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Changed calculations of time series for litter and soil carbon for Forest remaining forest and Grassland remaining grassland

Erik Karltun, SLU

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Table of contents

TABLE OF CONTENTS 4

SAMMANFATTNING 5

SUMMARY 7

BACKGROUND 9

METHODS 11

Present method 11

Introduction 11

Calculation of carbon stock change 11

Combining carbon stock change data with land-use time series 11

Tested new models 12

Average change method 12

Regression method 12

Method test 13

RESULTS 14

Fine litter carbon on Forest remaining forest 14

Soil carbon on forest land remaining forest land 15

Fine litter carbon on grassland remaining grassland 17

Soil carbon on grassland remaining grassland 18

DISCUSSION AND CONCLUSIONS 20

Sammanfattning

Denna rapport presenterar resultat från en jämförande studie av olika metoder att beräkna och interpolera tidserierna för kolpoolsförändringar i förna och markkol för markanvändningskategorierna *forest remaining forest land* och *grassland remaining grassland.* Tidsserierna utgör en del av Sveriges rapportering av LULUCF-sektorn i den årliga nationella växthusgasinventeringen till Klimatkonventionen och till EU.

Även om de relativa förändringarna i markens kolpooler är små så resulterar de i utsläpp eller upptag som är stora i den nationella växthusgasbudgeten. Variationer som i huvudsak utgörs av slumpmässig variation i provtagningar och analyser får därför stora genomslag. Därför har det funnits en önskan att hitta en alternativ metod som på ett bättre sätt utjämnar slumpmässig variation i tidserien och som minskar effekten av omräkningar av hela tidserien mellan rapporteringsår. Syftet med förändringen är att den rapporterade tidsserien skall ligga så nära den långsiktiga förändringen av markens kolpooler som möjligt och inte påverkas lika mycket av slumpmässiga variationer och interpoleringsmetoden. Förändringarna i beräkning och interpolation skall fortsatt vara baserade på återkommande mätningar av kolförråden i förna och mineraljord på Riksskogstaxeringens permanenta provytor.

Syftet med projektet har varit att utvärdera alternativa beräknings- och interpoleringsmetoder när det gäller förändringar i förna- och markolspoolerna i skogs- och betesmark. En förutsättning har varit att metoderna fortsatt ska bygga på de kontinuerliga mätningarna av kolpoolerna i markinventeringen. Metoderna har utvärderats mot bakgrund av (1) hur de påverkar variationen längs tiderserien för enskilda rapporteringsår, (2) hur de påverkar de omräknade tidserierna mellan rapporteringsår och (3) hur de skiljer sig åt när det gäller de aggregerade upptagen eller utsläppen över hela tidsserien.

Två nya metoder testades. Medelförändringsmetoden bygger på att använda medelvärdet för förändringen för alla provtagningar över hela tidsserien istället för medelvärdet för förändringarna mellan varje provtagningsår. Regressionsmetoden bygger istället på att beräkna poolförändringarna med hjälp av linjär regression av poolerna över tid.

För *forest remaining forest land* ledde medelförändringsmetoden till en större utjämning och mindre skillnader mellan submissioner. När det gäller *grassland remaining grassland* blev effekten mindre. Det förklaras av att en mycket högre andel ytor byter markanvändning eller torvklassificering så att de bara rapporteras under en del av rapporteringsperioden.

Medelvärdesförändringsmetoden ger inga förändringar i total rapporterade utsläpp eller upptag över hela tidsserien jämfört med nuvarande metod.

Regressionsmetoden leder till en total eliminering av variationerna över tidsserien. Däremot blir variationerna mellan submissionerna stora och oförutsägbara. Det är också mer komplicerat att kombinera metoden med data för markanvändningsförändringarna. Metoden leder också till stora förändringar i de aggregerade utsläppen över hela rapporteringsperioden.

Slutsatsen från projektet blir att rekommendera att Sverige använder medelvärdesförändringsmetoden för att beräkna och interpolera tidsserien för förna och markkol för markanvändningskategorierna *forest remaining forest* and *grassland remaining grassland*.

Summary

This report presents results from a methodological study on how to calculate and interpolate the time series of carbon stock changes in the fine litter and soil organic carbon pools on forest land remaining forest land and grassland remaining grassland for reporting of the LULUCF sector in the annual greenhouse gas inventory submitted to the UNFCCC and the EU.

Since rather small variations along the time series estimated by the present calculation and interpolation method results in huge national variations in sinks or sources of CO_2 at the national level, there has been a wish to find an alternative way of calculating the time series that reduces the effect of recalculations between submission years.. The aim of the project was to evaluate alternative calculation methods for the time series for changes in the litter and soil carbon pools. The ambition is that the new method should result in time series that are as close as possible to the long-term trends in litter and soil carbon pool change by reducing the effect of random variation and interpolation methods within and between the submissions. The changes should be calculated so that the reporting is still representing carbon pool changes based on repeated measurements on the permanent plots of the Swedish Forest Soil Inventory.

Two different calculation methods were tested and compared with the method used up to submission 2022. The “average change method” estimates the average annual change for each plot over the whole time series instead of between each measured occasion. This results in a time series at plot level with no variations. However, when changes from all plots are averaged for each year in the time series some variation is introduced due to that plots may enter or leave the time series due to land-use change. For forest land remaining forest land, the method worked best and it significantly reduced variation along the time series and inter annual variation was also reduced compared to the previous method. The method was less effective on grassland remaining grassland were the large proportion of plots involved in land-use change contributed significantly to time series variation. The total aggregated carbon pool changes over the whole time series for this method is identical with the method that has been used up to submission 2022.

The second method tested is based on regression of the carbon pool over the entire time series instead of estimating change on each inventory plot by repeated measurement. This method essentially leads to a total elimination of the variation over the reported time series but the difference between

different submissions were more substantial. The aggregated amount of reported changes differ a lot from the other methods.

The conclusion from this project is to recommend the average change method to be used for calculating and interpolating the time series for fine litter and soil organic carbon for forest remaining forest and grassland remaining grassland.

Keywords: soil, litter, carbon, interpolation, time series

Background

Sweden reports the time series for changes in the litter and soil carbon pools for forest land remaining forest land and grassland remaining grassland based on data from repeated soil inventories made by the Swedish National Forest Soil Inventory (NFSI). The inventories are made in a continuous 10-year cycle on the permanent plots of the National Forest Inventory (NFI). Ten (10) percent of the sample plots are inventoried every year. The data used for the inventory today are from the 2nd, 3rd and 4th cycle of the inventory. The 2nd inventory started 1993 and continued up to 2002, the 3rd cycle started from 2003 and continued up to 2012 and the 4th cycle started from 2013 and will be completed 2022. However, data on carbon from the analysis of samples are only available two years after sampling due to the process of drying, sieving and analyzing samples.

The changes in carbon pools are estimated based on calculated changes between inventories for each sample plot. The measured changes cannot be attributed to a specific year but are instead distributed over the whole period between the inventories. In most cases, it will mean that 10% of the change will be attributed to the plot each year between the inventories, i.e. the change is interpolated between the sampling occasions. Every year, 10% of the on-going cycle's data is added to the calculations. That means that the time series for each new submission of the greenhouse gas inventory to the UNFCCC and the EU will change 12 years back in time. For example, when we calculated submission 2022 we phased in data sampled in 2018. Those samples were used to calculated changes between 2008 and 2018. That means that the time series will change, with the changes affecting the time series from 2008 and onwards.

The time series reported for a particular stratum, e.g. soil carbon change on plots belonging to forest land remaining forest land on mineral soils, will consist of the yearly averages of the interpolated change between inventories for all sampled plots. As long as the reporting was based on only two inventory cycles, the change for a particular plot is a straight line in the time series, i.e. the change is constant for each year between the two measurement years and the extrapolated years before and after the inventoried years. Hence, the time series reported also became a straight line. When the 4th inventory cycle data became available for submission 2015 the interpolation turned out to be more complicated since each plot where the carbon stock had been measured on three occasions now had two different change levels. One change level between the 2nd and 3rd cycle inventories and one change level between the 3rd and 4th cycle inventories.

Hence, the time series for a particular plot will be two straight lines, one level of change between the first two measurement years and another level of change between the second and third measurement years. When the time series for an entire stratum is calculated the time series will be more or less straight until the year 2003. Then, the data from the 4th inventory cycle take effect and there will be a variation in the time series that expands with one year when data from a new set of re-inventoried plots are phased in.

In conclusion, the result of getting measurements from three inventory periods has resulted in a situation where the time series starts to vary twelve years back in time relative to the last reported year. Most of this variation can be explained as a random variation due to sample variation between years. Even if the changes in the time series are small relative to the measured stock, typically a few per mille per year, they are difficult to handle in the national context since they represent huge variations relative to the national carbon dioxide budget and may amount to several megatons of CO_2 equivalents.

The aim of this project is to evaluate alternative presentations of the time series for changes in the litter and soil carbon pools in order;

- to limit random variation in the time series and,
- to reduce the level of change in net carbon stock changes due to recalculations between the submissions.

The changes in methods should be made so that the reporting is still representing carbon stock changes measured in repeated inventories of permanent sample plots in the NFSI.

Methods

Present method

Introduction

The present method to calculate the time series of the changes in the litter and soil carbon pool can be divided into two steps:

1. Calculations of carbon stock changes for the different carbon pools based on plot level data for the three different inventory cycles used for the reporting.
2. Attributing the plots with the calculated change to the different land-use classes and inventory categories using the time series reporting data on land-use and land-use changes for the individual permanent NFI plots. This step interpolates data between measurement years.

Calculation of carbon stock change

The calculation of the carbon stock change begins with a compilation of a dataset containing all the necessary variables for all the inventories. In this step we also classify which plots that have organic soils, i.e Histosols. Thereafter the carbon amount of the litter and soil pools for each plot is calculated. The change is thereafter calculated by subtracting the carbon stock from the previous inventory from the carbon stock of the present inventory.

Combining carbon stock change data with land-use time series

In this step, a time series starting from 1990 to the last reporting year is created for each plot in the NFI. This time series also contain information on present and former land-use. Information on the determined changes in litter and soil carbon pools are integrated into the dataset, interpolated between

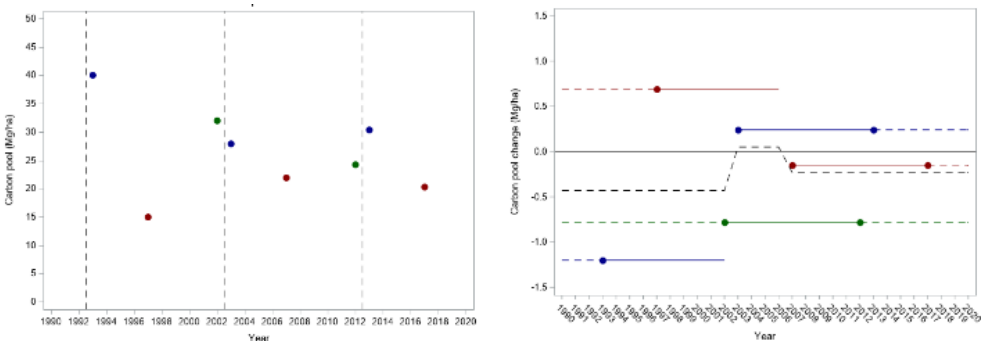

Figure 1. The left panel show measured values of the litter carbon stock for three permanent plots during the three inventory periods. The plot depicted by the green colour has only been measured twice. The right panel show the resulting calculated changes for the three plots. The black dashed line is the hypothetical reported average time series for the three plots.

measurement years and extrapolated backwards and forwards so that each plot has a complete time series for the whole reporting period. The principle is illustrated in Figure 1. Emissions from organic soils are calculated using emission factors.

Tested new models

Two alternative and principally different models for calculating the time series were tested and compared with the current method. The first method is referred to as the "average change" method and the second method is referred to as the "regression method".

Average change method

The average change method is similar to the presently used method. The difference is that the changes in carbon pools of a plot are averaged over the whole time series. This means that the calculated change for a plot becomes constant over the entire reporting period. However, it will change in level every time a new measurement is made on the plot.

Regression method

An alternative way of determining carbon change for different pools along the time series would be to use regression for the averaged measured carbon pools for each reporting category using year as the dependent variable (Figure 2). With this method, the carbon change for a pool would be equal to the slope coefficient in the regression and the change would be constant over the whole reporting period. Every year a new measurement will be added causing a change in level of the reported time series. A principal difference between this and the above-mentioned methods is that the change is not calculated on plot level but on the average of the carbon pool for each year for the entire sample. That means it becomes more difficult to attribute change to different land-use change classes.

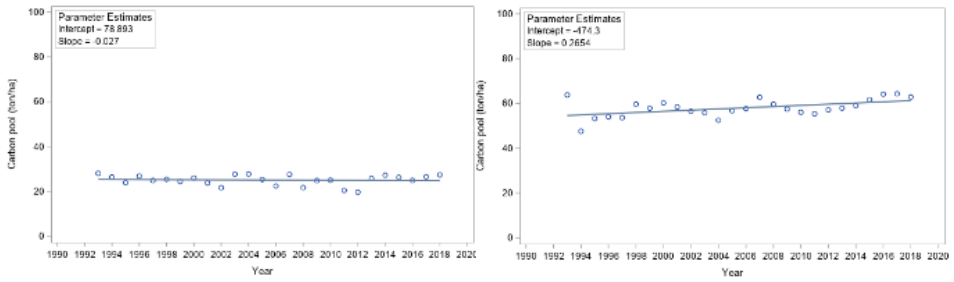

Figure 2. Regression of the fine litter and soil carbon pools. The slope indicates magnitude and direction of change.

Method test

Both the methods described above were tested on five consecutive submissions, 2018 until 2022, and the results were compared with the presently used reporting method.

Results

Fine litter carbon on Forest remaining forest

The results from applying the three different calculation and interpolation methods for the fine litter carbon pool on forest land remaining forest land are shown in Figure 3. The hitherto reported data show little variation up to

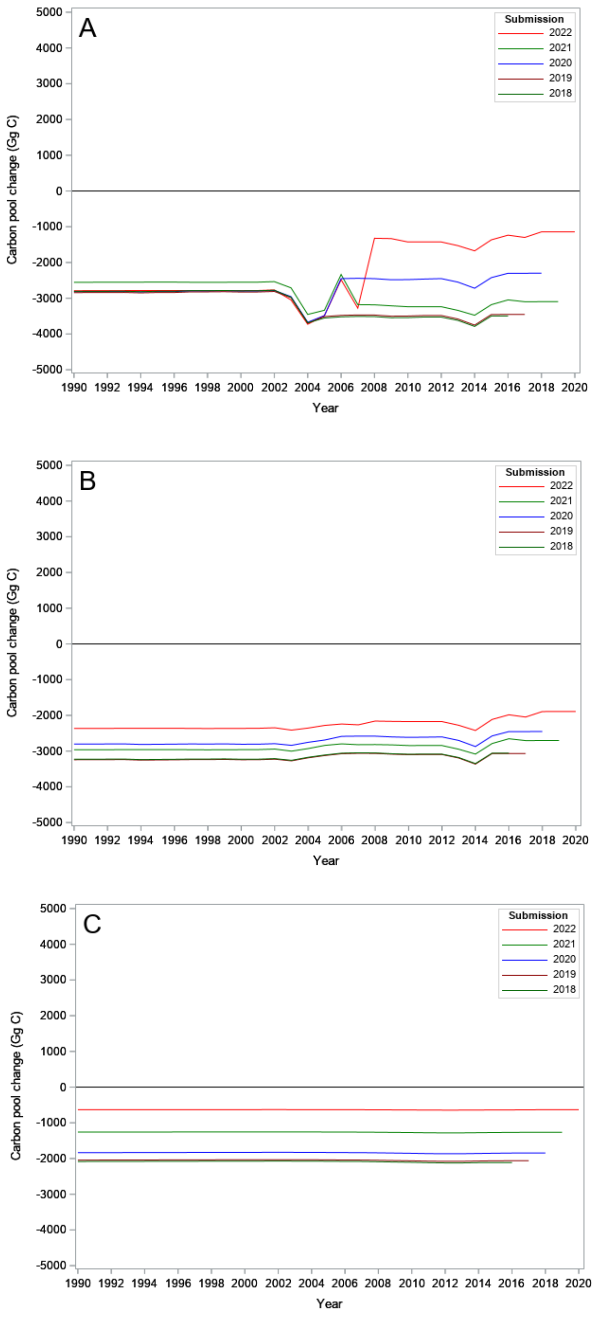

Figure 3. The upper panel (A) show reported data for the change in the fine litter pool for five submissions. In panel B the same pool is calculated using the average change method while panel C show time series data using the stock regression method. Positive values indicates a sink, negative values a source.

2003 but then varies considerably after 2010 with a difference in carbon stock change between the lowest (submission 2018) and the highest values (submission 2022) of around 2 100 kt C per year which corresponds to 7.7 Mt CO_2 per year. Using the average change method, the change is distributed over the whole time series. In this case the difference between the lowest and the highest values of the recalculated time series is 930 kt C per year corresponding to 3.4 Mt CO_2 per year. The total reported emission from the litter carbon pool for the entire time series from 1990 until 2022 is identical, 69 700 kt C, for the hitherto used method and the average change method.

The stock regression method also consistently shows that the fine litter carbon pool to be a source. Like the other two methods it also indicates that this source is getting lower with time. This method gives for each reported time series a straight line. The difference between the lowest and the highest calculated time series is 1 500 kt C per year which corresponds to 5.4 Mt CO_2 per year. Looking at the accumulated value for the emissions over the whole time series there is a considerable difference. The stock regression method has an average accumulated reported emission amount that corresponds to 54% of the accumulated amount for the current reporting method and the average change method.

Soil carbon on forest land remaining forest land

The results from applying the three different calculation and interpolation methods for the soil carbon pool on Forest remaining Forest land are shown in Figure 4. All methods show that soil carbon is a substantial sink. The reported data show little variation up to 2003 but then varies considerably after 2008 with a difference in carbon stock change between the lowest (submission 2022) and the highest values (submission 2019) of around 1 400 kt C per year which corresponds to 5.1 Mt CO_2 per year. There was a drastic drop in the change from 2008 and onwards in submission 2022. Even the average change method shows a similar, but much smaller, drop along the time series from 2008 and onwards. This has also resulted in a shift in the lines in the beginning of the time series where the data for submission 2022 has gone from having the highest value in the beginning of the reported data series to having the lowest value in the beginning of the averaged times series. In the averaged time series the difference between the lowest and the highest values is 890 kt C per year corresponding to 3.2 Mton CO_2 per year. The total reported emission from the soil carbon pool for submission 2022 is 109 000 Gg C, for the reported data and the average change method. The total reported uptake from the soil carbon pool for the

entire time series from 1990 until 2022 is identical, 109 000 kt C, for the hitherto used method and the average change method.

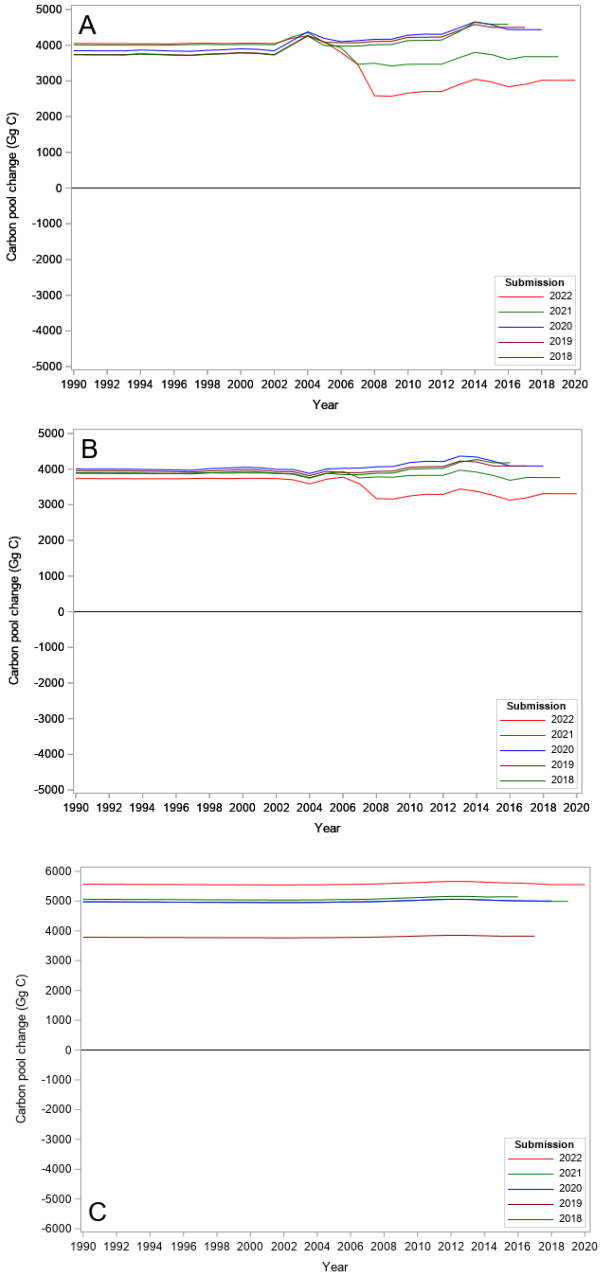

Figure 4. The upper panel (A) show reported data for the change in the soil carbon pool for five submissions. In panel B the same pool is calculated using the average change method while panel C show time series data using the stock regression method. Positive values indicates a sink, negative values a source

The stock regression method shows large variations between the years. Unlike the other two methods the time series for submission 2022 is highest and submission 2019 the lowest. The difference between the lowest and the highest calculated time series is 1 800 kt C per year that corresponds to 6.6 Mton CO_2 per year. Looking at the accumulated value for the emissions

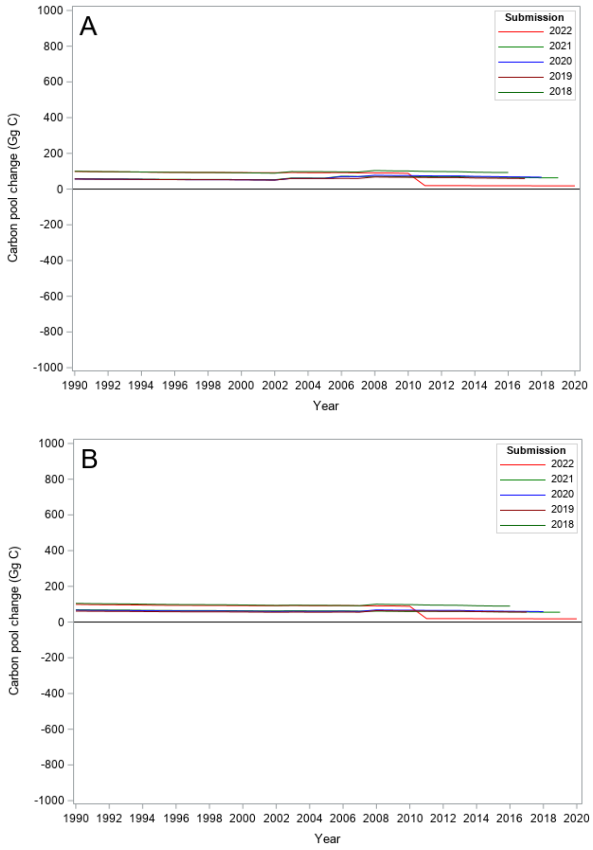

Figure 5. Time series of changes in the fine litter carbon pool on grasslands. Panel A is the reported time series in submission 2022 and panel B the same time series using the average change method. Positive values indicates a sink, negative values a source.

over the whole time series there is a considerable difference. The stock regression method has an average accumulated reported emission amount that corresponds to 126% of the accumulated amount for the reporting method and the average change method.

Fine litter carbon on grassland remaining grassland

The fine litter carbon fraction on grassland is a small pool. The average size of the pool for the time series reported in submission 2022 was 1.7 ton C/ha. In comparison, the same figure for forestland was 24.8 ton C/ha. Most soils on grassland do not have an O horizon. If the O horizon is missing, no litter layer sample will be taken and the fine litter fraction will be estimated based on annual litter fall only. Annual litter fall is calculated using empirical functions based on the tree stand so they are not subject to the same variation as a sampled fraction. Hence, the calculated change in the pool will be small with little variation, which can be seen in Figure 5. The variation that still can be seen along the time series is to a less extent due to

estimated changes in the pool on specific plots. It is merely caused by plots removed or added along the time series and not fully covering the whole time series. The reason for this can be that plots are removed due to land use change or added when they have been in a land-use change class for twenty years. In some cases, plots can also shift from mineral soils to organic soils or vice versa. The largest difference between the time series is between submission 2018 and submission 2022 is 79 kt C per year corresponding to 0.28 M ton CO_2 per year and the corresponding figure for the averaged time series is 76 Gg C per year which makes the difference between the two calculation models very small for this carbon pool.

Soil carbon on grassland remaining grassland

The grassland soil carbon pool is considerably larger than the fine litter pool with an average size of 74.9 ton C/ha. However, the variation of the change in this pool over the time series is limited (Figure 6) and of the same magnitude as the fine litter pool. A major part of the variation in the time series is not caused by large changes in carbon pools between inventories but by plots leaving or entering the time series resulting in the sample

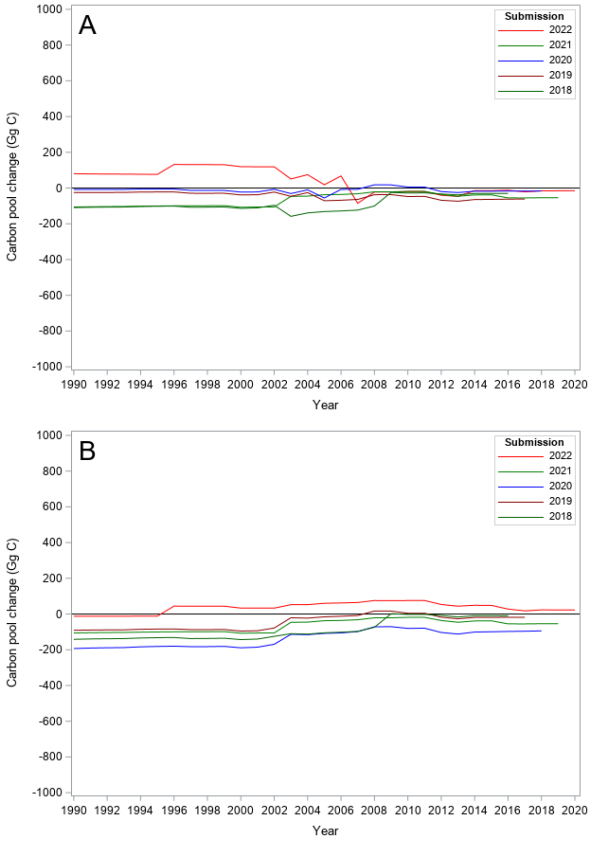

Figure 6. Time series of changes in the fine litter carbon pool on grasslands. Panel A is the reported time series in submission 2022 and panel B the same time series using the average change method. Positive values indicates a sink, negative values a source.

varying over the time series. The largest difference for the reported change in the grassland soil carbon pool between the submissions (submission 2022 and submission 2018) is 238 kt C per year corresponding to 0.8 Mt CO_2 per year. For the averaged time series it is a little bit higher, 274 Gt corresponding to 1 Mt CO_2 per year.

Grassland in Sweden frequently changes land-use, which as explained above, may lead to variation in the time series. One hundred and fifty-six (156) plots were registered as grassland remaining grassland sometime during the time series of submission 2022. Out of these, there were only 116 plots (74%) that were classified as grassland remaining grassland during the whole period between 1990 and 2022. In the beginning of the time series, 1990, there were 139 plots classified as grassland remaining grassland and in the end of the time series there were 131 plots classified as grassland remaining grassland. Most of the plots, 68%, that were removed from grassland remaining grassland were converted to forest. Most of the plots that were converted to grassland (60%) were previously cropland.

Discussion and conclusions

Sweden is one of few countries that report carbon stock changes based on repeated measurements in a soil inventory. The strength of such an approach is that it can describe changes over time but also give an estimate of the uncertainty of the predictions of carbon stock change. The difficulty of the approach is that the changes are small in relation to the stock but large in relation to the national carbon budget. Swedish forest soils contain in average 60 ton soil C/ha. If that stock changes with one part per thousand, i.e. 60 kg/ha the total change for mineral forest soils in Sweden is 1.4 Mt C or 5 Mt CO_2. Small changes lead to huge emissions or uptake. This is the core of the problem with the presentation of the time series for the fine litter and the soil organic carbon pool on mineral soils. Relatively small variations in the stock changes appear as huge sinks or sources in the reporting tables. Due to the annual recalculations, when new data is added to the data base, these changes may appear differently between years. The interpolation system has been designed to level out these changes and produce smoother time series. However, the introduction of data from the third inventory created variations in the time series that is difficult to handle and interpret in the context of national greenhouse gas reporting. The problem with the present interpolation system is that it changes the time series 12 years back in time, which is not intuitive unless you are familiar with the data and the method. Further, although real changes are very small on plot level the do give rise to large variations in sinks and sources between inventories on the national level.

The tested method on averaged change time series, where the change for a single plot is averaged over the whole time series instead of between measurements, results in smaller variations between years on forest remaining forest land for both fine litter and soil carbon. Further, it does not create any variation in the middle of the time series. It also gives a total estimate of emissions and uptake that is identical to the previously used reporting method. A technical advantage is that it is easy to integrate with the land-use change data on plot level. Since it distributes the changes over the whole time series it is less responsive to real changes induced, e.g. through management change.

Using the stock regression method has similarities to the average change method in the way that each recalculation when new data is added changes the whole time series. However, these changes seem to be larger than for the average change method. The fact that the figures do not show any change is a bit elusive. It is because the method does not calculate change at plot level

but using the entire dataset. This means that the land-use data has to be determined before the regressions are made, i.e. separate regression datasets has to be created for each land-use class. A problem with the regression method is that a new data point that is an “outlier” may have substantial leverage on the regression creating substantial shifts in the level of the time series.

The conclusion from this project is to recommend the average change method to be used for calculating and interpolating the time series for fine litter and soil organic carbon for forest remaining forest and grassland remaining grassland.