Dear Referee,

We sincerely appreciate your careful review and constructive scientific feedback on the manuscript. Your insightful comments and encouraging assessment have been highly valuable in improving the study. While addressing all specific technical comments in detail below, we have expanded the model's sensitivity analyses, results, and discussion sections. We also added some figures to this document that would go to the supplementary material and some figures to better explain the text in this document. These revisions have substantially improved the clarity, robustness, and transparency of the manuscript.

We have further modified the language and typos in the text along with the addition of tables intended for the supplementary material. In this document we marked the original manuscript text in black, reviewer's comments with indented paragraphs, answers to the comments in reddish orange color and modified text for manuscript in blue.

We look forward to your feedback on these modifications.

Best regards,

Ahmed Hasan Shahriyer, on behalf of all authors

Detailed comments

> L. 27: The contrast between nutrient-rich and nutrient-poor forested peat soils is not entirely clear in this section - maybe in partly because of missing literature. I trust that the statement that drainage of nutrient-rich soils is a source of CO_2 would also apply to nutrient-poor soils? And do the authors have sources for the impacts on both types (both the effect of drainage, and the offsetting effect of forestry)?

Thank you for pointing this out. We have now modified the paragraph and added some literature. The modifications will appear in the manuscript as written below.

Carbon-to-nitrogen ratio (C:N) is an often-used indicator for the nutrient status of peat soil and it is typically lower in drained nutrient rich peat. Decomposition of peat releases nutrients available to plants, and this nutrient input decreases from rich to poorer sites (Bayley et al. 2005). Peat soils on drained nutrient-rich sites tend to be sources of CO2 (He et al. 2016, Kasimir et al. 2018) and may act as a carbon sink in nutrient-poor sites (Ojanen et al. 2013). Forest ecosystems on nutrient rich soils have been significant CO2 sources (Lohila et al. 2007, Ojanen et al. 2013) to a small sink (Korkeakoski et al. 2023). Forest ecosystems on nutrient poor soils on the other hand have been moderate sinks (Tong et al. 2024) to high sinks (Laine et al. 1996, Lohila et al. 2011, Minkkinen et al. 2018). However, it may take decades for forest ecosystems to reach a net CO2 sink after drainage, if it is reached at all (Quesada et al. 2025).

> L. 47: There seem to be two contradicting arguments in this paragraph: On the one hand, CCF maintains a higher WT (L. 48), but the transpiration is large enough to keep a low WT that avoids hindering tree growth (L. 51). I think it would be nice to clarify this and provide a good overview of the trade-offs affected by WT here (peat degradation, tree growth, methanogenesis).

We clarified the issue and the whole paragraph will be modified as written below.

In drained peatlands, vegetation growth significantly influences the water table (WT) through evapotranspiration. Increased biomass, particularly from deep-rooted trees, promotes water loss, leading to a decrease in WT (Laiho, 2006). A non-harvested mature forest has higher evapotranspiration compared to the forest where a selective harvest has been conducted. In CCF, the WT remains higher than in the full-grown forest (Sarkkola et al., 2010), and results in reduced aerated peat layer and peat degradation, thus minimizing the carbon loss from the soil. In RF, after clearcut, WT rises significantly because of lack of transpiring vegetation (Leppä et al. 2020) and often requires ditch management to lower the WT before planting new seedlings.

In CCF, however, the remaining trees continue to transpire water and keep the WT low enough without hindering forest growth (Nieminen et al., 2018).

> L. 55: The Lettosuo site has not been introduced here yet - maybe provide a brief description of the site.

Thank you for your suggestions. We have now added a short text on Lettosuo in blue with the main text in black.

The Lettosuo site, a drained nutrient rich peatland forest in Southern Finland, had both selective harvest and clearcut management applied to the site to convert one part of the site into a CCF stand and another part of the site into RF stand. Measurements of the net ecosystem carbon exchange in Lettosuo showed the mature forest to be a small sink of CO2 before harvesting. The forest became a bigger CO2 source after harvest when CO2 flux from RF stand was compared against CCF stand (Korkiakoski et al., 2023). The same site was a sink for CH4 before harvest (Korkiakoski et al., 2017), and after selection harvest (Korkiakoski et al., 2020) due to low WT. However, RF stand was a source of CH4 after clear-cutting due to raised WT (Korkiakoski et al., 2019). An increase in WT could lead to higher anaerobic conditions in the soil layer that promotes methanogenesis and eventually even turn drained peatlands into a net CH4 source (Lohila et al., 2011). Further, temporal and spatial variations of CH4 can be attributed to the dynamics of soil temperature, WT, and vegetation communities (Minkkinen and Laine, 2006).

> L. 111 and elsewhere: To enhance understanding, I would recommend to add the units of the variables in the explanation of the equations.

We added the units as follows:

depth of groundwater is given in cm, ψ in cm^{-1}, K_x = cm min$^{-1.}$

> L. 112: Defining negative z_{gw} as below the surface seems to contradict with the definition in Eq. 1 (q will only be >0 if z_{gw} is more negative than the reference level Z_{gw}).

definition of Z_{gw} was removed and equation was modified so that it is now shown as absolute value, eq. 1: $|Z-z|$

> L. 114: Please explain the scaling of the recalcitrant old humus pool. I trust that the pool is computed dynamically, so where is the scaling happening, and how is excess C treated? And which shortcoming in the model is this change trying to resolve?

The scaling of the recalcitrant old humus pool was performed to better align with what is known from measurements about peat soil C/N characteristics (Laine 1989, Klavins et al. 2008, Alm et al 2023, Prescott et al. 2021). Further, the scaling to appropriate pools was done at the start of the simulation and the pools then changes dynamically over the duration of the simulation. We will modify the text in section 2.1 along the following lines.

Soil organic matter is represented by three conceptual pools (labile, recalcitrant young, recalcitrant old) differing in turnover time and C/N ratio. The C/N ratio of the young recalcitrant pool is 1.5 times the bulk soil C/N ratio, which is the model's default parametrization for agricultural (mineral) soils. Peat soils in this study are characterized by systematically higher bulk C/N ratios than mineral soils. For peat, we interpreted the young recalcitrant pool as the main peat pool and therefore aimed to reduce the initial relative share of the old recalcitrant pool compared to mineral soils. To achieve this while conserving bulk soil C and N, we assigned a lower C/N ratio to the old recalcitrant pool than to bulk soil, which reduces the amount of C that is allocated to this pool. The C/N ratio of the old recalcitrant pool is scaled as a function of the bulk soil C/N ratio:

> Fig. A1: Please add a scale. Also, it would be interesting to add the date of the photo in the caption (for comparison with the management dates in section 2.2).

The picture was taken in August 2016 (added to the caption) and a scale was added to the figure.

L. 147: Please clarify the CO_2 driving data: RCP 4.5 does not start in 1963. Also, please add a reference.

Indeed, we used the observation-based CO2 concentration data up to 2005 and RCP4.5 since then. The observed values do not deviate much from the RCP by the end of the simulated period (1.3 ppm by 2021) and therefore the impact to model results is minor. We will add the following details in the text with an appropriate reference to RCP.

The CO_2 concentration used to drive the model was based on observations up to 2005 and follows RCP4.5 since then (i.e. historical + scenarios) and deviates from the observed value (https://gml.noaa.gov/webdata/ccgg/trends/co2/co2_annmean_gl.txt) by 1.3 ppm by 2021 (Meinshausen et al. 2011).

Section 2.3: It would be nice to distinguish here between data used to drive the LDNDC model, and data used for evaluation.

Section 2.3 is now divided into 2 subsections called model driving data and model evaluation data.

Table A1: Please add units for the variables. The ranges are hard to interpret without knowing the unit in the model.

The units will be added to the table.

L. 194: An NSE value for "good" model performance ought to be variable-specific: Some variables are much harder to capture in models than others.

We have removed the following text

Preferably NSE values greater than 0.5 are desirable, indicating good model performance with respect to variable in question (here NEE).

It will be stated that,

The NSE value closer to 1 is desirable, indicating good model performance.

> L. 225: The parameter optimization method needs to be described in more detail. It is unclear to me how the best parameter value for an individual parameter can be found while varying a set of parameter values at once. Is there any optimization involved, or are you simply treating all sets of parameters as samples? In the case of the latter, the number of simulations could be worryingly low, given the high dimensionality of the problem (3 sets of 9 parameters to vary at the same time). But I may misunderstand the exact method used here.

We hope that the explanation below clarifies the application of the method associated with sensitivity analysis. We will modify the article text in the sensitivity section accordingly. We also added 3 figures from the sensitivity tests to the supplementary materials (also given at the end of this document).

The three sets of nine parameters were not varying simultaneously; instead, only one set of nine parameters was varied at a time. First, we selected 9 soil decomposition-related parameters and studied their sensitivity by running the simulation 8649 times. The values of these parameters were randomly selected by the FAST algorithm to run these simulations. After these runs, we selected the parameter values that produced the highest NSE (related to NEE) value. The first set of parameters had these values fixed when the next set of 9 parameters was running. Again, the parameters values that produced the best NSE (related to NEE) were selected. Now these eighteen parameters had values fixed when the next set of nine parameters was running. We consider the number of simulations per set of parameters to be adequate.

These were run purely to observe the sensitivity of the parameters, and no optimized parameter values were used in full forest simulations as such. Full simulations from seedlings to maturity were done separately with only a few select parameters, and the parameter values were chosen as such that maintain the observed species composition. This was done because slightly different parameter values could produce a different composition of forest compared to what is being observed at the site. Our goal requires that the simulation produce the observed forest structure. Many variables (NEE, soil moisture, water table, LAI and forest structure, CH4) were compared to the measurements in the full forest runs as opposite to the sensitivity runs where only NSE related to NEE was checked. Setting up the optimization of the full forest runs with all the variables might be possible, but the full runs are computationally time consuming.

> Also, it is unclear whether NEE is the only variable used to optimize against in the sensitivity analysis. It would also be good to report the default value used in set 2 and 3 while varying set 1.
>
> Finally, it would be nice to not only provide the ranges of parameter values that you apply in the sensitivity tests, but also the final values that you end up using.

Thank you for your valuable comment, reply to the previous comment contains the answer to the NEE question. But further a new table containing best NSE, best parameter values and default values will be added to the manuscript appendix.

> Fig. 2: What is "soil moisture" here referring to? Volumetric moisture content or saturation of the pore volume? The modelled value for 20 cm depth seems to peak around 60%, but there is one episode in May 2018 where it suddenly rises to 80% - it would be nice if the authors could investigate why the model produces this peak. Also, It would be interesting to see the model performance outside the growing season: Does LDNDC capture the freeze-thaw dynamics, too? And what causes the model to be so water-conserving in the 2018 drought?

The soil moisture refers to volumetric moisture content, this information will be added to the figure caption

Transition of 2018 winter to spring was faster compared to other years, thus the snow melted faster in the model, which could result in the peak in moisture content. We will add a notation regarding this to the text.

The model gives the soil moisture output as sum of water content and ice content whereas measurements are unable to capture the ice content. Because of that only the growing season is shown in the manuscript.

The model is indeed water-conserving in 2018, which could be related to the value of VanGenuchten parameters used to run the simulation and the interaction between the vegetation and soil moisture. These aspects might be restricting the water content from going below a certain level. However, thorough investigation of extreme drought episodes is out of the scope of this study as we focus on the general development of forests under different management regimes in typical climate conditions. We will add text about this in the discussion.

> L. 269: I like Fig. S5 and would urge the authors to bring it into the main manuscript (and include a description of it). The figure displays the difference between the three setups, and hence illustrates both the lateral groundwater movement that was introduced in LDNDC in this manuscript, and the difference in influence of the forest practice on water dynamics, which is one of the key arguments in the introduction.

Moved to the main text.

> Section 3.3: It would be nice to describe the two simulations with different water tables in more detail. How was the WT variation imposed (varying Z_{gw}?), and what was the rationale for these changes?

Thank you for raising the discussion. WT variation was imposed by modifying the groundwater lateral gradient parameter (ψ). The manuscript text was modified as written below with the blue sections added as new text and the rationale of the changes were that CH4 is influenced by various environmental variables listed (literature) in blue text below and only WT was selected to show modeled CH4 behavior to changing WT.

Manual chamber measurements showed RF stand to be a source of CH4 in summer months after clear-cut harvest. The simulations originally showed a CH4 sink for the same period. As temporal and spatial variations of CH4 can be attributed to the dynamics of WT, soil temperature and vegetation communities (Minkkinen and Laine, 2006) and in dry conditions to the wind speed (Korkiakoski et al. 2017) and soil temperature (Sundqvist et al. 2014). The role of WT on the CH4 flux difference was further investigated. Indeed, the CH4 flux in the simulation was found to be sensitive to WT variations after clear-cut. To simulate two different WT, the groundwater lateral gradient parameter (ψ) was modified while keeping the reference WT (Z_{gw}) same. Simulated WT before clear-cut did not change because of modification to ψ but simulated wt did indeed changed after clear cut. Modification to ψ produced two simulated WT that were similar to the lowest and highest observed WT at the RF stand (Fig. 4). No additional changes were needed for the model setup to produce this shift in WT.

Simulation with the original value ψ = 28.7, produced the lowest WT, led to a higher sink of CH4. While the modified parameter value (ψ = 38.7) produced a higher WT and resulted in smaller sink of CH4. In high WT simulation, the site was even a source of CH4 on some occasions. Both RF simulations showed very little changes in modeled CH4 fluxes before harvest and the model simulated a lower CH4 sink compared to the measurements (Fig. 4).

> Figure 5: It would be nice to have the legend outside the figure box, or with a box around it - to ensure that there is a clear difference between observation points and legend.

A legend box was added to the legend to separate the data.

> L. 283: There is an interesting difference in the simulated and observed timing of CH_4 fluxes. The authors describe this to some extent, but do not comment on it or provide possible explanations. It would be nice to hear whether the authors have a possible explanation for it (this could also be a part in the Discussion).

We do not have solid explanation to the differences, but we will modify the text based on some literature in the result section 3.3 (blue text) and discussion (blue text)

Section 3.3

Modeled CH4 flux was within the variation of the automatic chamber measurements for both control and CCF stand (Fig.5). The measurements showed mostly uptake of CH4 from the atmosphere over the 3.5 years of measurements at both stands. When looking at the seasonal dynamics, compared to the measurements, the model was in the upper end of CH4 uptake during spring and summer, while the model underestimated the uptake during autumn and early winter. Korkiakoski et al. 2017 showed that CH4 flux aligned with soil temperature at the beginning of summer and with WT from the mid-July onward at this site. However, the underestimation of uptake was not clear in 2016 for either stand.

Discussion:

Simulation showed that the uptake in CCF stand, over the next 5 years after selective harvest, was on average 17% smaller than the control stand. Reduction in CH4 uptake, after selective harvest, has been observed in drained peatland (Korkiakoski et al. 2020) as well as in an upland boreal forest (Sundqvist et al. 2014).

> Fig. 6: Is this based on the half-hourly data, or the daily averages? Please add this information to the figure caption.

The caption was modified to highlight that daily aggregate was taken from half hourly good quality measurement and corresponding modeled data.

Fig. 7: "Uncertainties in the EC-based NEE [...] are shown with the error bars". Please explain how these uncertainties were derived.

The following explanation was added to the figure caption:

Uncertainties in the EC-based NEE [...] calculated by Korkiakoski et al. 2023 following the uncertainty estimates by Heimsch et al. 2020 included statistical measurement error and gap-filling error. These uncertainties are shown with the error bars.

Section 3.4: The analysis is based primarily on a comparison between daily (or subdaily?) model and observation estimates (Fig. 6) and annual sums (Fig. 7). It would be interesting to learn a bit more on the seasonality in the CO_2 fluxes: How well are these captured, and how well does the model capture differences between individual summers (similar to the analysis of the CH_4 flux in section 3.3)?

There was text related to analysis of individual seasons in the supplementary material; that text was modified and brought back to the main manuscript text to explain the seasonality observed by the model, while keeping the seasonal time series figures in the supplementary material.

Section 3.5: It would be nice to see an analysis that describes the impact of the changes made to the model. You have captured the description of the drainage nicely by showing differences in hydrology between the sites. What has been the impact of the changes in the recalcitrant humus pool? Has this been improving the seasonal behavior, the long-term trend, or both?

Text related to allocation of humus pools was modified based on the referee's comment related to L114 in section 2.1. Based on that text, further explanation was added as given below to section 3.5 and discussion.

There were no measurement data available to compare seasonal behaviors of the pools but below the figures from the old and new model versions are given, but we do not write anything in the manuscript since it is out of scope for this study.

Section 3.5:

The bigger fraction of carbon in humus pools was allocated to the recalcitrant young pool and figures for pool developments of the three different humus pools before management are given in the supplementary material.

Discussion:

Previously, the model was constructed to represent the mineral soil, thus changes to the carbon allocation in humus pools were necessary to capture the peatland characteristics. The soil layer with mineral soil pool allocation setup produced too low respiration from the soil. This was because, before modification to the pool allocation, a bigger fraction of carbon was allocated to the recalcitrant old pool. But with the new implementation a higher fraction of carbon was allocated to the recalcitrant young humus pool, which had a higher turnover rate than the recalcitrant old pool. Thus, it helped to increase the respiration associated with the decomposition of peat.

> Section 4: The discussion is mainly used to highlight results, and to describe the comparison between simulation results and observations. It would be nice to strengthen it by (1) discussing the importance of the model developments (new functionality, altered parameterization) made in this study, (2) comparing the results more to other studies, and (3) highlighting potential use of the model with this new functionality.

We will use the following additions (marked in blue) to strengthen the original discussion (marked in black). The text in the earlier comments marked for discussions are included in the text below, so there will be some repetition:

Modified discussion:

The process-based model LandscapeDNDC realistically simulated the forest structure of the drained forested peatland, both before and after management events, using the prescribed species composition. Simulated mature forest LAI was similar to field-estimated LAI reported by Leppä et al. 2020 for the same site. Seasonal variation, the sum (2-4 m^2 / m^2) of the three tree species (Pine, Spruce and Birch) LAI in the simulation, was within the range reported by Rautiainen et al. 2012 in several mixed forests in southern Finland. However, the summed modeled LAI of all individual tree species did not correspond well with the satellite-estimated LAI for the site. This could be because the satellite-estimated LAI most likely reflects the primary canopy structure consisting of dominant pine and birch trees at the study site. Indeed, the control stand had a dense canopy (Fig. A1) and the visibility of the secondary vegetation and forest floor can be poor with the satellite.

Modeled LAI matched the satellite-estimated LAI well for CCF and RF stands after management because vegetation was sparse at the CCF stand immediately after selective harvest and almost no vegetation at the RF stand after clear-cut (Fig. A1). So model comparison with satellite estimates for these sparse vegetation stands gives much more accurate picture. Further, the declining trend in the modeled LAI for pine and spruce in control stand could be a result of competition between species in the model as well as the nutrient distribution among the species.

While simulation using site measured WT was possible with LDNDC, implementation of dynamic WT in this study gives the capability to generate the WT internally for peatland ecosystem. The fluctuations in WT, because of applied management, at the RF simulation were more pronounced and captured by the model. However, the fluctuations were hard to distinguish in the CCF immediately after harvest, but simulated WT was similar to the measured WT from the third year in CCF. Fluctuations in the WT due to management had been reported for the Lettosuo site from previous field studies (Leppä et al. 2020, Korkiakoski et al. 2019, 2020) and suggested an increase of 18-23 cm in WT at RF.

The model is water-conserving in 2018, which could be related to the interaction between the vegetation and soil moisture. Parameter values used for VanGenuchten parameters to calculate the water retention curve and saturated hydraulic conductivity might be restricting the water content from going below a certain level. However, thorough investigation of extreme drought episodes is out of the scope of this study as we focus on the general development of forests under different management regimes in typical climate conditions.

The simulation of the CH_4 fluxes for control and CCF was good, and the site was mostly a uptake of CH_4. Simulation showed that the uptake in CCF stand, over the next 5 years after selective harvest, was on average 17% smaller than the control stand. Reduction in CH4 uptake, after selective harvest, has been observed in drained peatland (Korkiakoski et al. 2020) as well as in an upland boreal forest (Sundqvist et al. 2014). Further, we have investigated the autumn mismatch of CH4 fluxes by changing the CH4 oxidation and production parameters. While it shifted the CH4 flux from higher sink to lower sink if CH4 oxidation is low and vice versa, but that did not remove the mismatch. We were satisfied with the simulated CH4 flux, since it was within the observed CH4 flux measured with chamber measurements. The chambers had different species abundance and that might impact how CH4 was transported from soil to atmosphere within the chamber. Our model had simplistic ground vegetation and three tree species. Further, the individual chamber could have different soil moisture, water table, and soil temperature. Those might have an effect on the CH4 flux. All these factors could result in the difference observed in the CH4 flux.

However, CH_4 flux dynamics after clear-cut in the RF were quite sensitive to the changes in WT. According to the measurements, RF changed from CH_4 sink to source after clear-cut (Korkiakoski et al. 2019). However, the model showed the RF to be a sink of CH_4 after the clear-cut in the RF simulation with low WT, and a season-dependent source and sink in the RF simulation with high WT. Another measurement study with two different RF sites showed that the sites remained small sinks (0.07 and 0.52 mg CH_4 m^{-2} d^{-1}) of CH_4 even after clear-cut

(Huttunen et al. 2003). CH_4 flux could be dependent on the localized WT. Thus, the placement of the chambers compared to the distance of ditches is an important factor to consider when comparing the model results with measurements (e.g., Laurén et al. 2021). The locations for the manual chambers in this study varied within 4--22.5 meters from the ditch and here we used an average WT from the chambers. Additionally, logger WTs were included in the study to cover the variability in the study site.

The simulated CO_2 annual balances showed net CO_2 sink similar to the observation for the pre-harvest period. Also, the simulated CO_2 annual balances for $CCF_{postharvest}$ and $RF_{postharvest}$ were in good agreement with the measurements in terms of when the stand (CCF) became a sink after harvest or how long the stand (RF) stayed a source. In RF, after the clear-cut, the ecosystem was a source of CO_2 to the atmosphere according to both model and observations, which is largely due to the removed assimilation capacity of trees and increasing respiration from the harvest residuals (Korkiakoski et al. 2019).

In CCF, after selective harvest, the annual balance had a similar trend for both observation and simulation, where the first three years were a source of CO_2 and the next three years were a sink. However, we saw a small increase in the modeled GPP and TER already on the third year after the harvest, which was not evident in the observation-based GPP and TER. This could suggest that the simulation overestimates the recovery speed of the vegetation. The simulated WT could not get below the prescribed Z_{gw} of 0.62m, which in turn have contributed to the trees not suffering from any drought effect in the simulations. As water was always available for the trees to uptake, this fact could explain why the effects of drought on CO2 balance in summer 2018 (Korkiakoski et al. 2023) were not captured by the model when daily time series was investigated. But on annual scale for both CCF and RF the discrepancies in CO2 balance in 2018 were not large even though 2018 was exceptionally dry (Lehtonen et al. 2019). This suggests that water availability below Z_{gw} for roots had only a minor influence on the overall CO2 balance.

The underestimation in the NEE for the first two years after clear-cut resulted from the model estimate of TER being lower compared to observations. The higher GPP in the year 2020 and 2021 is related to the introduction of the birch seedlings in 2019. The model only allows the seedlings to have a certain diameter (1 cm) at breast height and height of 50 cm when introduced for the first time. Thus, birch in the simulation may be slightly larger than the ones observed in the field conditions at that time resulting in higher GPP in 2020 and 2021. Additionally, lower self-thinning could also result in the initial high GPP (Forrester et al. 2021). Thus, a lower number of seedlings than observed numbers can be used to get a more accurate GPP in the initial years. Indeed, a test with birch seedlings number of around 11000, instead of 17000, produced GPP values that were closer to the observation-based estimates.

Previously, the model was constructed to represent the mineral soil, thus changes to the carbon allocation in humus pools were necessary to capture the peatland characteristics. The soil layer with mineral soil allocation setup produced too low respiration from the soil. This was because, before modification to the pool allocation, a bigger fraction of carbon was allocated to the recalcitrant old pool. But with the new implementation a higher fraction of carbon was allocated to the recalcitrant young humus pool, which had a higher turnover rate than the recalcitrant old pool. Thus, it helped to increase the respiration associated with the decomposition of peat.

In this study, the simulated annual soil carbon loss was -421 g C m^{-2} y^{-1} over 30-years period (1980-2009). A study by Simola et al. 2012, where 37 samples from peat sites with different fertility types from all over Finland were taken during the same time, reported a minimum carbon loss from the drained peatland soil to be around -150 g C m^{-2} year^{-1}. Soil carbon loss at a fertile drained peatland site in southern Finland can even be around -1000 g C m^{-2} year$^{-1\,(}$Ojanen et al. 2013). Our study site is a MtkgII type peatland forest (Vasander and Laine2008). Different drained sites with the MtkgII status could have varying amounts of carbon loss from peat, which is regulated by WT and temperature (Ojanen et al. 2013). Thus, the soil carbon loss from the simulation was in an acceptable range when compared to the literature. The slowdown in SC loss for CCF and SC gain in RF compared to continuous SC loss in control was due to the large input of carbon from fresh litter and harvest residue into the soil. The residue contribution was larger in RF compared to CCF, resulting in the SC storage gaining more carbon in RF. Higher WT in the RF could also affect soil carbon storage, resulting in reduced carbon loss from soil. SC storage started to decrease again at the RF already from the fourth year after the harvest and for CCF even earlier as input from the decomposition of harvest residue started to diminish. Also, the lowering of WT because of the increased transpiration from the growing vegetation started to contribute to the SC loss.

Overall, the model captured the transition of a mature forest stand to a forest stand that is under CCF and RF management. Annual CO2 balances suggested the faster transition of a CCF stand from source to sink compared to RF stand, a result similar to observations (Korkiakoski et al. 2023). CH4 sink was smaller in CCF compared to control stand and higher WT sensitivity for CH4 flux was evident in RF. WT reacted faster in the RF compared to CCF after harvest but simulated WT for both was similar to the measurements in the later years after harvest.

The simulated LAI fluctuations in mature forest are likely related to species competition and nutrient distribution among species within the model and could be investigated further in future studies. The water conserving behavior of the model in drought years and associated CO2 balance requires future considerations along with vegetation distributions within the chambers when comparing chamber measurements of CH4. The simulations were run from the initial drainage year in 1969 to stand maturity to examine tree growth and soil carbon development over time. This long-term simulation approach was intended to ensure that the model can also be applied to future scenario analyses. Although the assessment of future scenarios is beyond the scope of this study, the model is well suited for investigating future developments of forest management practices, carbon dynamics, and water balance.

These figures will probably be added to the supplementary material.

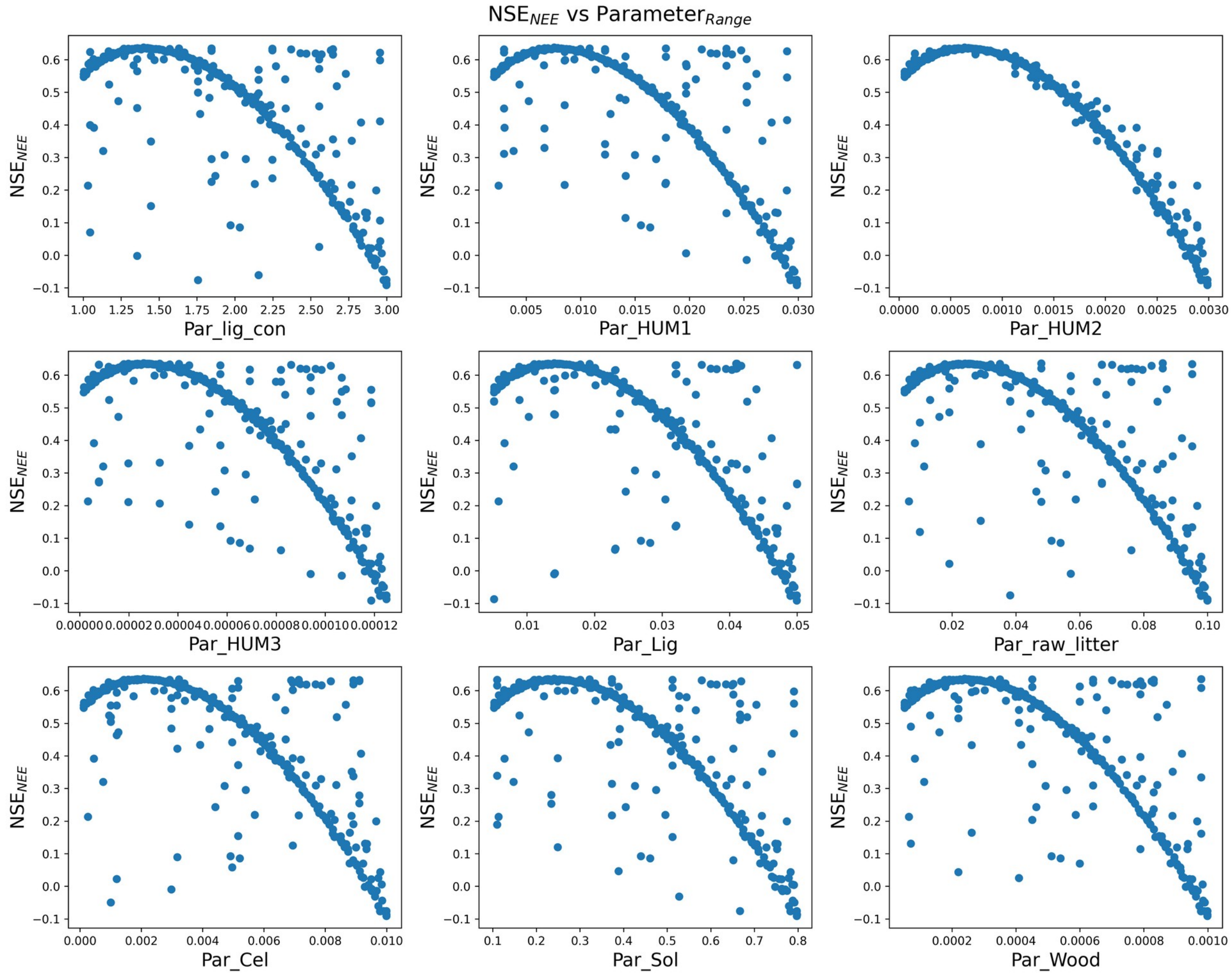

Figure: Distribution of Nash-Sutcliff efficiency (NSE) of net ecosystem exchange within the parameter range for the set 1 parameters. During these runs, default parameter values for set 2 and 3 parameters were used while running the sensitivity tests for set 1 parameters.

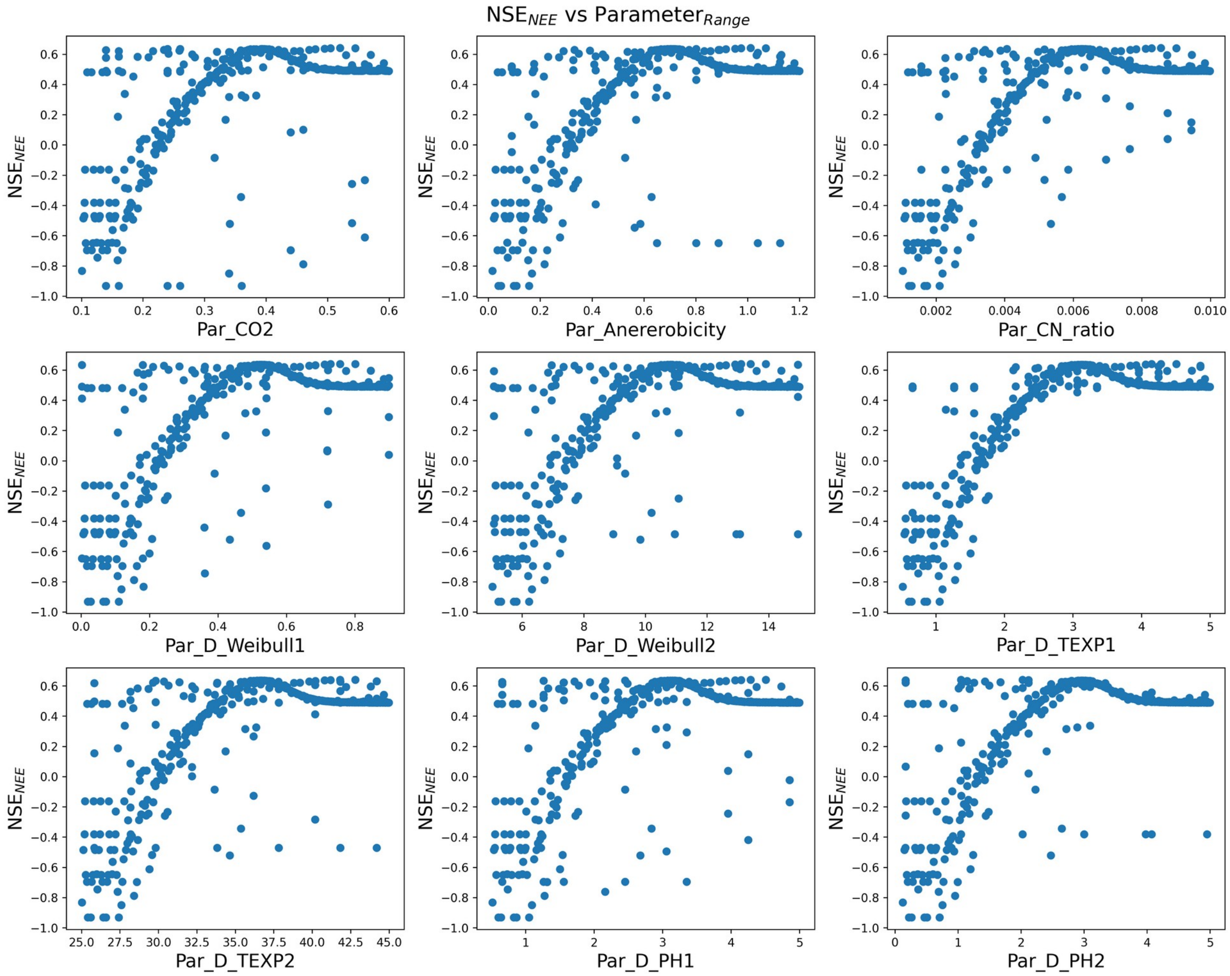

Figure: Distribution of Nash–Sutcliffe efficiency (NSE) values for net ecosystem exchange within the parameter range of set 2 parameters. During simulations for set 2, parameters in set 1 had the parameter values that yielded the highest NSE in set 1 test runs. While set 3 parameters had the default values.

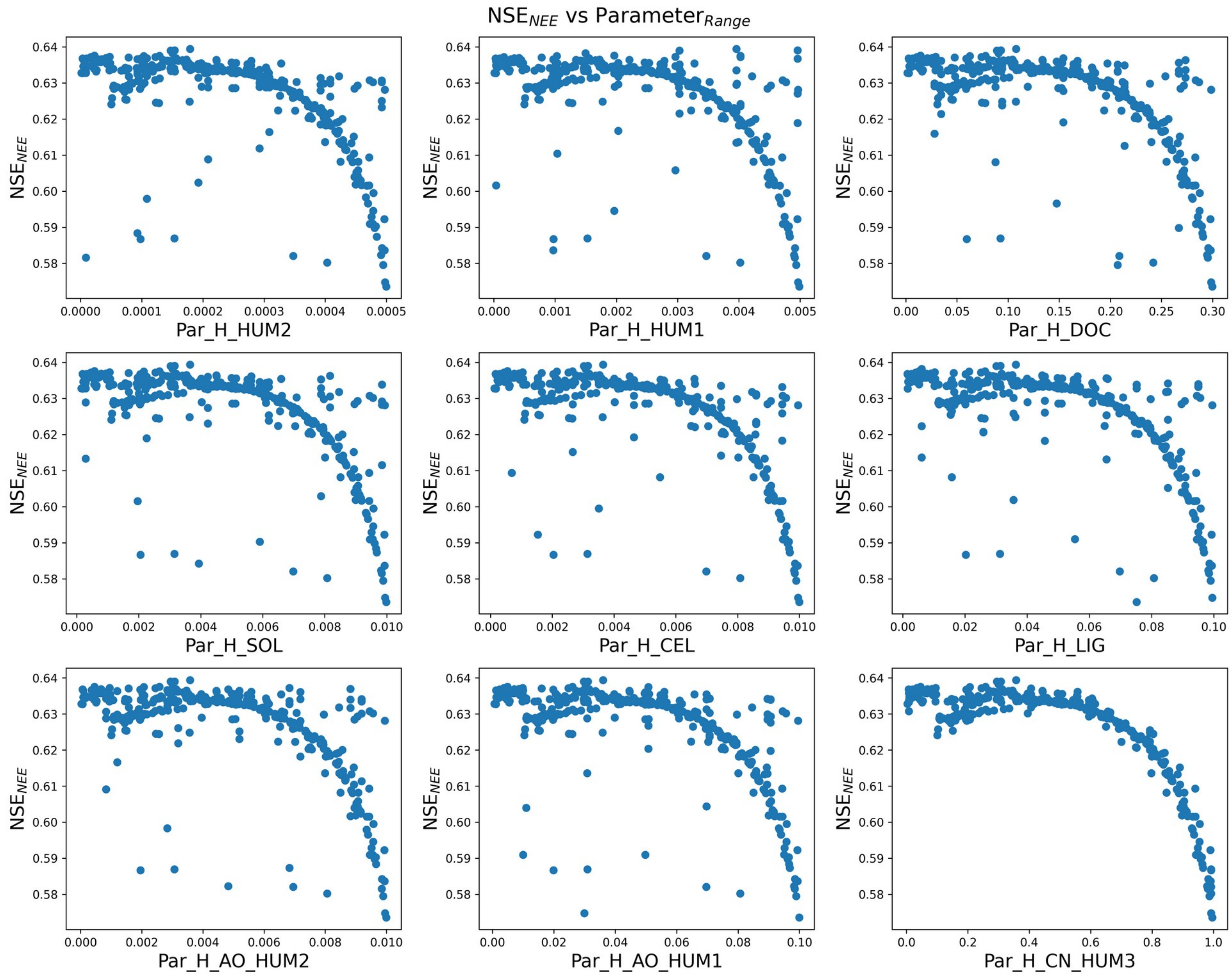

Figure: Distribution of Nash–Sutcliffe efficiency (NSE) values for net ecosystem exchange within the parameter range of set 3 parameters. During simulations for set 3, parameters in set 1 and 2 had the parameter values that yielded the highest NSE in set 2 test runs.

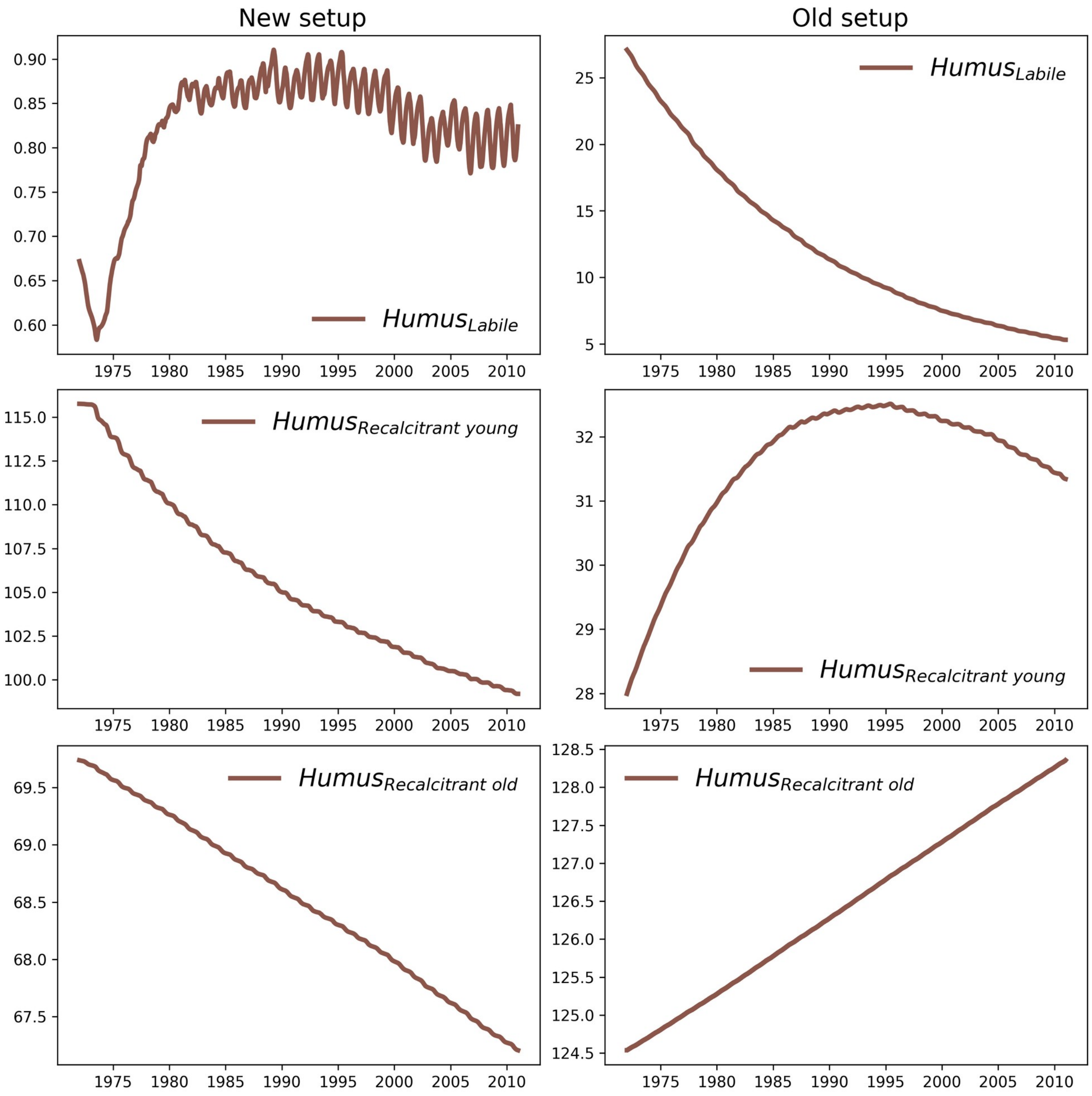

Figure: Carbon allocations of the different humus pools from the old and new model version. In the new model version, the largest fraction of carbon was allocated in the recalcitrant young pool. While in the old model version, the recalcitrant old pool had the biggest fraction.

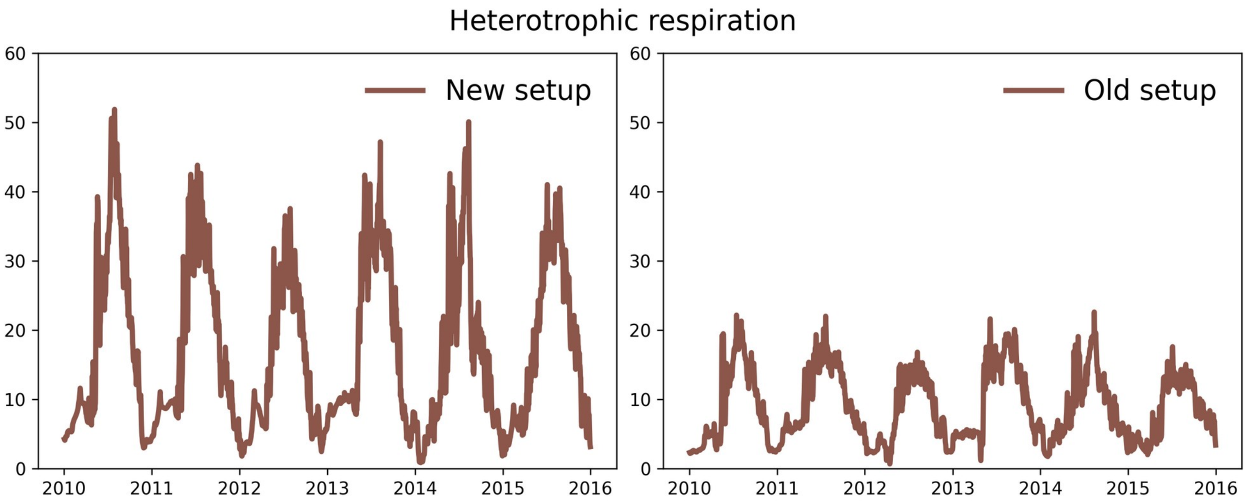

Figure: Heterotrophic respiration from the new peat model version was much larger compared to the old mineral soil version.

These figures are produced to answer questions related to section 3.5. These will not be added to the supplementary material.

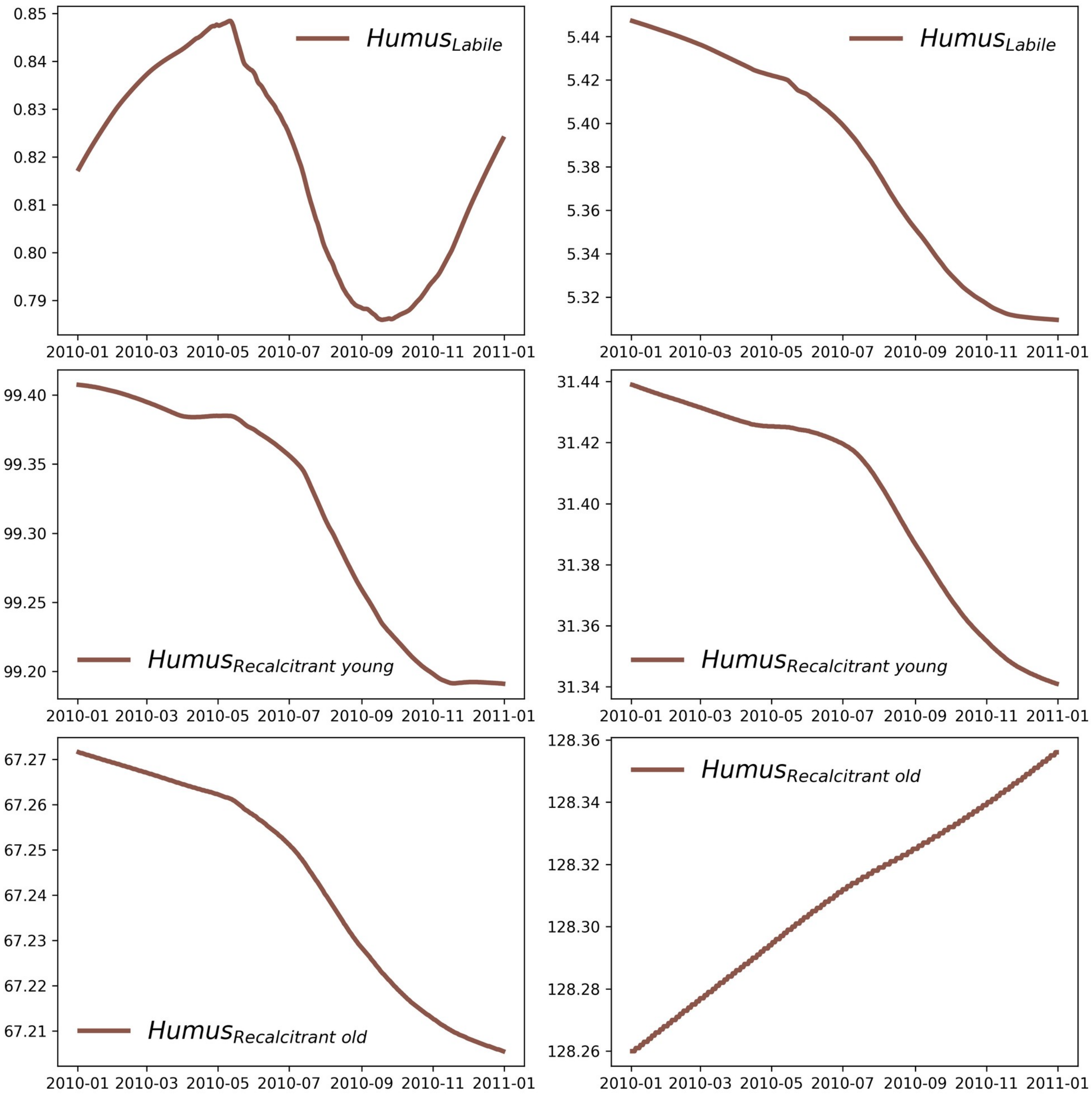

Figure: Behavior of the different humus pools over the whole year of 2010 from the new and old model version. While the recalcitrant young pool had almost the same feature, labile and recalcitrant pool were different in the two versions.

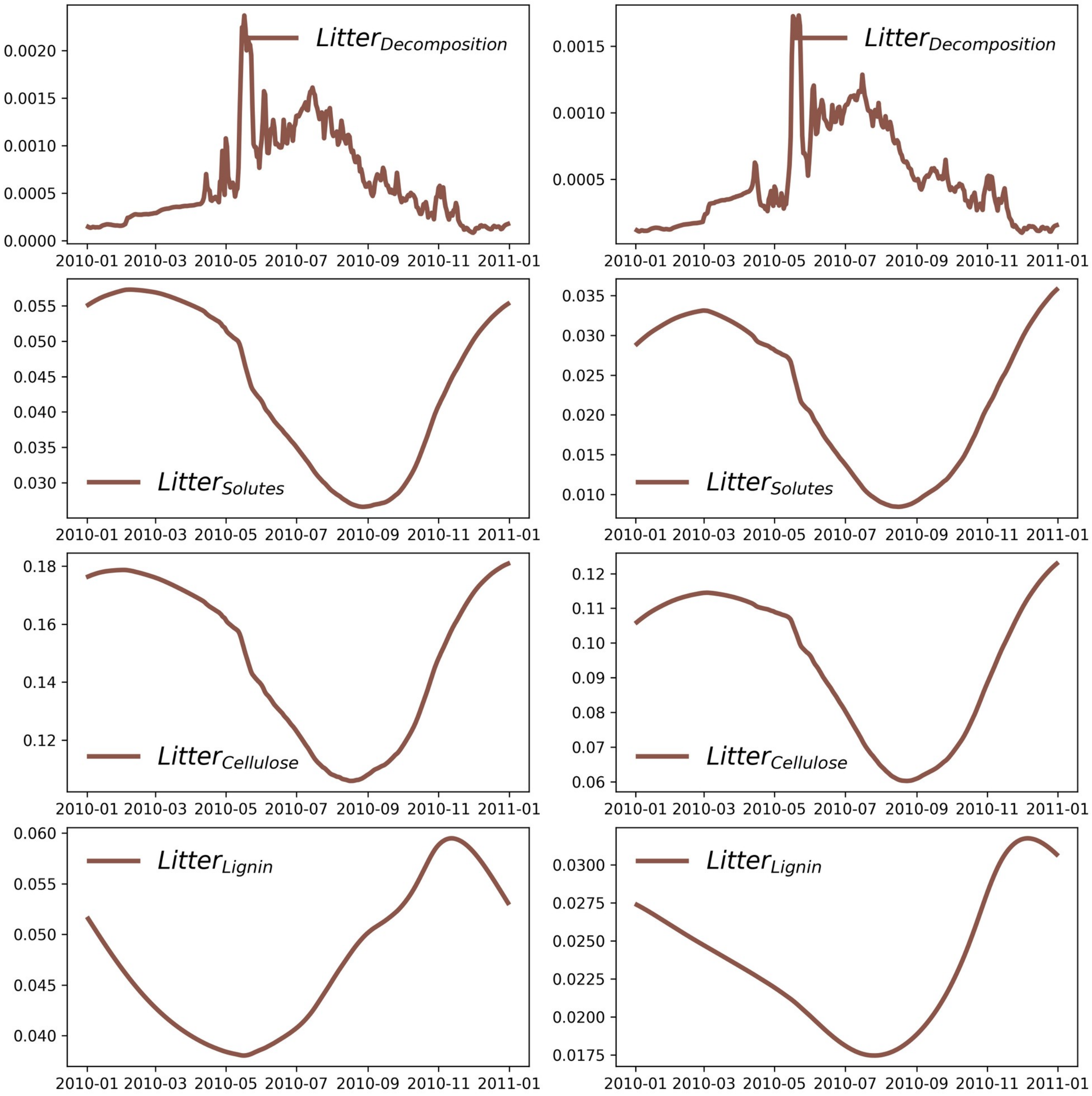

Figure: Behavior of the different litter pools and litter decomposition over the whole year of 2010 from the new and old model version. Both model versions had similar features.

References:

Alm, J., Wall, A., Myllykangas, J.-P., Ojanen, P., Heikkinen, J., Henttonen, H. M., Laiho, R., Minkkinen, K., Tuomainen, T., and Mikola, J.: A new method for estimating carbon dioxide emissions from drained peatland forest soils for the greenhouse gas inventory of Finland, Biogeosciences, 20, 3827–3855, https://doi.org/10.5194/bg-20-3827-2023, 2023.

Baylay S. E., Thormann M. N. and Szumigalski A. R.: Nitrogen mineralization and decomposition in western boreal bog and fen peat. Ecoscience Vol 12 (4): 455-465 (2005).

Forrester D. I., Baker T. G., Elms S. R., Hobi M. L., Ouyang S., Wiedemann J. C., Xiang W., Zell J., and Pulkkinen M.: Self-thinning tree mortality models that account for vertical stand structure, species mixing and climate. Forest Ecology and Management 487, 118936 2021.

He, H., Jansson, P.-E., Svensson, M., Björklund, J., Tarvainen, L., Klemedtsson, L., Kasimir Å.: Forests on drained agricultural peatland are potentially large sources of greenhouse gases – insights from a full rotation period simulation, Biogeosciences, 13, 2305—2318, 2016, https://doi.org/10.5194/bg-13-2305-2016, 2016.

Kasimir Å., He H., Coria J., Nordén A.,: Land use of drained peatlands: Greenhouse gas fluxes, plant production, and economics. Glob Change Biol. 2018; 24:3302–3316. https://doi.org/10.1111/gcb.13931

Klavins M., Sire J., Purmalis O. and Melecis V. Approaches to estimating humification indicators for peat, Mires and Peat, Volume 3, Article 07, http://www.mires-and-peat.net/, ISSN 1819-754X, 2008.

Laine J. 1989: Classification of peatlands drained for forestry, Suo 40, 37-51, Helsinki. ISSN 0039-5471.

Meinshausen M., Smith S. J., Calvin K., Daniel J. S., Kainuma M. L. T., Lamarque J-F., Matsumoto K., Montzka S. A., Raper S. C. B., Riahi K., Thomson A., Velders G. J. M., van Vuuren D.P. P., The RCP greenhouse gas concentrations and their extensions from 1765 to 2300, Climatic Change 2011, 109:213–241, 2011.

Peltoniemi, M., Li, Q., Turunen, P., Tupek, B., Mäkiranta, P., Leppä, K., et al. (2023). Soil GHG dynamics after water level rise – Impacts of selection harvesting in peatland forests. Science of the Total Environment, 901, 165421. https://www.sciencedirect.com/science/article/pii/S0048969723040445

Prescott C. E., Vesterdal L.: Decomposition and transformations along the continuum from litter to soil organic matter in forest soils. Forest Ecology and Management 498 119522, https://doi.org/10.1016/j.foreco.2021.119522 2021

Sundqvist E., Vestin P., Crill P., Persson T., and Lindroth A.: Short-term effects of thinning, clear-cutting and stump harvesting on methane exchange in a boreal forest. Biogeosciences, 11, 6095–6105, 2014. doi:10.5194/bg-11-6095-2014.

Tong, C. H. M., Noumonvi, K. D., Ratcliffe, J., Laudon, H., Järveoja, J., Drott, A., Nilsson, M. B., & Peichl, M. (2024). A drained nutrient-poor peatland forest in boreal Sweden constitutes a net carbon sink after integrating terrestrial and aquatic fluxes. Global Change Biology, 30, e17246. https://doi.org/10.1111/gcb.17246.

Quesada G. D., Rautakoski H., Xu J., Li Q., Larmola T., Salovaara P., Anttila V., Peltoniemi M., Koskinen M., Lohila A., Aalto J., Lehtonen A., Bäck J., Mäkipää R., Heinonsalo J., Salmon Y., Lintunen A.,: Carbon dynamics after thinning in two boreal forest sites: Upland and drained peatland, Forest Ecology and Management, 595, 123024, https://doi.org/10.1016/j.foreco.2025.123024 2026.