 2020; Wakelin & Beets, 2013
Pre-1990 planted forest	Production forest	131,914	–28.81	–3,801	24	MfE, 2020; Paul et al, 2016
	Non-production forest	24,927	0	0	–	MfE, 2020; Paul et al, 2016
Post-89 planted forest	Production forest	182,070	–36.15	–6,582	25	MfE, 2020; Paul et al, 2019b
	Non-production forest	26,280	0	0	–	MfE, 2020; Paul et al, 2019b
Total				**–12,623**	18	
Biomass emissions						
Pre-1990 natural forest	Deforestation	345	548.9	189	23	MfE, 2020; Paul et al, 2019a
Post-1989 natural forest	Deforestation	61	125.2	8	26	Beets et al, 2014
Grassland with woody biomass	Scrub clearance	1,679	37.3	63	112	MfE, 2020; Wakelin & Beets, 2013
Pre-1990 planted forest	Deforestation	932	801.9	748	25	MfE, 2020; Paul et al, 2016
	Harvest	4,589	841.3	3,861	29	MfE, 2020; Paul et al, 2016
Post-1989 planted forest	Deforestation	547	433.2	237	28	MfE, 2020; Paul et al, 2019b
	Harvest	3,021	587.9	1,776	29	MfE, 2020; Paul et al, 2019b
Total				**6,882**	18	
Soils						
Drained organic soils		34,188	7.5	255	90	MfE, 2020; IPCC, 2006b
Total						
Total net emissions				**–5,487**	**47**	

Note: Net removals are expressed as a negative value, to clarify that the value is a removal of CO_2-e from the atmosphere. Columns may not total due to rounding.

Net emissions and removals

Pre-1990 natural forests on sheep and beef farmland are estimated to be removing 1796 kt CO_2-e in 2018. This figure is derived from 120 plots from the natural forest inventory, with an average sequestration rate of –1.57 t CO_2-e ha^{-1} yr^{-1}.

Post-1989 natural regenerating forest has a higher sequestration rate (–7.75 t CO_2-e ha^{-1} yr^{-1}), as it comprises younger, faster-growing trees. However, it covers a much smaller area, resulting in total removals of 297 kt CO_2-e (excluding wilding pines).

Grassland with woody biomass was identified from the LUCAS LUM as having 61,520 hectares in transition (newly established since 1990), contributing to 82 kt CO_2-e of removals. This is largely offset by the 63 kt CO_2-e of emissions from the clearance of this vegetation, taking total net removals from this category to 19 kt CO_2-e.

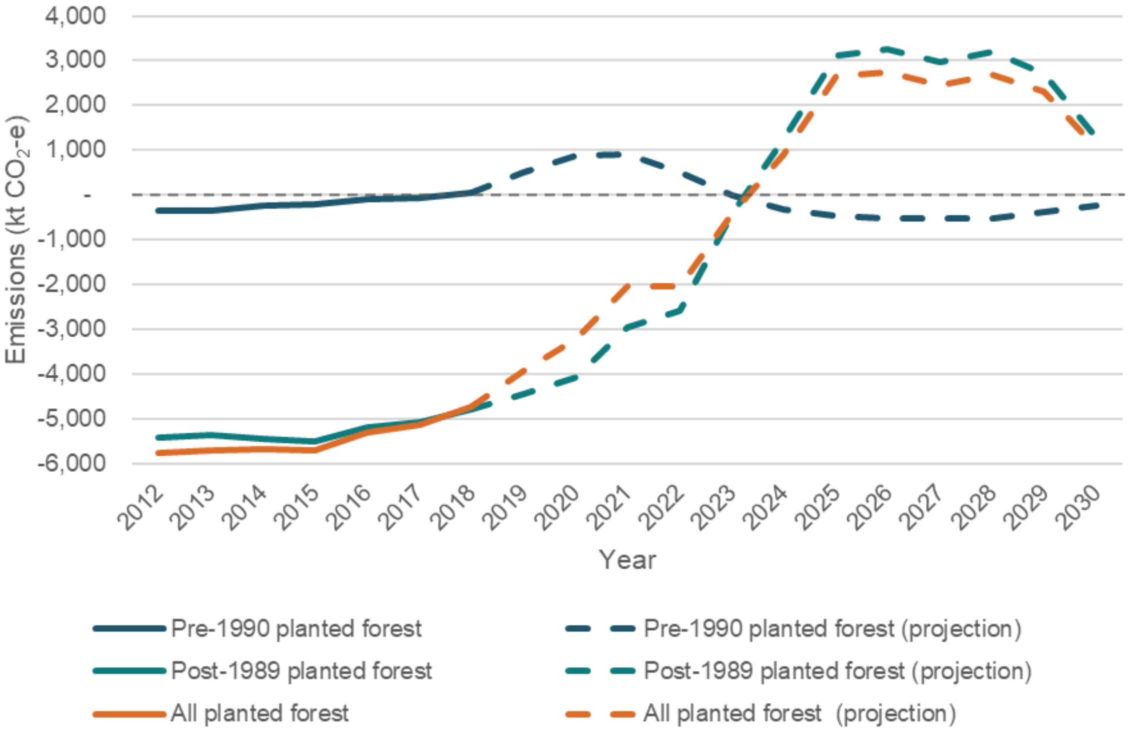
Planted forests are the largest contributor to net removals, estimated at 4744 kt CO_2-e in 2018. This is driven by the large area of **post-1989 planted forest** (with removals of 4805 kt CO_2-e) established in the 1990s. **Pre-1990 planted forests** by contrast, are estimated to be a slight net source of emissions (around 60 kt CO_2-e in 2018), because emissions from harvesting (3861 kt CO_2-e) exceed removals from forest growth (3801 kt CO_2-e).

Emissions from harvesting

Emissions from planted forests are driven by harvesting, with an estimated 7610 hectares harvested on sheep and beef farmland in 2018. This is based on pro-rating the national harvest area activity data to the area of planted forest on the farmland. When taking the same approach for 2016, the harvest area was estimated to be 6825 hectares, 19 per cent higher than the 5738 hectares detected in the LUCAS LUM in 2016. This lower estimate is still within the uncertainty range estimate for harvesting data. Furthermore, a lower rate of harvest detected in previous years suggests that there is likely to be more forest available for harvest in current and future years, resulting in increased emissions.

The large area of **post-1989 planted forest** established in the 1990s has recently started to reach harvest age. The rate of harvest is expected to rise over the next decade as more of this forest matures, resulting in an increase in net emissions (figure 2). Assuming an age profile and level of harvesting similar to all New Zealand planted forests (pre-1990 and post-1989), planted forests on sheep and beef farmland are projected to be a net source of emissions, averaging around 2000 kt CO_2-e per year from 2024 to 2030 (figure 2).

Figure 2: Projected net emissions from planted forests on sheep and beef farmland



Note: A 3-year moving average is applied to the projected net emissions to smooth out year-to-year fluctuations.

Discussion

Net emissions and removals from woody vegetation and drained organic soils on sheep and beef farmland in 2018 are estimated to be –5487 kt CO_2-e. This indicates that while sequestration is occurring, it is at a much lower rate than the estimate of –10,394 to –19,655 kt CO_2-e in Case and Ryan (2020). By including emissions from the clearance of vegetation and drained organic soils, and by using appropriate emissions factors for each vegetation type, the approach in this report gives a more accurate and comprehensive estimate of the net removals on sheep and beef farmland.

Natural forests

Natural forests on sheep and beef farmland are estimated to be removing around 2160 kt CO_2-e per year, driven mainly by the large area of natural forest existing before 1990. This report provides the first representative national estimate of carbon stock change occurring in pre-1990 natural forests on sheep and beef farmland in New Zealand.

Some granularity in forest type is lost by grouping all pre-1990 natural forests into a single category. However, by using carbon stock change estimates derived solely from plots in pre-1990 natural forests on sheep and beef farmland, we reached a more accurate sequestration estimate that is representative of this forest type. Furthermore, grouping all natural forest types into two subcategories (established before or after 1990), better captures the forest-age effects that drive sequestration rates in these strata.

Comparison of sequestration rates

The estimated rate of sequestration from pre-1990 natural forest on farmland (–1.57 t CO_2-e ha^{-1} yr^{-1}) is slightly higher than that reported for all forest outside the conservation estate (–1.48 t CO_2-e ha^{-1} yr^{-1}) in Paul et al (2019a). This suggests that the national estimate for sequestration in pre-1990 natural forests on private land could serve as a suitable proxy in the absence of other information. Both rates are lower than the mid-point estimate in Case and Ryan (2020), who use a rate for regenerating natural forest to represent all land mapped as tall indigenous forest on sheep and beef farmland.

Measurement rate of plots

Around 62 per cent of pre-1990 natural forest plots on sheep and beef farmland have had at least one plot measurement recorded in the national forest inventory (120 out of 194 plots), compared to 87 per cent for all plots across the entire pre-1990 natural forest estate. The lower measurement rate is due to lower access rates granted by landowners. This introduces additional uncertainty in the sequestration estimate for pre-1990 natural forest on the farmland. It reduces both the sample size and the representation of forest area by measured plots (62 per cent of the forest area is represented by measured plots).

Increasing the measurement rate of plots on private land would help to reduce the uncertainty in the estimated sequestration rate for this forest type. To identify ways to increase the sequestration in natural forests, research could focus on how to enhance the rate of net sequestration in pre-1990 natural forests on private land, and how to encourage the transition of scrub and shrubland into regenerating forest.

Planted forests

Planted forests are the largest contributor to net carbon dioxide removals on sheep and beef farmland, removing 4744 kt CO_2-e, even with the inclusion of emissions from harvesting.

The net removals are driven by the large area of post-1989 forest planted in the 1990s that is now reaching harvest age. As planted forest emissions are mainly driven by the harvest cycle, it is important to assess how the annual flux in net CO_2-e emissions may change through time.

Projected emissions

Using the national estimate to account for the age and harvest activity to estimate net emissions, a projection of future emissions is possible. As large areas of post-1989 forest are harvested over the next decade, net emissions are expected to increase. If the age profile and projected harvest activity of New Zealand's entire planted forest estate is assumed to be representative of sheep and beef farmland, these forests are expected to be a net source of emissions from 2024 to 2030. Although there is some uncertainty in this projection, it is still the best current estimate of harvest activity and net emissions, given the absence of harvesting information specific to planted forests on these farms.

Harvested wood products

A portion of the carbon lost from the harvesting of planted forests is transferred into the harvested wood products (HWP) carbon pool, where the carbon is stored before returning to the atmosphere when the product is discarded. However, it is particularly complicated to apply a model of HWP removals and subsequent emissions to a sector-based subset of planted forests, such as to forests on sheep and beef farms. Furthermore, it is unclear how the carbon dioxide removals from carbon gains in the HWP carbon pool, and the subsequent emissions as products are discarded, should be allocated at a subset below the national level (such as those coming from forests on sheep and beef farms). For these reasons, our analysis did not include HWPs.

Including harvesting emissions

Despite only occupying 3 per cent of sheep and beef farmland, planted production forests accounted for 82 per cent of the estimated gross sequestration (total removals excluding harvest emissions) on the farmland in 2018, at 10,382 kt CO_2-e. This is similar to the upper range estimate for exotic forests in Case and Ryan (2020), of 10,773 kt CO_2-e. As most of the gross sequestration is from exotic planted forests, it is essential to consider both the sequestration and emissions from harvesting that arise from this land use. Future projections of net emissions and removals from planted forests (figure 2) highlight the issue with just considering a point-in-time estimate – particularly for planted forests, which are highly variable through time.

Taking an averaging approach

An alternative method to estimate net emissions and removals from planted forest categories would be to take an *averaging approach*. This only measures carbon dioxide removals from the afforestation of planted forests up to the age when they reach their average long-term carbon stock (around 17 years, or 22 years when including HWP (Wakelin et al, 2020)).

Once sequestration has been measured up to the long-term average carbon stock, there are assumed to be no further emissions or removals (ie, no additional removals from growth nor emissions from harvest). An advantage of this approach is that it is simpler to measure net removals (only afforestation activity data is required). There is also the option to include HWP in the long-term average.

Using this approach is consistent with both New Zealand's approach to accounting for afforestation towards the 2030 emissions reduction target under the Paris Agreement, and upcoming changes to afforestation in the New Zealand Emissions Trading Scheme (NZ ETS). In 2018, around 40 per cent of New Zealand's post-1989 planted forests had already reached their long-term average stock and are not considered to be contributing to additional long-term sequestration (MfE, 2020).

Deforestation

On average, 1885 hectares of deforestation occurred annually on sheep and beef farmland from 2013 to 2016, contributing to an estimate of 1187 kt CO_2-e emissions per year in 2018. This accounts for 24 per cent of New Zealand's total deforestation area over this period. The deforestation intentions survey indicates that deforestation across all New Zealand's planted forests is expected to average 3375 ha per year between 2018 and 2030 (Manley, 2019), the majority coming from smaller growers. This suggests that while some deforestation is expected to continue on sheep and beef farmland, the rate may be lower in future.

Grassland with woody biomass

Scrub and shrub vegetation, represented by the grassland with woody biomass category, is a small net sink of CO_2-e emissions on sheep and beef farmland, removing 82 kt CO_2-e per year. Of this amount, 76 per cent is offset by the emissions from clearance back to pasture.

Differences in estimated sequestration rates

The total net removals from grassland with woody biomass are considerably lower than the estimated total of 567 kt CO_2-e yr^{-1} to 3232 kt CO_2-e yr^{-1} for scrub and shrub vegetation in Case and Ryan (2020). The difference is largely due to Case and Ryan (2020) using emissions factors derived from studies that represent forest land (such as Paul et al, 2019a; indigenous forest yield table from MPI, 2017) or that specifically selected sites that were considered likely to transition into forest (such as Carswell et al, 2009; 2013), and applying these to the entire vegetation area.

However, these are not considered to be nationally representative estimates for all of the scrub and shrub vegetation on sheep and beef farms. In contrast, the national estimate for grassland with woody biomass used in this analysis has a lower sequestration rate (MfE 2020; Wakelin and Beets, 2013). This was applied to the vegetation that was newly established since

1990, making up 12 per cent of the total vegetation area. The remaining 88 per cent (439 kilohectares) is considered to be in steady state and therefore not sequestering any additional carbon.

Estimating carbon stocks and stock change

Grassland with woody biomass is a variable land use class with a high uncertainty in its carbon stocks. The average carbon stocks for matagouri or grey scrub (13.0 t C ha^{-1}) and gorse and/or broom (14.9 t C ha^{-1}) reported in Case and Ryan (2020, Table A1), are similar to the estimate of 13.05 t C ha^{-1} for grassland with woody biomass in this report (Wakelin and Beets, 2013). This suggests that the estimate of 13.05 t C ha^{-1} is appropriate for this land use type at the national level.

Burrows et al (2018) attempted to quantify the sequestration rate for on-farm vegetation on retired land, where the forest definition was not met, but found very little nationally representative data for this land type. They proposed using the values for grassland with woody biomass from New Zealand's Greenhouse Gas Inventory (as used in this study) as the best available alternative (MfE, 2020; Wakelin and Beets, 2013).

Future work could focus on improving the accuracy of this estimate, by dividing grassland with woody biomass into further subcategories, each with a specific carbon stock value (eg, indigenous vs exotic scrub and shrub classes). Although a potentially higher estimate of carbon stocks in grassland with woody biomass could result in an increase in sequestration towards this long-term stock, it could also result in a corresponding increase in emissions from clearance of this vegetation.

Improvements through finer resolution mapping

The detection of carbon stocks and stock change in woody vegetation on farms could also be improved through better detection of woody vegetation that is not currently mapped as forest land or grassland with woody biomass. This includes small pockets of vegetation that are missed using current mapping methods, such as riparian plantings and hedgerows, which may be contributing to sequestration on farmland.

A case study of a farm in Kaipara, Northland revealed that finer scale mapping at a higher resolution (10 cm pixels) detected 11.7 per cent more woody vegetation than the LUCAS LUM, and 14.3 per cent more than the LCDBv4 (Case and Ryan, 2020). This was mainly small pockets of younger vegetation that, when included in analysis, were claimed to be contributing 33 per cent to 300 per cent more sequestration than when using the LCDBv4 or LUCAS LUM classes, respectively (Case and Ryan, 2020). Although this provides useful insight into the vegetation area not being detected via current mapping approaches, increased detection does not necessarily translate into a direct linear increase in sequestration, due to the unknown age and management of the vegetation. These smaller pockets of younger vegetation may be more likely to be subject to periodic clearance and subsequent regeneration on farmland. Without evidence of an overall increase in this vegetated area, the net emissions and removals may be expected to be roughly zero.

Further work should investigate the age of the additional vegetation detected at finer resolution mapping. This will allow an assessment of:

- how much vegetation may be recently established and therefore sequestering additional carbon
- the carbon losses that may arise if it is being cleared.

The net sequestration occurring that may be missed using current mapping methods could then be estimated. This could inform how cost-effective finer resolution mapping at a national scale would be. An alternative approach could be to take a statistical grid-based sample of woody vegetation in non-forest land at the national scale, as is currently done for forest land. This could be done virtually by using satellite data to detect woody vegetation, and then estimating carbon stock and stock change for these sample plots.

Soils

Drained organic soils on sheep and beef farmland are estimated to be emitting 255 kt CO_2-e each year. This accounts for 14 per cent of the total emissions from drained organic soils in New Zealand, the remainder coming mainly from other types of farming.

Organic soils

Organic soils occur on peatlands, wetlands, or wetlands that have been drained in the past. When they are drained, usually to make way for agriculture, carbon dioxide is emitted each year as the peat shrinks and is oxidised. These emissions can be reduced and possibly reversed by rewetting the soils or converting them back to wetlands. Although the rewetting can increase methane emissions, there is still considered to be a net decrease in overall greenhouse gas emissions (Wilson et al, 2016).

Mineral soils

This report did not include emissions from mineral soils. This is due to the complexity of applying the delayed emissions from multiple changes in land use over time. Given the time constraints, it was considered beyond the scope of the report.

After a change in land use, mineral soils are considered to transition to a new steady carbon stock value specific to the new land use over a 20-year period, resulting in either emissions or removals. Net emissions from mineral soils due to land use changes across New Zealand totalled 383 kt CO_2-e in 2018. As the patterns of changing land use on sheep and beef farmland over the last decade have been similar to those at the national scale, we would expect to see a similar direction of emissions.

We recommend including emissions from mineral soils due to land use change where possible, in future assessments of this nature. Current work is underway in New Zealand to set up a national soil monitoring system on agricultural land (Manaaki Whenua, 2020). This will provide much-needed information to improve estimates of how soil carbon stocks are changing at both the farm and national scale.

Uncertainty

The estimated net removals of 5487 kt CO_2-e in this report have an associated uncertainty of 48 per cent (table 1). This indicates that the expected net removals may range between 2900 kt CO_2-e and 8075 kt CO_2-e. The estimates include the uncertainty associated with each emissions factor, the estimate of land use area and associated activity (eg, harvesting), and an adjustment to scale these estimates to sheep and beef farmland.

The land uses that contribute most to overall uncertainty are post-1989 planted forest, pre-1990 planted forest and pre-1990 natural forest. This is because these three categories have a high contribution to net emissions and removals, and because of the uncertainty associated with each of these estimates.

Grassland with woody biomass had the highest uncertainty. However, due to its relatively low contribution to net emissions, it did not have a large impact on the overall uncertainty.

The assessment of uncertainty did not include the accuracy of AgriBase™ mapping of sheep and beef farmland. However, other studies of similar nature have assumed that the AgriBase™ layer does not introduce much additional uncertainty to vegetation areas on this farmland (Case and Ryan, 2020; Norton and Pannell, 2018).

Conclusion

Woody vegetation and drained organic soils on sheep and beef farmland are estimated to be a net sink of 5487 kt CO_2-e in 2018, equivalent to 33 per cent of the 16,537 kt CO_2-e gross agricultural emissions from this sector (MfE, 2020). These removals are 63 percent lower than Case and Ryan's (2020) mid-point estimate. The main reasons for the lower estimate are:

- the inclusion of carbon losses from vegetation and drained organic soils
- more appropriate sequestration rates for natural forest and scrub/shrub classes, which better reflect vegetation age and management practices.

This report provides a robust and up-to-date estimate of the net emissions and removals occurring on sheep and beef farmland, using the best available current data. The approach combines national emissions data with mapped land use data to derive a sector-based emissions estimate. This could be replicated and applied to other area boundaries within New Zealand such as other primary sectors, land ownership or regions.

The methods are consistent with New Zealand's National Greenhouse Gas Inventory (MfE, 2020) and international guidelines (IPCC, 2006b). By applying a consistent methodology and land use classification, net emissions and removals from land use types can be further examined in the context of climate change, forestry and agricultural policy. Future research into sequestration on farmland could focus on improving these estimates and identifying ways to further enhance and encourage sequestration.

Appendix

This section summarises the key reasons for the overestimation of net carbon dioxide removals on sheep and beef farmland reported in Case and Ryan (2020).

I. Carbon losses from forest harvesting, deforestation and scrub clearance

The exclusion of carbon losses arising from forest harvesting, deforestation and scrub clearance has a significant impact on the overall estimate of net emissions and removals. Exotic planted forests (exotic conifer and deciduous forest classes) had the greatest contribution to removals reported by Case and Ryan (2020), estimated at between 7135 kt CO_2-e and 10,773 kt CO_2-e per year.

However, there was no assessment of the carbon losses that would be occurring from the harvesting or deforestation of these forests. Case and Ryan (2020) acknowledge the absence of harvesting emissions as a limitation in their study, and recommend including it in future estimates. As harvesting is such a significant driver of net emissions in planted forests, emissions from this activity must be included when assessing the overall net removals from this land use.

New Zealand's Greenhouse Gas Inventory highlights the importance of including emissions from harvesting, as it has a significant impact on overall net emissions. In 2018, New Zealand's planted forests removed 55,167 kt of CO_2-e from forest growth, while the harvest of these forests contributed to 41,168 kt CO_2-e emissions, resulting in a total net removal of 13,998 kt CO_2-e (MfE 2020). In any assessment of the net emissions or removals on farmland (or any other land type), it is imperative to account for both the carbon gains and losses.

II. Using appropriate and representative emissions factors

Consistent and appropriate emission factors are crucial for an accurate nationally representative estimate of net emissions and removals. When assigning a rate of sequestration to a given vegetation type (t CO_2-e ha^{-1} yr^{-1}), the estimate should be representative of the entire area of that vegetation. For indigenous tall forest on sheep and beef farmland, Case and Ryan (2020) reportedly use a sequestration rate for indigenous forest occurring outside the conservation estate (-2.2 ± 1.1 t CO_2-e ha^{-1} yr^{-1}). However, this is actually the sequestration rate for all pre-1990 natural regenerating forest in New Zealand (Paul et al, 2019a).

Data from New Zealand's national forest inventory indicate that net emissions from pre-1990 tall natural forest are only slightly positive, and very close to zero (0.14 ± 0.74 t CO_2-e ha^{-1} yr^{-1}) (MfE, 2020). They are generally regarded to be in equilibrium (Paul et al, 2019a). In comparison all pre-1990 natural forest outside the conservation estate, including large areas of regenerating mānuka and kānuka (reported in a separate category in Case and Ryan (2020)), has an estimated sequestration rate of -1.48 ± 1.01 t CO_2-e ha^{-1} yr^{-1} (Paul et al, 2019a). As a result, the sequestration rate for tall indigenous forest on sheep and beef farms in Case and Ryan (2020) is likely to be overestimated. To ensure a robust estimate, it is essential to use carbon stock change estimates that are the best possible representation of a mapped area of land use or land cover type. This can be achieved by using: representative plot-based sampling within a mapped vegetation type (as in New Zealand's National Forest Inventory) or, in the absence of this information, suitable proxies based on existing research.

The sequestration rates for scrub and shrub vegetation used in Case and Ryan (2020) are biased towards higher rates of sequestration and are highly unlikely to represent the total mapped area they were applied to. The estimate for exotic scrub and shrubland is based on studies that specifically selected sites likely to transition into tall natural forest (Carswell et al, 2009; 2013), and is not intended to be nationally representative. Furthermore, the upper estimate for exotic scrub and shrub vegetation is mainly driven by a single plot for a single vegetation type (gorse) that was able to grow undisturbed to age 30 (see Carswell et al, 2013, figure 25).

Similarly, the sequestration estimates for indigenous scrub and shrub vegetation are based on vegetation types classified as forest (MPI, 2017; Paul et al, 2019a). However, in reality much of this vegetation on sheep and beef farmland would not be expected to transition into forest, due to management (eg, grazing, burning) or environmental factors (eg, high altitude) that limit continued growth. These estimates are therefore highly unlikely to be representative of the total area of scrub and shrub vegetation on this farmland.

For these reasons, the sequestration rates used in Case and Ryan (2020) may give an indication of the potential sequestration some of these vegetation types could reach under specific conditions, but do not accurately represent the total vegetation area present on farmland.

Case and Ryan (2020) give an upper and lower estimate for each vegetation type, using the mid-point to estimate an average. If the mid-point is to indicate the 'most likely' rate between high and low estimates, then the upper and lower rates should be equally plausible. In the report the upper rate is consistently much more optimistic than the lower rate is pessimistic, which biases the mid-point upward. An alternative approach to avoid this would be to determine a balanced nationally representative mid-point estimate for each vegetation type, and report this with an associated confidence interval.

III. Vegetation age and management are key drivers on the rate of sequestration

When determining the rate of sequestration of a vegetation type, the management and age of the vegetation are key factors (Burrows et al, 2018; Carswell et al, 2012). Scrub and shrub classes were reported to be removing between 567 kt CO_2-e and 3232 kt CO_2-e per year in Case and Ryan (2020). However, this assumes that the total area of this vegetation is sequestering carbon indefinitely. Most of this vegetation has remained as scrub and shrubland classes for over 20 to 30 years, without transitioning into forest. This is due to environmental limitations (eg, subalpine shrubland at high altitudes) or management of the vegetation or surrounding area (such as grazing or burning) impeding their continued growth or seed recruitment. Consequently, most of this vegetation is unlikely to be sequestering additional carbon. By not considering vegetation age, and that much of the on-farm vegetation has likely already reached maturity (or has constrained growth as noted), the sequestration rates in Case and Ryan (2020) are likely to be overestimated.

A core principle in calculating carbon stock change is that the estimate must reconcile with the estimate of carbon stocks (IPCC, 2006a). Case and Ryan (2020) estimate the entire area of exotic scrub vegetation on sheep and beef farmland to be gaining carbon at a rate of 0.55 to 4.15 t C ha^{-1} yr^{-1}, and indigenous scrub at 0.46 to 1.77 t C ha^{-1} yr^{-1}. The average carbon stored in these vegetation types was estimated to be 14.9 t C ha^{-1} for exotic scrub and 13 t C ha^{-1} for indigenous scrub (Case and Ryan, 2020, table A1). Reconciling these estimates indicates that the average carbon stock value would be reached after 4 to 27 years for exotic scrub and 7 to 28 years for indigenous scrub.

Accordingly, if applying these sequestration rates, it would be assumed that no further sequestration would occur after these times since establishment and the average carbon stock is reached, which would apply to most of the scrub and shrub vegetation area on sheep and beef farmland. Considering the current distribution of age classes of this vegetation yields a more accurate sequestration estimate.

IV. Emissions from soils

Emissions and removals from soils were not included in the overall estimates in Case and Ryan (2020). This was suggested to be due to difficulties in obtaining data for accurate estimates, and the assumption that gains and losses in carbon stocks were in equilibrium (Case and Ryan, 2020).

Net emissions from **mineral soils** are mainly driven by land use change (IPCC, 2006b), and may result in net emissions or removals, depending on the change in land use. This can make calculating the net emissions from mineral soils a complex process.

However, **drained organic soils** (eg, previously drained wetlands) are known to be continually emitting carbon, and data is available for this soil type in New Zealand. Drained organic soils across New Zealand emitted 1860 kt CO_2-e in 2018 (MfE, 2020). Given that these soils are a known source of emissions, for completeness they should be included in an assessment of net emissions and removals on sheep and beef farmland.

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