 DOI: 10.22616/rrd.28.2022.006

CASE STUDY ON GREENHOUSE GAS (GHG) FLUXES FROM FLOODED FORMER PEAT EXTRACTION FIELDS IN CENTRAL PART OF LATVIA

***Aldis Butlers, Andis Lazdiņš**
Latvian State Forest Research Institute 'Silava', Latvia
*Corresponding author's email: aldis.butlers@silava.lv

Abstract
Flooded Land is defined as water bodies where human activities have caused changes in the amount of surface area covered by water, typically through water level regulation. Former peat extraction fields are a type of flooded lands which are often mentioned as significant source of greenhouse gas (GHG) emissions. In Latvia, the area of flooded lands in former peat extraction fields is 5.3 kha.
The aim of the study is to evaluate GHG emissions from flooded former peat extraction fields to define that the flooded lands are the key source of GHG emissions and approve that further studies are necessary to elaborate country specific emission factors. The study is implemented in three areas in central part of the country, where peat extraction was stopped 25-35 years ago. Measures continued for 12 months, in 9 subplots, each was represented by 3 measurement points. Water and air temperature, as well as water level was measured during the study.
According to the study results, flooded areas are a significant source of CO_2 emissions (967±107 kg CO_2-C ha^{-1} yr^{-1}); however, the most significant agent of GHG emissions in flooded areas is methane (CH_4) – 435±98 kg CH_4-C kg ha^{-1} yr^{-1}. Flooded areas are not significant source of nitrous oxide (N_2O) emissions. The net emissions from flooded areas are 18.1±3.7 tons CO_2 eq ha^{-1} yr^{-1}. According to the study results, flooded lands are a significant (one of the largest) source of emissions, and further studies are necessary to improve GHG modelling solutions and activity data.
Key words: greenhouse gas, emissions, flooded land, peat extraction.

Introduction

Organic soils are formed by accumulation of dead organic matter. Organic soils are outcome of a long development process during which vegetation adds litter into soil and the stock of C in the litter exceeds the amount of C losses due to decomposition of the recently added litter and in formerly added organic C. Organic soils are typically found in wetlands, where high groundwater level ensures anoxic conditions and decomposition of organic matter is generally slow; however, anaerobic decomposition continues (Straková *et al*., 2012).

The development of northern peatlands began more than 15000 years ago, and they expanded during the Holocene period (the past 12000 years after the latest glaciations) on land that became exposed when glaciers retreated (MacDonald *et al*., 2006). Most of the organic soils we have currently are located in temperate and boreal regions. Peatlands and other organic soils hold about 20-25% of global soil C stock but occupy only 2-3% of the world's ice-free land surface (Hiraishi *et al*., 2013; Mokma, 2005).

In Latvia, total area of organic soils is 1205 kha (19% of the country area), including 629 kha of drained and 577 kha of naturally wet organic soils. In wetlands (according to the definition of Intergovernmental panel on Climate Change – IPCC), the area of drained soil is 12.8% of the total area of wetlands (Ministry of Environmental Protection and Regional Development, 2021). The area of former peat extraction sites is 54.9 kha. Significant areas of drained wetlands used for peat extraction earlier are already afforested (mostly naturally), flooded area is about 5.3 ha (Butlers & Ivanovs, 2018). No significant potential to increase the flooded area is found (Krīgere, Dreimanis *et al*., 2019; Krīgere, Kalniņa *et al*., 2019).

The National GHG inventory of Latvia (Ministry of Environmental Protection and Regional Development, 2021) uses default (tier 1) method to calculate GHG emissions from flooded peat extraction fields. The emission factors for rewetted areas are applied to avoid potential underestimation of the GHG emissions; specifically, emission factor (EF) for CO_2, 0.5 tons CO_2-C ha^{-1} yr^{-1} (Table 3.1 Tier 1 CO_2 from rewetted organic soils (temperate, nutrient rich soil)), EF DOC, 0.24 tons CO_2-C ha^{-1} yr^{-1} (Table 3.2 Default DOC emission factors (EF DOC_REWETTED in tonnes CO_2-C ha^{-1} yr^{-1}) for rewetted organic soil (temperate climate zone), EF CH_4 216 kg CH_4-C ha^{-1} yr^{-1} (Table 3.3 Default emission factors for CH_4 from rewetted organic soils (temperate, rich)). Total GHG emissions from flooded lands equal to 7.2 tons CO_2 eq yr^{-1}. Emission factors for nutrient rich soils are used to avoid underestimation of GHG emissions, since the activity data (soil type) are usually very uncertain.

During recent years significant improvements were applied to the National GHG inventory to calculate GHG fluxes from organic soils. Improved emission factors are applied to peat extraction sites (Lazdiņš & Lupiķis, 2019), croplands and grasslands (Licite & Lupikis, 2020) and forest lands (Lupiķis, 2019). Reporting of land use and land use changes are significantly improved (Krumšteds *et al*., 2019). Soil carbon stock modelling tools are not jet implemented; however, knowledge on carbon turnover, e.g., litter input and soil moisture regime are now in place

and should be integrated with modelling solutions (Bārdule *et al*., 2021; Ivanovs *et al*., 2017).

Flooded lands are a potential key source of the GHG emissions, and there are proposals to implement flooding as a mitigation measure; therefore, it is important to acquire measurement based information on the GHG fluxes from flooded areas. This study is aimed to provide such information to avoid inefficient use of the state funding aimed at reduction of GHG emissions.

Materials and Methods

GHG measures were implemented in 3 sites in central part of Latvia in Zilākalna and Tēvgāršas swamps (former raised bogs). Peat extraction in these areas was terminated 25-30 years ago leaving 0.6-2.8 m deep peat layer in the measurement sites. Water level in the measurement sites at minimum level was 0.2-0.4 m and at maximum level – 1.2-1.8 m (Table 1).

Large opaque chambers are used to take GHG samples. Floating collars and footbridges are used to position chambers during gas sampling (Figure 1). Footbridges, collars and chambers are moved from site to site. A set of five collars are used for gas sampling. Three permanent subplots are established in every site, respectively, in total data from 45 sampling sites are used in analysis. Sampling was repeated once per 3 weeks during vegetation season (March to October) and once per month in November to February, from January to December, 2021; respectively, every month is represented by 1-2 measurement series. During ice cover period sampling was done from surface of ice. If ice was not strong enough to hold duckboards, it was broken and removed from water surface. Gas sampling was done at least one hour after removing ice.

Gas samples are collected in 50 ml glass bottles which are vacuumized before sampling. Samples are collected directly after chamber is located on a collar, then in 10, 20 and 30 minutes; 4 samples per set. In parallel to gas sampling, air and water temperature, wind speed, cloudiness and water level are fixed. Gas analyses are performed using Shimadzu Nexis GC-2030 gas chromatograph equipped with an electron capture detector (ESD), a flame ionization detector, and automatic sampling device (Loftfield *et al*., 1997).

Data quality control involves separation of data sets, having coefficient of determination less than 0.95 for the CO_2 concentration change, except data sets with concentration change less or equal to the method uncertainty. These data sets were not excluded.

The emission level of each gas is calculated assuming a linear increase in gas concentration over time at the specified chamber area and volume. Following formula is used to calculate GHG fluxes:

$$CO_2 - C[\mu g C m^{-2} h^{-1}] =$$

$$= \frac{M[g mol^{-1}] * P[Pa] * V[m^3] * \delta v[ppm(v)] * f_1}{R[m^3 Pa K^{-1} mol^{-1}] * T[K] * t[h] * A[m^2] * ppm},$$ where

P – air pressure during measurement, Pa – 101300;

Table 1

Description of measurement plots

Object	Abbreviation	Coordinates (LKS92)		Comment
		X	Y	
Zilākalna swamp	ZILĀ_2	383725	569608	flooded area, 0.7-1.2 m deep, decrease by up to 0.5 m during summer
Tēvgāršu swamp	TĒVG_2	392382	556892	flooded area, 1.0-1.5 m deep, decrease by up to 0.6 m during summer
Zilākalna swamp	ZILĀ_1	384112	569884	8 m wide channel, water depth – 0.8-1.8 m, relatively stable (0.3 m difference) during vegetation season

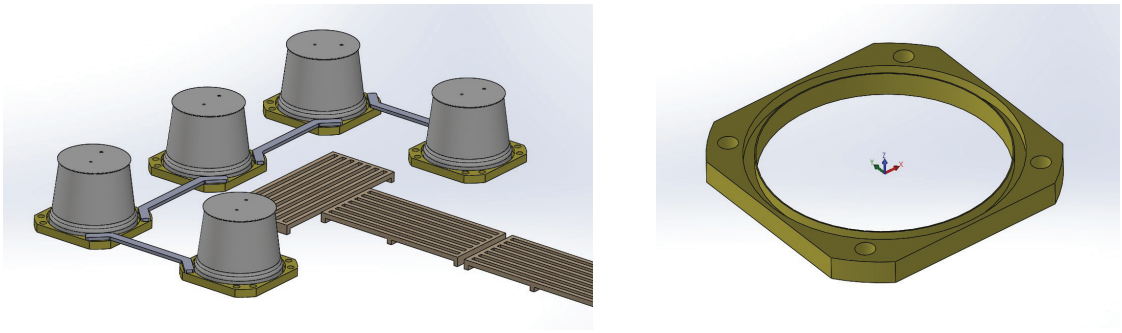

Figure 1. Gas measurement chambers, floating platform and the whole sampling setup.

δv – slope of volumentric concentration changes during measurement period, ppm(v);

R – universal gas constant, m^3 Pa K^{-1} mol^{-1} – 8.3143;

t – measurement period, h – 0.5;

T – air temperature during sampling, Kelvins;

V – volume of chamber, m^3 – 0.0655;

A – surface area of chamber, m^2 – 0,19625;

M CO_2, g mol^{-1} – 44,01;

M CH_4, g mol^{-1} – 16,04;

M N_2O, g mol^{-1} – 44,01;

f_1 – recalculation factor (for CO_2 0.27, for CH_4 0.75 and for N_2O 0.64).

Recalculation to GHG emissions to monthly base is done by calculation of average monthly fluxes (the average values from samples series collected in a particular month from each sampler) and multiplication with number of days in a month. Yearly emissions are calculated as sum of monthly averages. Uncertainty is represented as standard error of mean following to methodology applied in the National GHG inventory (Ministry of Environmental Protection and Regional Development, 2021).

Results and Discussion

Data from 3 measurement sites are used to evaluation of the GHG fluxes in flooded areas. After initial quality assessment by separation of the data sets where concentration gradient of CO_2 $R^2 < 0.95$, Ttest is used to compare data sets acquired in different sites and average monthly data on CO_2, N_2O and CH_4 fluxes. No significant difference is found between the data sets; however, in Zilākalna swamp (ZILĀ_2) CO_2 emissions in spring and autumn months are significantly smaller than from other sites; while CH_4 emissions in this site are significantly bigger than in other sites.

Comparison of the average monthly fluxes is provided in Figure 1. Not surprising, during summer months all fluxes are increasing, but in winter GHG fluxes are negligible. N_2O fluxes are negligible during the whole year and flooded areas in former peat extraction sites can be considered as not a source of N_2O emissions. Monthly fluctuations of CO_2 and CH_4 emissions can be explained by polynomial equations with statistically significant coefficient of correlation.

Average monthly fluxes are summarized in Figure 3. CO_2 emissions exceed uncertainty rate (standard error of mean) during the whole year, except the period when water is covered with ice. In further studies, it is reasonable to measure GHG fluxes only during ice-free period and the CO_2 modelling tools should consider this parameter. CH_4 emissions exceed uncertainty range from June to October. During other months CH_4 emissions are negligible; therefore, this source can also be measured only during summer and autumn months. However, temperature regime in spring can have an impact on GHG emissions. N_2O emissions are negligible during the whole period; however, in summer and autumn months the N_2O emissions slightly exceed uncertainty range. This can point to a potentially significant N_2O emissions from nutrient rich soils or water bodies receiving nutrient rich inflow. The acquired results also point out necessity to increase regularity of measurements during spring period to catch out GHG fluxes, which occur during ice melting period, and cracks and openings in ice should also be considered by measurement of fluxes, by

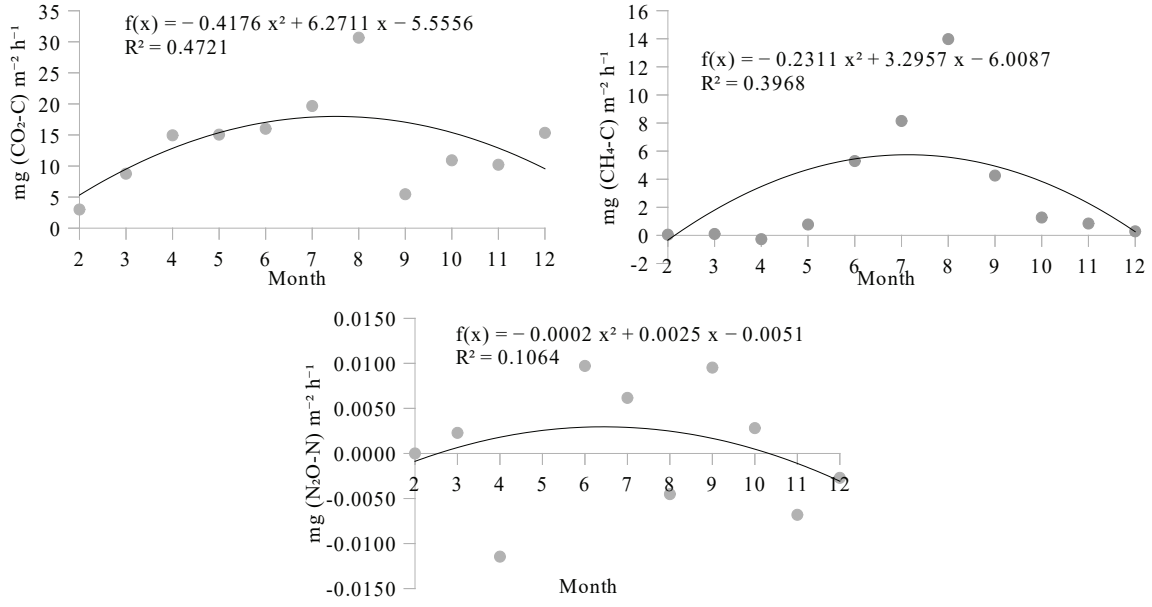

Figure 2. GHG fluxes from flooded lands in different months.

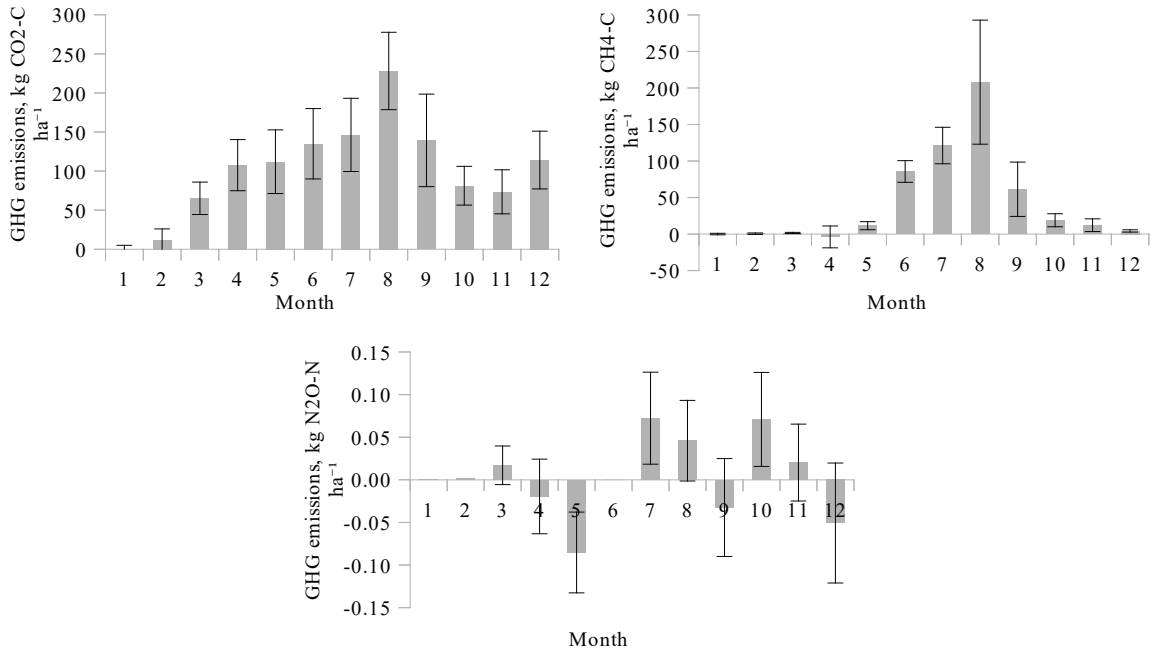

Figure 3. GHG emissions from water surface recalculated to area.

improvement of activity data and / or by introduction of a correction factor characterizing sporadic fluxes during ice melting period.

One of the parameters, which can be easily acquired and applied to model GHG emissions is air temperature; however, due to different heat exchange properties and other differences air temperature is not equal in air and water, especially in spring and autumn, which can lead to underestimation of the emissions during these seasons. Figure 4 shows relationship between the air and water temperature, explaining why flooded areas remain sources of emissions even if air temperature is negative – water remains warm and flooded area continues to create emissions. Therefore, it is important to improve activity data to apply in a model water temperature. Daily data in combination with information on ice-free period should be used to increase the accuracy of the assessment, especially in future, considering increase of the air temperature in winter.

The relationship between water temperature and CO_2 emissions from water surface is weak and can be explained by polynomial equation (Figure 5), while CH_4 emissions have good correlation with water temperature. In case of CO_2 weak correlation can be explained either by different solubility of CO_2 in different temperatures, impact of additional chemicals, e.g., bicarbonate anion in water on the solubility (Tang *et al*., 2015), or amount of dissolved oxygen. These parameters have to be studied further.

The net GHG emissions from flooded peat extraction sites equal to 18.07±3.73 tons CO_2 eq ha^{-1} yr^{-1}. Most of the emissions occur during summer and autumn months (figure 6). The most

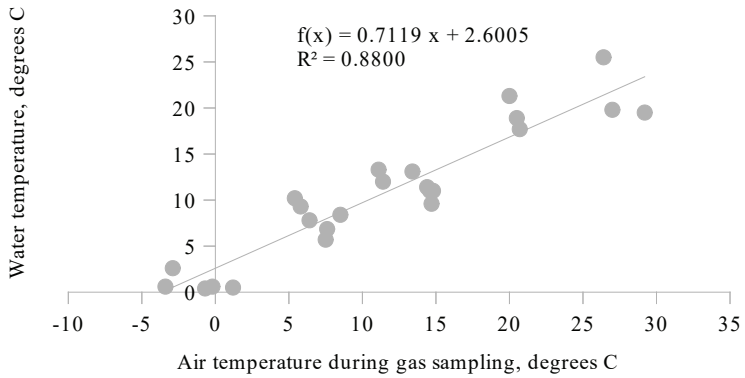

Figure 4. Relationship between water and air temperature.

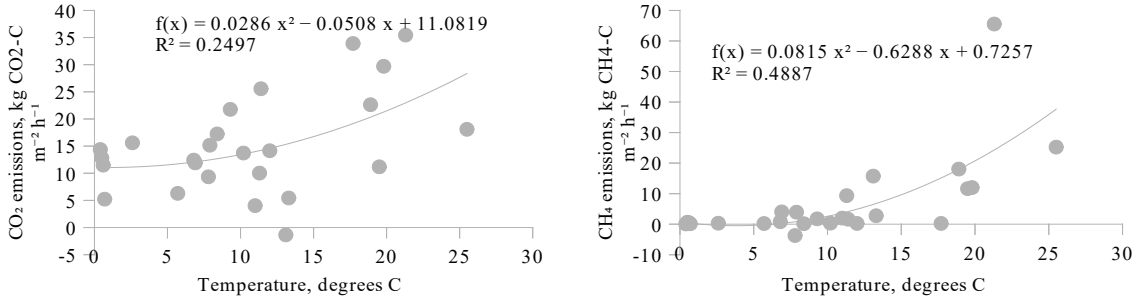

Figure 5. Relationship between water temperature and GHG fluxes.

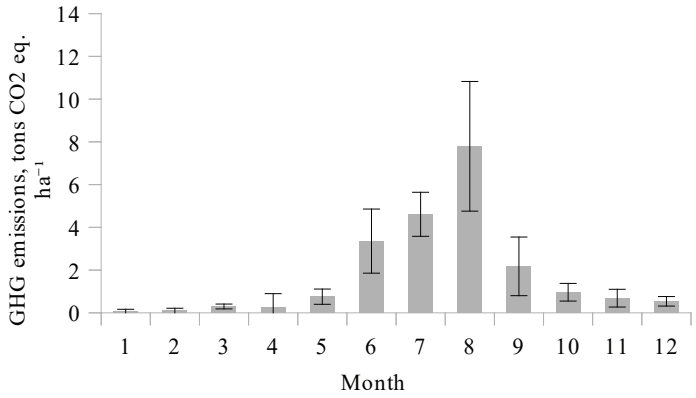

Figure 6. Total GHG emissions from water surface in flooded areas.

significant source of emissions from flooded areas is CH_4 (14.5±3.3 tons CO_2 eq ha^{-1} yr^{-1}). If compared to other land uses, GHG emissions from flooded peat extraction sites exceed the emissions from the most of the land use categories, except arable lands (by 360% more than afforested peatland, by 288% more than from peat extraction field and by 199% more than from rewetted area (Lazdiņš & Lupiķis, 2019; Upenieks & Rudusāne, 2021).

The project also highlighted another issue, which can affect the emissions – water level fluctuations in the measurement sites exceed 0.5 m, in flat landscape significantly affecting the area covered with water during the season; therefore, it is necessary to estimate GHG emissions also from periodically dried areas. The implemented pilot study clearly demonstrates significance of flooded peatlands as a source of GHG emissions. Net GHG emissions from flooded peatlands would increase to 95.8 Gg CO_2 eq yr^{-1}, if the project results are applied in the GHG inventory. Potential increase of the GHG emissions in case of flooding of all extracted peatlands would increase to 832 Gg CO_2 eq yr^{-1}.

Conclusions

1. Flooded areas in Latvia are a significant source of CO_2 emissions (967±107 kg CO_2-C ha^{-1} yr^{-1}) and the net CO_2 emissions from flooded areas may be about twice bigger than currently accounted in the National GHG inventory.
2. The most significant source of GHG emissions in flooded areas is CH_4 (435±98 kg CH_4-C kg ha^{-1} yr^{-1}) pointing out that currently accounted CH_4 emissions from flooded lands in the National GHG inventory may be about twice smaller than those proved by the study.
3. CO_2 and CH_4 fluxes are correlating with water temperature, especially, CH_4 emissions, which are occurring only if water temperature is above 5 °C. CO_2 emissions continue also during winter months, except the period, when water body is covered with ice.
4. The net GHG emissions from flooded areas are 18.1±3.7 tons CO_2 eq ha^{-1} yr^{-1}, which is about twice than the currently accounted GHG emissions in the National GHG inventory. Further studies are necessary to increase accuracy of the elaborated emission factors, as well as to improve activity data – period when water bodies are covered with ice, water temperature regime and other parameters, which could increase accuracy of the estimate.
5. Flooding of peatlands cannot be recommended as climate change mitigation measure before more detailed studies are done and additional GHG emissions should be considered if this option is selected, e.g., to increase the ecosystem value of peatlands.

Acknowledgements

The study is implemented within the scope of the project European Regional Development Fund Project 'Development of greenhouse gas emission factors and decision support tools for management of peatlands after peat extraction' (No. 1.1.1.1/19/A/064).

References

Bārdule, A., Petaja, G., Butlers, A., Purviņa, D., & Lazdiņš, A. (2021). Estimation of litter input in hemi-boreal forests with drained organic soils for improvement of GHG inventories. *BALTIC FORESTRY*, *27*(2), Article 2. DOI: 10.46490/BF534.

Butlers, A., & Ivanovs, J. (2018). Improved activity data for accounting greenhouse gas emissions due to management of wetlands. *Annual 24th International Scientific Conference Research for Rural Development 2018*, *1*, 27–33. DOI: 10.22616/rrd.24.2018.004.

Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Fukuda, M., Troxler, T., & Jamsranjav, B. (2013). *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (p. 354). IPCC.

Ivanovs, J., Sietiņa, I., Lazdiņš, A., Skola, U., Zvirgzdiņš, A., & Zvaigzne, Z.A. (2017). Identification of wet areas in forest by using LiDAR based DEM. In: *Proceedings from Joint Seminar Arranged by NB – NORD and NOFOBE*, 54.

Krīgere, I., Dreimanis, I., Ozola, I., Dreimanis, I., & Lazdiņš, A. (2019). Establishment of paludiculture fields. In A. Priede & A. Gancone (Eds.), *Sustainable and responsible after-use of peat extraction areas* (pp. 169–173). Baltijas Krasti.

Krīgere, I., Kalniņa, L., Dreimanis, I., Pakalne, M., & Lazdiņš, A. (2019). Rewetting (re-creating mire conditions). In A. Priede & A. Gancone (Eds.), *Sustainable and responsible after-use of peat extraction areas* (pp. 195–202). Baltijas Krasti.

Krumšteds, L.L., Ivanovs, J., Jansons, J., & Lazdiņš, A. (2019). Development of Latvian land use and land use change matrix using geospatial data of National forest inventory. *Agronomy Research*, *17*. DOI: 10.15159/AR.19.195.

Lazdiņš, A., & Lupiķis, A. (2019). LIFE REstore project contribution to the greenhouse gas emission accounts in Latvia. In A. Priede & A. Gancone (Eds.), *Sustainable and responsible after-use of peat extraction areas* (pp. 21–52). Baltijas Krasti.

Licite, I., & Lupikis, A. (2020). Impact of land use practices on greenhouse gas emissions from agriculture land on organic soils. *Proceedings of 19th International Scientific Conference Engineering for Rural Development*, 1823–1830. DOI: 10.22616/ERDev.2020.19.TF492.

Loftfield, N., Flessa, H., Augustin, J., & Beese, F. (1997). Automated Gas Chromatographic System for Rapid Analysis of the Atmospheric Trace Gases Methane, Carbon Dioxide, and Nitrous Oxide. *Journal of Environment Quality*, *26*(2), 560. DOI: 10.2134/jeq1997.00472425002600020030x.

Lupiķis, A. (2019). Results of GHG emission measurements in differently managed peatlands in Latvia – the basis for new national GHG emission factors. *Sustainable and Responsible Management and Re-Use of Degraded Peatlands in Latvia*, 24–26.

MacDonald, G.M., Beilman, D.W., Kremenetski, K.V., Sheng, Y., Smith, L.C., & Velichko, A.A. (2006). Rapid Early Development of Circumarctic Peatlands and Atmospheric CH_4 and CO_2 Variations. *Science*, *314*(5797), 285–288. DOI: 10.1126/science.1131722.

Ministry of Environmental Protection and Regional Development. (2021). *Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990-2019* (p. 545). Ministry of Environmental Protection and Regional Development of the Republic of Latvia.

Mokma, D.L. (2005). ORGANIC SOILS. In *Encyclopedia of Soils in the Environment* (pp. 118–129). Elsevier. DOI: 10.1016/B0-12-348530-4/00034-5.

Straková, P., Penttilä, T., Laine, J., & Laiho, R. (2012). Disentangling direct and indirect effects of water table drawdown on above- and belowground plant litter decomposition: Consequences for accumulation of organic matter in boreal peatlands. *Global Change Biology*, *18*(1), 322–335. DOI: 10.1111/j.1365-2486.2011.02503.x.

Tang, Y., Bian, X., Du, Z., & Wang, C. (2015). Measurement and prediction model of carbon dioxide solubility in aqueous solutions containing bicarbonate anion. *Fluid Phase Equilibria*, *386*, 56–64. DOI: 10.1016/j.fluid.2014.11.025.

Upenieks, E.M., & Rudusāne, A. (2021). Afforestation as a type of peatland recultivation and assessment of its affecting factors in the reduction of GHG emissions. *Proceedings of the International Scientific Conference 'Rural Development'*, 295–300. DOI: 10.15544/RD.2021.0.