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A strategy for improving emissions estimates from peaty-mineral soils in the national greenhouse gas inventory

Prepared for: The Ministry for the Environment

July 2024

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Contract Report: LC4489

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Summary

Changes in mineral soil carbon stocks associated with land-use transitions within the national greenhouse gas (GHG) inventory are estimated using a key simplifying assumption that those carbon stocks reach a new steady-state after 20 years. In contrast, emissions from Organic Soils on managed land (mostly former peat wetlands) employ emission factors and lose carbon at a constant rate through time as long as they remain drained (i.e. they never reach steady-state). At the margins between mineral and Organic Soils, and often in low-lying areas of the landscape are large areas of peaty-mineral soils. These areas are either Organic Soils where relatively shallow peat layers have oxidised and no longer meet the definition of 'Organic Soils', or occupy similar landscape features where they developed shallow peaty layers but never fully developed into peatlands. Like Organic Soils, these marginal peaty-mineral soils also often require drainage to manage water table depth. The current inventory soil carbon stock change model considers these peaty-mineral soils using the same approach as other mineral soils (i.e. steady-state, unless a land use change has occurred in the past 20 years), despite evidence from New Zealand and international studies suggesting these soils are likely losing carbon through time, potentially at similar rates to drained Organic Soils.

We estimated the potential national emissions from peaty-mineral soils by extracting the area of mineral soils with peaty surface horizons, using S-Map where available and the older fundamental soils layer otherwise. These areas were aggregated by land-use category using the 2016 land use and carbon analysis system (LUCAS) land use map (LUM). We limited our estimates to areas of managed land most likely to be exposed to altered hydrology (i.e. drainage) and organic matter oxidation. Therefore, we did not include the categories of Natural Forest, Wetlands, and Other land, leaving a total area of 92,793 ha from which we estimated emissions. In the absence of country-specific emission information for peaty-mineral soils, we applied a range of default emission factors taken from the 2013 IPCC Wetlands Supplement for drained Organic Soils for both CO_2 and N_2O. Combining the area estimates with this range of emission factors led to a total of 0.99 – 2.40 $MtCO_2eq\ yr^{-1}$ in national emissions from peaty-mineral soils. This represents 23% to 57% of the current best estimate of drained Organic Soil emissions (4.2 $MtCO_2eq\ yr^{-1}$), and would become a key category in the national greenhouse gas inventory if soil emissions were disaggregated from land-use emissions in the key category analysis.

To determine the best approach for improving the emissions estimated from peaty-mineral soils, we held a workshop with relevant researchers and representatives from local and central government. We discussed the potential for these soils to be GHG emissions sources, and associated approaches for improving data that would aid emission factor development (plot-based soil resampling, direct flux measurements), activity data improvements (spatial mapping improvements and modelling), along with the associated benefits, drawbacks, and limitations. From this discussion the following recommendations were developed.

Recommendations

- There was strong consensus among workshop attendees that potential emissions from peaty-mineral soils are of a magnitude that warrants further investment, especially because they would reach the threshold for a key category if included. However, any resources allocated to refining emissions estimates from peaty-mineral soils should be aligned with and not be in competition with efforts to constrain emission estimates from drained Organic Soils, given the scale of the problem Organic Soil emissions pose, and ongoing funding constraints.
- Results from a previous study indicated that Gley Soils (a key poorly drained mineral soil order) across New Zealand had lost carbon between resampling periods (averaging 29 years). However, the sampling excluded plots where surface soils exhibited peaty layers. Therefore, the results are not representative of peaty-mineral soils. However, given peaty-mineral soils are common within the Gley soil order, the losses observed may provide a useful boundary condition. There was strong agreement that resampling the mineral Gley Soil sites from that previous study would constrain the rate of loss for that soil order and confirm whether losses are still ongoing.
- Plot resampling on peaty-mineral soils may be a useful approach but there is likely to be considerable variability across short spatial distances. A drawback of this approach is that the number of samples required to detect changes in carbon stocks with the desired precision is likely larger for peaty-mineral soils than other mineral soil types. This is because of variability in their physical properties (e.g. undulating microtopography of the original peat surface) and resulting carbon dynamics, which makes statistically robust sampling of soils with similar properties very difficult. Therefore, the number of samples required to detect changes of significance may need special assessment if a plot resampling approach is taken.
- Eddy covariance flux measurements could be established at a peaty-mineral soil site with a shallow organic layer (20–29 cm). This would provide very detailed paddock-scale information towards the development of emission factors, including boundary condition data for future emission modelling work, and address questions regarding the potential for managed peaty-mineral soils to produce similar GHG emissions to drained Organic Soils. A key limitation of this approach is the upfront set-up cost, including required field measurement gear. This typically constrains spatial coverage, often to one measurement site, but it does provide very robust emissions factor (EF) data for the measured soil. If there is interest in pursuing this approach, alignment with other agencies where research objectives overlap may be advantageous (e.g. New Zealand Agricultural Greenhouse Gas Research Centre). Measurements at a site with 20–29 cm organic layer would help to constrain emission estimates for shallow Organic Soils while simultaneously providing a likely upper estimate for emissions from peaty-mineral soils.
- Despite recognition of the need to improve activity data associated with peaty-mineral soils, the consensus among workshop attendees was that more information regarding the potential emissions should come first. This was because of the costly nature of the field mapping validation that may be required, and our current poor understanding of which soil types or characteristics would result in high potential emissions.

1 Introduction

New Zealand reports on changes in soil carbon stocks associated with land-use change only (i.e. management effects within land use categories are not explicitly considered). The approach to estimating changes in soil organic carbon stocks in New Zealand's national greenhouse gas (GHG) inventory adopted by the Ministry for the Environment (MfE), as stated in MfE 2024, is outlined in McNeil et al. 2014. There are two assumptions underpinning the way this model generates estimates of soil carbon stock changes. One is that soil carbon stocks within a given land use category are at steady state. The other is that the transition of soil carbon stocks occurring due to land use change happens linearly over 20 years. The one exception is drained Organic Soils, which are not assumed to be at steady state. Instead, these soils are assigned emission factors according to the land use they underlie, and emissions continue at this constant annual rate in the absence of a land use transition (IPCC 2006). Drained Organic Soils under Grassland and Cropland contribute disproportionately large emissions (5%–10% of New Zealand's net emissions) relative to their area, covering < 1% of New Zealand (Pronger et al. 2022).

For inventory reporting, New Zealand defines 'Organic Soil's as those having at least 18% organic carbon in horizons at least 30 cm thick within 60 cm of the soil surface (MfE 2024). Peaty-mineral soils, many of which are classified within the Gley Soil order (within the New Zealand Soil Classification) are poorly or very poorly drained, occupying low-lying areas with high groundwater tables, and exhibit topsoils with high organic matter content and often peaty layers (Hewit 2010). These soils can often be found at the margins of Organic Soil areas or occupy similar areas of a landscape, and therefore behave in a similar way to Organic Soils (Dresser et al. 2011). Furthermore, the distinction between organic and mineral soil used for New Zealand's GHG inventory is somewhat more restrictive than that offered by IPCC Good Practice Guidelines (IPCC 2006), which allows for inclusion of organic layers with as low as 12% organic carbon content in peaty horizons where the thickness criteria depends on percent organic carbon and clay content. Given the prevalence of allophanic mineral soils with high organic carbon content (often > 12%) in New Zealand, reevaluating the thresholds defining Organic Soils based on these thresholds is well beyond our current scope. However, consideration of peaty-mineral soils and how they are treated when estimating soil carbon changes within the GHG inventory is well justified.

There are several reasons why mineral soils with a peaty layer ('peaty-mineral soils') may warrant separate treatment from the default approach used to estimate soil carbon stock changes for mineral soils in the inventory. Marginal peaty-mineral soils that require drainage for agricultural production may behave similarly with respect to their biogeochemistry and resulting emissions (Kelliher et al. 2002). Furthermore, the delineation of organic and mineral soil, in part using the depth of organic layer in the surface horizon, creates a conceptual issue with how emissions are estimated. An issue with the 30 cm depth cut-off for Organic Soils is that areas drained for agriculture (where subsidence and continued oxidation has led to reduction in surface peat depths) will eventually cease to fit the definition of Organic Soil. Once that occurs, these soils should theoretically transition to the mineral soil carbon stock change modelling approach where we assume a steady state. If such a transition could be dynamically mapped, this would lead to cases where a former drained Organic Soil with 30 cm of peat at the surface then

becomes a mineral soil with 29 cm of peat, leading us to report that emissions have stopped because soil carbon has reached its steady-state value. On the other hand, and given that we are unlikely to detect those transitions with such accuracy, our current inventory reporting assumes no change in the area of drained Organic Soils from year to year. This is despite confidence that Organic Soil area is diminishing as marginal peat areas are oxidised (Pronger et al. 2014). If we assume that emissions from peaty-mineral soils are lower than those from drained Organic Soils per se, then we may be over-estimating or mis-attributing emissions from this source. Lastly, Gley Soils, more broadly, were one of two soil types shown to have lost carbon over time, as detected by a national resampling study (Schipper et al. 2014). That analysis was not able to allocate a timescale to the estimated soil carbon losses because of the variable intervals between sampling that spanned several decades. However, the result is not consistent with the default assumption of steady-state carbon stocks for mineral soils. Furthermore, the study avoided samples with peaty layers, indicating their findings are likely to represent the low end of possible losses from mineral soils with high carbon stocks (at least, before drainage) that were protected by a high water table, often as a result of low landscape position.

2 Analysis

2.1 Peaty-mineral soil area

To estimate the area of peaty-mineral soils, we identified soils with sibling classifications indicating peaty layers using S-Map[1] where coverage was available or the fundamental soils layer (FSL) otherwise (Table 1). These areas were then aggregated by land-use category using the 2016 Land Use Carbon Analysis System (LUCAS) land use map (LUM)[2]. To generate preliminary emissions estimates, we aggregated land use categories most likely to represent managed areas where drainage of these soils may occur. We therefore excluded Natural Forest, Other, and Wetlands (Table 1). This resulted in a total area for managed peaty-mineral soils of 92,793 ha, which is similar to that estimated by Dresser et al. (2012) of 99,464 ha. The reduced area in our estimate may derive from updated soil maps, given we now have S-Map coverage for a greater percentage of the country, whereas Dresser et al. (2012) would have relied more heavily on the older FSL information.

[1] See https://smap.landcareresearch.co.nz/

[2] See https://environment.govt.nz/facts-and-science/science-and-data/new-zealand-land-use-map/

Table 1. Peaty-mineral soil area in hectares (ha) aggregated by land use category using the 2016 LUCAS land-use map (LUM). Land use categories considered unmanaged are in blue font, while those in black were used to estimate emissions.

LUCAS LUM 2016	Peaty acid brown	Peaty acid gley	Peaty orthic gley	Peaty recent gley	Peaty sandy gley	Peaty-silt-mantled perch gley podzol	Total area
Natural forest	494,534	307	994	17	1	1,552	497,405
Other	1,965	3	4	-	-	72	2,043
Wetland - Open water	2,402	162	255	20	15	3	2,856
Wetland - Vegetated non forest	306	1,079	2,660	196	32	336	4,608
Unmanaged area	499,206	1,551	3,913	233	47	1,962	506,912
Settlements or built-up area	3	47	555	0	2	1	607
Post-1989 Forest	29	30	380	1	0	161	601
Grassland - Low producing	26,303	160	1,351	31	9	313	28,167
Grassland - With woody biomass	29,702	174	457	21	7	1,059	31,420
Cropland - Annual	-	55	3,306	-	6	-	3,367
Cropland - Orchards and vineyards (perennial)	-	61	157	-	-	-	218
Grassland - High producing	-	6,042	17,691	1,239	1,088	1,015	27,075
Planted Forest (Pre-1990)	-	414	308	3	0	614	1,338
Managed area	56,037	6,982	24,205	1,295	1,113	3,162	92,793
Total area	**555,240**	**8,487**	**27,563**	**1,528**	**1,159**	**5,123**	**599,098**

2.2 Peaty-mineral soil emissions

The 2013 Intergovernmental Panel on Climate Change (IPCC) wetlands supplement (IPCC 2014) does not provide updated guidance on how to estimate emissions or soil carbon stock changes for inland wetland mineral soils, nor specifically for soils that were previously drained Organic Soils but no longer meet the definition of Organic Soil due to prolonged oxidation of the surface organic layer. The 2013 IPCC Wetlands Supplement defers to the 2006 IPCC (IPCC 2006) guidelines outlining default model assumptions and emission factors (i.e. reference soil organic carbon stock values). The lack of updated guidance on this topic was due to insufficient information available at the time (see Chapter 5 of IPCC, 2014). As such, we used three different CO_2 and N_2O emission factors (Table 2) to generate some preliminary estimates of the potential emissions from peaty-mineral soil areas identified above. At the high end, we used the default emission factors (EF) for drained Organic Soils as given in the 2013 IPCC Wetlands Supplement for Forest, Cropland and Grassland (temperate, nutrient poor or nutrient rich). To reflect assumptions that emissions from peaty-mineral soils may be lower than drained Organic Soils, we also used the lower 95% confidence interval value. Additionally, we tested the approach taken by Denmark in their national inventory report (Nielsen et al. 2022) and used half the value of the default emission factors given by the 2013 Wetlands Supplement (Table 2). For all approaches, we used either the nutrient-rich or nutrient-poor grassland EF for CO_2 and N_2O applied to the entire grassland area together with the cropping and planted forest EFs. As recommended in the IPCC guidelines (IPCC 2006), we applied grassland EFs to areas under settlements.

Table 2. Emission factors used for both CO_2 (top) and N_2O (bottom) emissions from peaty-mineral soils, plus 95% confidence intervals (CI). (Source: values taken from the 2013 IPCC Wetlands Supplement [IPCC 2014].)

	Emission factor $tCO_2eq\ ha^{-1}\ yr^{-1}$	95% CI	
CO_2			
Drained, nutrient-rich Grassland	22.4	18.3	26.8
Drained, nutrient-poor Grassland	19.4	13.6	25.3
Cropland	29.0	23.8	34.5
Forest	9.5	7.3	12.1
N_2O			
Drained, nutrient-rich Grassland	3.5	2.1	4.7
Drained, nutrient-poor Grassland	1.8	0.8	2.9
Cropland	5.6	3.5	7.7
Forest	1.2	-0.2	2.6

We used these emission factors and the spatial areas for each aggregation of peaty-mineral soils to estimate emissions (in CO_2eq) for the country according to Equation 1.

$$CO_2eq = A_{i,j} \times EF_{i,j} \quad \text{[Equation 1]}$$

where:

- A is the area of peaty-mineral soils under a given land use
- EF is the emission factor pertaining to that land use
- i is land use type
- j is greenhouse gas (CO_2 or N_2O)

Each combination of the three CO_2 and N_2O EFs (Table 2) was used to generate preliminary emission estimates. The resulting national-scale emissions estimates from peaty-mineral soils range from 0.99 – 2.40 $MtCO_2eq\ yr^{-1}$ (Table 3). For context, Pronger et al. (2022) determined that implementing the 2013 IPCC Wetlands Supplement default EFs and refining the area of Organic Soils using the best available spatial information (combining S-Map and FSL) resulted in national emissions estimates of 4.2 $MtCO_2eq\ yr^{-1}$ for drained Organic Soils under Grassland and Cropland. The preliminary estimates presented here (Table 3) for peaty-mineral soils represent about 23% to 57% of those drained Organic Soil emission estimates[3]. For 2022 emissions, the lowest contributing key category was 'Cropland Remaining Cropland' at 0.27 $MtCO_2eq\ yr^{-1}$. If emissions from peaty-mineral soils were a separate category in the 2024 national inventory report (MfE 2024), they would represent a key category. However, it should be noted that soil carbon stock changes or emissions are not disaggregated into their own category for key category analysis. If they were incorporated into the inventory, the emissions would be embedded within emissions reported from broad land use categories, particularly Grassland and Cropland (as is the case with drained Organic Soils).

[3] This analysis includes planted forest (pre-1990 and post-1989), whereas the analysis of GHG emissions from Organic Soils by Pronger et al (2022) did not. However, planted forest only covers 1.5% of the total national area of peaty-mineral soils and the EFs are low compared to other land uses, therefore the contribution to total emissions is very small.

Table 3. National-scale peaty-mineral soil emissions estimates (in Mt CO_2eq yr^{-1}) using each combination of three different emission factors which included grassland (high or low nutrient), cropland, and forest for both CO_2 and N_2O. (Note only Grasslands require the choice of nutrient-poor or nutrient rich emissions factors (EF) (Table 2). The highest and lowest emissions estimates, and therefore the range of emissions, are in red and blue text, respectively.)

	Drained, nutrient rich N_2O EF	Drained, nutrient- rich N_2O lower 95% CI EF	Drained, nutrient-rich half of N_2O EF	Drained, nutrient poor N_2O EF	Drained, nutrient poor N_2O lower 95% CI[1] EF	Drained, nutrient poor half of N_2O EF
Drained, nutrient rich, CO_2 EF	2.40	2.27	2.24	2.26	2.16	2.17
Drained, nutrient rich, CO_2 lower 95% CI EF	2.03	1.90	1.87	1.88	1.78	1.80
Drained, nutrient-rich, half of CO_2 EF	1.37	1.23	1.21	1.22	1.12	1.13
Drained, nutrient-poor, CO_2 EF	2.15	2.01	1.99	2.00	1.90	1.91
Drained, nutrient-poor, CO_2 lower 95% CI EF	1.61	1.48	1.45	1.47	1.37	1.38
Drained, nutrient-poor, half of CO_2 EF	1.24	1.10	1.08	1.09	0.99	1.00

[1] CI – Confidence interval.

3 Workshop summary

3.1 Developing a strategy for refining emissions estimates for peaty-mineral soils

To refine the estimates we developed towards a defensible inventory methodology, more information and data are needed that specifically address the uncertainty associated with this group of soils. In order to discuss these requirements and prioritise the work required to meet them, we convened a short (2.5 hr) workshop with relevant experts and government representatives. The workshop attendees (and their affiliations) included 9(2)(a) 9(2)(a) of Manaaki Whenua – Landcare Research (MWLR), 9(2)(a) (MWLR), 9(2)(a) 9(2)(a) (MWLR), 9(2)(a) (University of Waikato – UoW), 9(2)(a) (UoW), 9(2)(a) (Waikato Regional Council), 9(2)(a) (MWLR), 9(2)(a) (MfE), 9(2)(a) 9(2)(a) (MWLR), and 9(2)(a) (Ministry for Primary Industries – MPI).

The workshop discussion was divided into two main topics. The first was focused on our approach to generating preliminary emissions estimates, where attendees offered suggestions for adjustments or additions. The second was focused on future measurement approaches to constrain estimates from peaty-mineral soils.

There was strong consensus among workshop attendees that potential emissions from peaty-mineral soils are of a magnitude that warrants further investment, especially because they would reach the threshold for a key category if they were included. However, it was also felt that any resources allocated to refining emissions estimates from peaty-mineral soils should be aligned with – and not in competition with – efforts to constrain emission estimates from drained Organic Soils, given the scale of the problem Organic Soil emissions pose and ongoing funding constraints.

3.2 Discussion of preliminary estimates

This discussion was focused primarily on the emission factors we used to estimate the peaty-mineral soil emissions. Initially, we used results from Schipper et al. (2014) to generate a lower boundary emission estimate. That study found Gley Soils in New Zealand had lost 0.78 kgC m^{-2}, although the time between resampling was variable, so we tested 20–50 year intervals in converting that loss to an emission factor in tCO_2-eq ha^{-1} yr^{-1}. However, it was noted in both the 2014 Schipper paper itself, and by 9(2)(a) in the workshop, that the results from that study were not applicable to peaty-mineral soils because they specifically avoided samples with a peaty layer. There was a consensus among the researchers at the workshop that default EFs from the 2013 IPCC Wetlands Supplement for Organic Soils were the most appropriate for peaty-mineral soils in the absence of country-specific data. 9(2)(a) noted that results from a Waikato-based study on two drained Organic Soil locations showed emissions were most sensitive to near-surface soil moisture variations (Campbell et al. 2021). This would indicate that an Organic Soil layer would not necessarily need to be very deep to produce large CO_2 emissions due to oxidation in a drained agricultural environment.

A suggestion was also raised that we should not limit our estimates to the 'nutrient-poor' default emission factors provided in the 2013 IPCC Wetlands Supplement for grasslands. Most of New Zealand's drained Organic Soils are found on former bogs, which are rain fed and therefore low-nutrient environments. However, there is potential for peaty-mineral soils to occur in locations across the landscape beyond where we find bog-derived peat. For example, areas with surface hydrological links may exhibit different nutrient dynamics to rain-fed bogs. Therefore, we included both nutrient-rich and nutrient-poor default emission factors in our analysis.

Despite the consensus that results from Schipper et al. (2014) were not applicable to peaty- Gley Soils, a strong recommendation that arose from the workshop was that resampling of non-peaty Gley Soils would be useful to constrain the losses reported in that study (but not at the expense of much needed further research on Organic Soils emission factors). Not only would resampling the same locations from that study provide a definitive timescale from which to determine rates of carbon stock changes, but this would also help determine whether the reported losses are ongoing. In the future, this targeted resampling could be complemented by the national soil carbon benchmarking programme in agricultural land uses. A subset of the 500 nationally distributed sampling sites for that programme fall within the Gley Soil order, and all sites are intended to be re-sampled approximately every 5 years.

3.3 Discussion of possible measurement approaches to improve peaty-mineral soil carbon emissions estimates

3.3.1 Plot re-sampling for peaty-mineral soils

One way of determining changes in carbon stocks through time (in the absence of any change in land use) is by sampling the same plots multiple times across multiple years using standardized core or pit sampling methods. A drawback of this approach is that the number of samples required to detect changes in carbon stocks with the desired precision is likely larger for peaty-mineral soils than other mineral soil types. This is because of variability in their physical properties (e.g. undulating microtopography of the original peat surface), and resulting carbon dynamics makes plot sampling of soils with similar properties difficult. Therefore, the consensus among workshop attendees was that peaty-mineral soils are likely to be particularly difficult to constrain with this approach. If this type of approach was taken, there would likely need to be an intermediate sampling exercise to determine the number of samples needed for adequate precision in stock change estimates, which would then inform whether a nationally representative sampling approach could be achieved.

3.3.2 Flux measurements to develop emission factors

Emission factors can be developed from continuous measurements of GHG (e.g. CO_2 or N_2O) exchange by integrating through time. Eddy covariance flux measurements can provide hectare-scale emissions and allow for measurements over multiple years. This approach provides the necessary detail to develop emission factors but can be expensive to establish, and therefore spatial coverage (in terms of geographic location) would

probably be constrained. Nonetheless, given the growing evidence of emissions from drained Organic Soils using this technique (Campbell et al. 2015, 2021) and the likely overlap between peaty-mineral soils with Organic Soils (geographically and biogeochemically), the workshop attendees agreed there would be substantial value in expanding the existing data from deep Organic Soil sites (or even a single site) with a shallow peaty-layer soil. This could provide information on whether peaty-mineral soils have the potential to exhibit similar emissions to drained Organic oils, or if peaty-mineral soils indeed require a separate characterisation.

Either result would provide valuable information about the continuum of organic to mineral soils, including the necessary detail that could inform future process-based models of their GHG emissions. An important point was also raised in the workshop regarding the value of eddy covariance flux measurements being tied to the duration of the time series. The strength of these types of measurements is in the length of their record. Therefore, we recommend starting measurements as early as possible.

3.3.3 Activity data improvements

The area of peaty-mineral soils in each of the relevant managed land-use types is half of the equation in scaling the emissions estimates (Equation 1). Efforts to refine mapping of drained Organic Soils and peaty-mineral soils could both lead to improvements in inventory estimates. The primary issue raised in the workshop was that peaty-mineral soils include a highly diverse group of soils that are difficult to map for various reasons. Soils of various New Zealand Soil Orders have the potential to develop peaty or highly organic layers. Therefore, we cannot limit consideration to one soil order without potentially underestimating the areas of interest. Furthermore, some peaty layers can be buried beneath a shallow (< 30 cm) mineral layer, which adds complexity in how to delineate peaty-mineral soils. However, potentially the most important issue associated with activity data for peaty-mineral soils is that they often occupy relatively small, discontinuous areas within a landscape, which can be lost when generating 1:50,000 scale maps, as is the case with S-Map. There may be numerous small patches of peaty-mineral soils that integrate to a substantial area, but these are not captured with standard mapping techniques, and we are almost certainly underestimating their area in New Zealand. However, more advanced modelling techniques are available to improve the predictive resolution of soil maps that could be deployed specifically for this problem, given that their occurrence should be predictable with other existing spatial attributes (e.g. wetness and terrain). There is ongoing work related to mapping historic wetland areas, leveraging the increasing LiDAR coverage for the country, which has synergies with the problem of delineating peaty-mineral soils given the overlap with wetland attributes.

A key challenge for drained Organic Soils is that the area decreases over time due to organic matter oxidation. Around the fringes of drained peatlands these Organic Soils will eventually transition to peaty-mineral soils, and then assuming oxidation continues could become non-peaty mineral soils. If GHG emissions reduce anywhere along that transition, then this could lead to an over-estimate or mis-attribution of emissions. If this is the case it will be important to predict that transition for GHG accounting purposes. Furthermore, within the current national GHG inventory approach being able to predict how Organic Soil area is changing through time would improve estimates of emissions.

While there was agreement among workshop attendees that activity data improvements would ultimately be needed, the consensus was that information constraining the potential EFs from peaty-mineral soils should come first. Then, once we understood the soil types or physical characteristics most likely to lead to higher emissions, we would then recommend improved mapping to capture these identified characteristics. The general sentiment was that we first need to understand if managed peaty-mineral soils behave similarly to drained Organic Soils, and if not, how can we most accurately estimate their emissions without taking resources away from drained Organic Soils that we already know are a large emissions source that requires significant investment to quantify their emissions better.

4 Recommendations

- There was strong consensus among workshop attendees that potential emissions from peaty-mineral soils are of a magnitude that warrant further investment, especially because they would reach the threshold for a key category if they were included. However, any resources allocated to refining emissions estimates from peaty-mineral soils should be aligned with and not be in competition with efforts to constrain emission estimates from drained Organic Soils, given the scale of the problem Organic Soil emissions pose and ongoing funding constraints.
- Results from Schipper et al. (2014) indicated that Gley Soils (a key poorly drained mineral soil order) across New Zealand had lost carbon between resampling periods (averaging 29 years). However, the associated sampling excluded plots where surface soils exhibited peaty layers. Therefore, the results are not representative of peaty-mineral soils. However, given peaty-mineral soils are common within the Gley Soil order, the losses observed there may provide a useful boundary condition. There was strong agreement that resampling the mineral gley sites from Schipper et al. (2014) would constrain the rate of loss for that soil order and confirm whether losses are still ongoing.
- Plot resampling on peaty-mineral soils may be a useful approach but there is likely to be considerable variability across short spatial distances. A drawback of this approach is that the number of samples required to detect changes in carbon stocks with the desired precision is likely larger for peaty-mineral soils than other mineral soil types because of variability in their physical properties (e.g. undulating microtopography of the original peat surface) and resulting carbon dynamics, which makes statistically robust sampling of soils with similar properties very difficult. Therefore, the number of samples required to detect changes of interest may need special assessment in these soils if a plot resampling approach is taken.
- Eddy covariance flux measurements could be established at a peaty-mineral soil site with a shallow organic layer (20–29 cm). This would provide very detailed information towards the development of emission factors, including boundary condition data for future emission modelling work, and address questions regarding the potential for managed peaty-mineral soils to produce similar GHG emissions to drained Organic Soils. A key limitation of this approach is the upfront set-up cost, including required field measurement gear. This typically constrains spatial coverage, often to one measurement site, but it does provide very robust EF data for the measured soil. If

there is interest in pursuing this approach, alignment with other agencies where research objectives overlap may be advantageous (e.g. New Zealand Agricultural Greenhouse Gas Research Centre). Measurements at a site with 20-30 cm organic layer would help to constrain emission estimates for both shallow Organic Soils while simultaneously providing a likely upper estimate for emissions from peaty-mineral soils.

- Despite recognition of the need to improve activity data associated with peaty-mineral soils, the consensus among workshop attendees was that more information regarding the potential emissions should come first. This was because of the costly nature of the field mapping validation that may be required, and our current poor understanding of which soil types or characteristics would result in high potential emissions.

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