

Dear Referee,

We greatly appreciate your thorough review and constructive scientific comments on the manuscript. Your insightful suggestions and encouraging evaluation have been invaluable in strengthening the study. In response to the review, we have addressed all specific technical comments in detail below and expanded the model sensitivity analyses, results, and discussion sections. Overall, these revisions have considerably improved the clarity, robustness, and transparency of the manuscript.

We have further modified the language and typos in the text along with addition of tables and figures 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:

L30: I think you can be specific here. C:N is an indicator for the “nitrogen” status.

Thank you for pointing this out, I have written it in more specific form.

L147: Why did you use RCP4.5 instead of the actual observations of atmospheric CO<sub>2</sub> levels, given that no future climate scenario forecasting was conducted in this study?

There is a manuscript in preparation which will look into different forestry management with different climate scenarios. That is also the reason we used the RCP4.5. We will add the following details in the text with appropriate reference:

The CO<sub>2</sub> 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](https://gml.noaa.gov/webdata/ccgg/trends/co2/co2_annmean_gl.txt)) by 1.3 ppm by 2021 (Meinshausen et al. 2011).

Table 1: Some other publications may contain layer-specific C, N, C:N information, such as Peltoniemi et al. (2023). However, as the values may not vary much across layers, the current setting (where the same value is used for 0-90 cm) is probably okay.

Thank you for your comment. While setting up the model I have observed minor changes to the simulation output when there is small changes to the carbon and nitrogen content, thus the table content is kept as it is.

Fig. 1: There appears to be a mismatch in the seasonal patterns between the observations and the simulated variables here (especially in the autumn), as well as in Fig. 5. Is this my illusion or could there be an explanation for this?

Thank you for the comment.

Fig 1: Rautiainen et al. 2012 reported that MODIS LAI product starts to decrease earlier in the fall with reference to ground-based LAI. So that autumn mismatch might be production effect of the satellite product.

(This was added to discussion) Fig 5: We have looked into the autumn mismatch of CH<sub>4</sub> fluxes by changing the CH<sub>4</sub> oxidation and production parameters. While it shifted the CH<sub>4</sub> flux from higher sink to lower sink if CH<sub>4</sub> oxidation is low and vice versa, but that did not remove the mismatch. We were satisfied with simulated CH<sub>4</sub> flux, since it was within the observed CH<sub>4</sub> flux measured with chamber measurements. The chambers had different vegetation and that might impact how CH<sub>4</sub> was transported from soil to atmosphere within the chamber. Our model had a 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 in the CH<sub>4</sub> flux. All of these factors could result in the difference observed in the CH<sub>4</sub> flux.

L250: What do you mean by “during harvest and insect spruce LAI...”?

We have modified the sentence to make it clearer.

LAI for both pine and spruce decreased in the control stand simulation. However, because pine was removed in the CCF stand, the decreasing LAI trend was not observed there; instead, spruce LAI increased following the harvest.

L259: the “modeled” 10cm...

Thank you for pointing this out, it is fixed.

Figs. 6&7: It seems that the high values of GPP are overestimated by the model, especially in postharvest rotational forests. This was explained in L372 that the discrepancy arose from the overestimated recovery speed of vegetation. However, I think exploring a bit more into potential processes would be helpful for future improvement of the model. For example, could high photosynthesis or low self-thinning be responsible for the overestimation of GPP?

Thank you for your feedback.

The overestimation in the GPP for 2018-2020 in CCF simulation could be related to the vegetation recovering faster in the simulation, additionally the vegetation may not be suffering from drought in the model because of the water conserving behavior in the simulation (this was previously mentioned in the WT paragraph but now moved to the CO2 balance section of the discussion).

The reason for simulated high GPP in the last two years in rotational forestry is explained below and this explanation is now also added to the discussion.

This was added to the discussion:

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 initial 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.

Discussion: It is good that the authors compared their simulations with various field observations. However, I feel that the current discussion focuses only on the reliability of the simulated variables (which is good). Additionally, it would be valuable to see the practical implications of the model outputs, as well as the limitations/future perspective of LDNDC.

(1) Practical implications: The authors did interesting simulations of different management practices (i.e., continuous cover vs. rotational forestry). I believe a section/paragraph dedicated to summarizing the pros and cons (in terms of carbon and water cycles) of the two practices may provide valuable information for the management of drained peatland ecosystems.

(2) Model limitations: The authors noted the current model's failure to capture the effect of drought, which may explain why the CO2 balance in 2018 was not accurately represented. This highlights the need for the model to better represent drought-induced tree mortality. Additionally, I wonder if mismatched seasonality (of LAI or CH4 flux, see my previous comment) could be due to the function used to simulate vegetation phenology. By examining the simulated output variables and intermediate parameters more closely, I believe the

authors can identify the modules/functions that are underperforming. Discussing such limitations could have important implications for future model development.

To address the points raised by reviewer we added the text written in blue below to the discussion.

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<sup>2</sup> / m<sup>2</sup>) 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, Korhonen 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<sub>4</sub> fluxes for control and CCF was good, and the site was mostly a uptake of CH<sub>4</sub>. 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 CH<sub>4</sub> 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 CH<sub>4</sub> fluxes by changing the CH<sub>4</sub> oxidation and production parameters. While it shifted the CH<sub>4</sub> flux from higher sink to lower sink if CH<sub>4</sub> oxidation is low and vice versa, but that did not remove the mismatch. We were satisfied with the simulated CH<sub>4</sub> flux, since it was within the observed CH<sub>4</sub> flux measured with chamber measurements. The chambers had different species abundance and that might impact how CH<sub>4</sub> 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 CH<sub>4</sub> flux. All these factors could result in the difference observed in the CH<sub>4</sub> flux.

However, CH<sub>4</sub> flux dynamics after clear-cut in the RF were quite sensitive to the changes in WT. According to the measurements, RF changed from CH<sub>4</sub> sink to source after clear-cut (Korkiakoski et al. 2019). However, the model showed the RF to be a sink of CH<sub>4</sub> 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<sub>4</sub> m<sup>-2</sup> d<sup>-1</sup>) of CH<sub>4</sub> even after clear-cut (Huttunen et al. 2003). CH<sub>4</sub> 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<sub>2</sub> annual balances showed net CO<sub>2</sub> sink similar to the observation for the pre-harvest period. Also, the simulated CO<sub>2</sub> annual balances for CCF<sub>postharvest</sub> and RF<sub>postharvest</sub> 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<sub>2</sub> 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<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub> 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  $-421 \text{ g C m}^{-2} \text{ y}^{-1}$  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  $-150 \text{ g C m}^{-2} \text{ year}^{-1}$ . Soil carbon loss at a fertile drained peatland site in southern Finland can even be around  $-1000 \text{ g C m}^{-2} \text{ year}^{-1}$  (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 CO<sub>2</sub> 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). CH<sub>4</sub> sink was smaller in CCF compared to control stand and higher WT sensitivity for CH<sub>4</sub> 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 related to species competitions and nutrient distribution among species within the model and could be investigated further in the future studies. The water conserving behavior of the model in drought years and associated CO<sub>2</sub> balance requires future considerations along with vegetation distributions within the chambers when comparing chamber measurements of CH<sub>4</sub>. 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.

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