CARBON DIOXIDE (CO_2) EMISSIONS FROM NATURALLY WET AND DRAINED NUTRIENT-RICH ORGANIC FORESTS SOILS

Aldis Butlers, Gints Spalva, Ieva Licite, Dana Purvina
Latvian State Forest Research Institute "Silava", Latvia
aldis.butlers@silava.lv, gints.spalva@silava.lv, ieva.licite@silava.lv, dana.purvina@silava.lv

Abstract Implementation of climate change mitigation measures in forestry has a key role to successfully fulfil the climate change policy goals of Land use, land use change and forest sector set by the Paris Agreement to fully offset total GHG emissions in the country by CO_2 removals in 2050. GHG emissions from organic soils in forest land have significant impact on total emissions of Latvia, however, high emissions also indicate the potential of climate change mitigation measures. This study aims to evaluate CO_2 emissions from drained and naturally wet nutrient-rich forest soils to improve knowledge of forest management practice impact on GHG emissions. The study is conducted in 21 drained (*Myrtillosa turf.mel.* and *Oxalidosa turf. mel.*) and 10 naturally wet (*Dryopterioso–caricosa and Filipendulosa*) forest sites with nutrient-rich organic soils for 12 consecutive months. Soil total CO_2 emissions were measured by closed manual non-transparent chamber method. The groundwater level, soil and air temperature were measured to evaluate factors affecting CO_2 emission. Empirical data collected within the scope of the study showed high correlation (r = 0.85) between CO_2 emissions and temperature, however, the groundwater level depth had no considerable impact on emissions. Total soil CO_2 emissions from drained nutrient-rich organic soils ranged from 5.44 t ± 0.1 $tC \cdot ha^{-1} \cdot yr^{-1}$ in black alder stands to 9.76 ± 2.47 $tC \cdot ha^{-1} \cdot yr^{-1}$ in clearcut areas (average 7.35 ± 0.89 $tC \cdot ha \cdot yr^{-1}$), while CO_2 emissions from forest sites with naturally wet soil ranged from 5.73 ± 2.23 $tC \cdot ha^{-1} \cdot yr^{-1}$ in spruce stands to 10.41 ± 4.33 $tC \cdot ha^{-1} \cdot yr^{-1}$ in clearcut areas (average 7.02 ± 0.96 $tC \cdot ha^{-1} \cdot yr^{-1}$). The study results demonstrate that drainage does not have significant effect on CO_2 emissions.

Keywords: organic soil, naturally wet, drained, CO_2 emissions

Introduction

Organic soil is one of the largest carbon (C) storages of terrestrial ecosystems globally [1] and also in Latvia [2]. Depending on the land use and management practices organic soil can act as C sink or source [3]. Share of organic soils is 19% of total area of Latvia [4]. According to the national forest site type classification system [5] and information provided by the national forest inventory (NFI) the area of organic soils in forest land is 723 kha of which 53% are drained.

According to the Intergovernmental panel on Climate change (IPCC) guidelines [6] for National GHG inventories human induced GHG emissions shall be estimated – regarding organic forest soils only GHG emissions from drained and rewetted organic soils are reported in Latvia, respectively. IPCC guidelines divide organic soils as nutrient-poor and nutrient-rich, however, if the IPCC default methodology is applied, the most of forest organic soils in Latvia can be considered as nutrient-rich, since they are receiving nutrients with groundwater and precipitation. The IPCC default emission factor (2.6 t CO_2-$C \cdot ha^{-1} \cdot yr^{-1}$) for calculation of CO_2 emissions from drained organic forest soils [7] is replaced by the national emission factor 0.52 t CO_2-$C \cdot ha^{-1} \cdot yr^{-1}$ developed as a result of multiple studies evaluating long term C stock changes after drainage [2; 8; 9]. The national emission factor characterises emissions from organic soils in forest site types *Callunosa turf. mel.*, *Vacciniosa turf. mel*. and *Myrtillosa turf.mel*. with nutrient-poor to moderate-rich soils [10], yet it is applied to all drained organic forest soils in the national GHG inventory. While for rewetted organic soils the IPCC default emission factor 0.5 t CO_2-C $ha^{-1} \cdot yr^{-1}$ is used [7]. According to this approach total estimated human induced CO_2 emissions from organic forest soils in forest lands were almost 800 kt CO_2 or 7% of total GHG emissions in Latvia in 2020.

Although it is not mandatory to report GHG emissions from naturally wet organic forest soils, information on such emissions is necessary to elaborate and implement knowledge-based climate change mitigation measures in forest management to work towards climate neutrality policy goals set by the Paris Agreement, as well as to provide scientifically substantiated assessment of the effect of drainage and rewetting of forest soils. This study aims to work towards better understanding of differences between the net CO_2 emissions from drained and naturally wet nutrient-rich organic forest soils.

Materials and methods

The study was conducted in 31 forest sites in central Latvia with nutrient-rich (the most fertile site types for drained and naturally wet soils) organic soils [5]. One sample plot (500 m^2) was established in each of the selected forest stands: 10 sample plots in naturally wet (*Dryopterioso–caricosa and Filipendulosa*) and 21 sample plots in drained (*Myrtillosa turf.mel.* and *Oxalidosa turf. mel.*) sites (Table 1). Dominant tree species of Norway spruce, silver birch, black alder, as well as 1 year old clearcuts of deciduous, mixed stands. To check the forest site conformity to the specified site type the peat depth was determined (threshold value of at least 20 cm in drained and 30 cm in naturally wet soils by 5 measurement replicates. Additionally, ground floor vegetation was characterized to select areas representing plant communities typical for certain site types. The centre of the sample plots was at least 20 m from the stand border.

Table 1

Study site characteristics

Parameter	Value	Naturally wet forest sites				Drained forest sites			
		Norway spruce	Silver birch	Black alder	Clearcut	Norway spruce	Silver birch	Black alder	Clearcut
Number of study sites	number	1	3	5	1	12	3	2	4
Age of dominant tree species, years	Average	67	56	43	-	55	39	40	-
	range (min...max)	-	21-77	10-80	-	14-86	18-60	26-53	-
Growing stock, $m^3 \cdot ha^{-1}$	average	446	225	170	-	269	135	189	-
	range (min...max)	-	78-365	35-325	-	7-521	38-210	123-254	-
Peat layer, cm	average		41	59	47	81	43	65	90
	range (min...max)	-	31-52	23-99	-	37-99	25-75	60-70	63-99

During the study period from October of 2019 till June of 2021 soil CO_2 emissions were monitored for 12 consecutive months by the closed manual non-transparent chamber method [11], when the mean air temperature was 9.2 ± 0.8 ºC (min 8.0 ± 0.7, max 31.4 ± 0.1) and annual precipitation 668 ± 136 mm (ranged from 472 mm to 860 mm) according to 5 meteorological stations in a range of up to 30 km from the sample plots. 5 collars were installed in every plot at least 1 month prior the first CO_2 emission measurement. Sides of the collars reached approximately 5 cm depth. Roots were not trenched and ground vegetation as well as the litter layer were left intact, therefore CO_2 emissions measured include soil heterotrophic and both above- and belowground ground vegetation autotrophic respiration (soil total emissions).

Sample plots were surveyed once per month by taking 4 gas samples from each chamber position on each collar installed. Gas samples were collected with the interval of 10 minutes: 0; 10; 20 and 30 minutes after carefully positioning chambers on the collars. The samples collected in underpressurized 100 mL glass vials were transported to the laboratory to be analysed by a gas chromatograph equipped with an electron capture detector [12]. Simultaneously with gas sampling the air and soil temperature at 5 cm depth, as well as the ground water level in the groundwater level monitoring wells (140 cm long PVC pipe) installed at time of establishment of the sample plots were measured.

Soil total CO_2 emissions are estimated by using the slope acquired form the linear regression curve representing CO_2 concentration changes in the chamber during the measurement period of 30 minutes. For quality assurance purpose only slopes with $R^2 > 0.7$ were used for further analysis. The ideal gas equation is used for calculation of soil total CO_2 emissions:

$$CO_2 = \frac{MPVslope}{RTtA}, \quad (1)$$

where CO_2 – soil total CO_2 emissions, µg CO_2 $m^2 \cdot h^{-1}$;
M – molar mass of CO_2, $g \cdot mol^{-1}$;
R – universal gas constant, 8.314 $m^3 \cdot Pa \cdot K^{-1} \cdot mol^{-1}$;
P – assumption of air pressure inside the chamber, 101 300, Pa;
T – air temperature, K;
V – chamber volume, 0.063 m^3;
t – time, 1 h;
$slope$ – CO_2 concentration changes in time, $ppm \cdot h^{-1}$;
A – collar area, 0.1995 m^2.

All soil total CO_2 emission measurement results in the paper are expressed in unit of $tC \cdot ha^{-1} \cdot yr^{-1}$, indicated uncertainty is the confidence interval. Data compliance to normal distribution is checked by Shapiro-Wilk test and differences of mean values – by Mann-Whitney test. Significance level $\alpha = 0.05$ is applied in statistical analysis.

Results and discussion

According to the data acquired in the study monthly average total CO_2 emissions from soil in naturally wet and drained sites are not significantly different ($p = 0.25$) and ranged from 2.39 to 15.81 $tC \cdot ha^{-1} \cdot yr^{-1}$ in February and June, accordingly (Fig. 1).

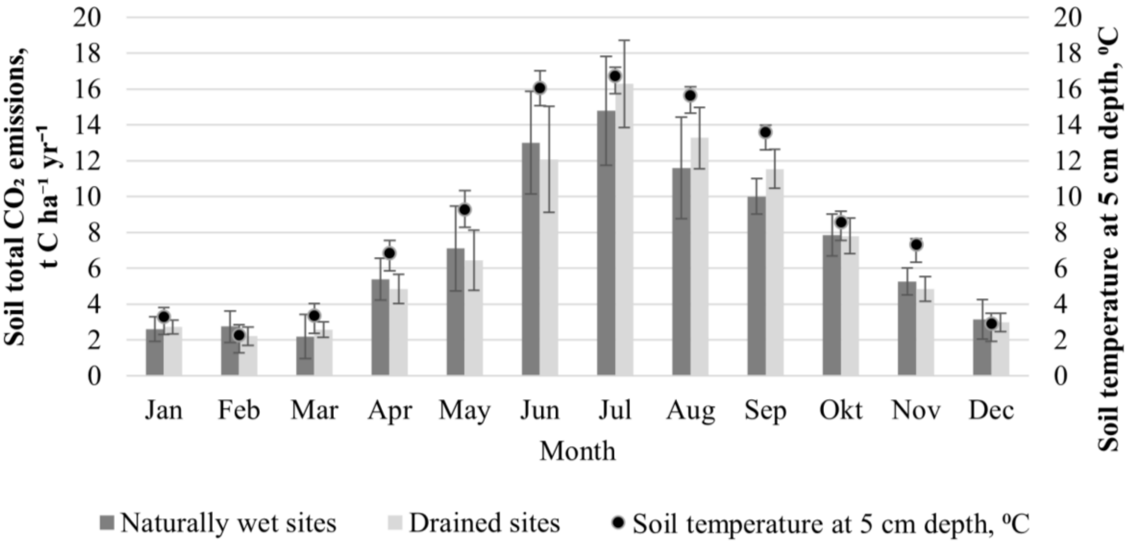

Fig. 1. **Variation of monthly soil total CO_2 emissions**

The groundwater level has low correlation with CO_2 emissions ($r = -0.30$). Variations of soil CO_2 emissions can be explained with changes of the soil temperature. Relationship of CO_2 emissions and soil temperature at 5 cm depth is characterized by exponential regression (Fig. 2). While the air and soil temperature have significant correlation (r = 0.89) characterised by linear equation:

$$t_{soil} = 0.64 t_{air} + 1.96 \quad (2)$$

where t_{soil} – soil temperature at 5 cm depth, ºC
t_{air} – air temperature, ºC.

Total annual CO_2 emissions from soil range from 5.44 ± 0.10 to 9.76 ± 2.47 $tC \cdot ha^{-1} \cdot yr^{-1}$ in drained black alder dominated stands and clearcuts and from 5.81 ± 2.23 to 10.55 ± 4.33 $tC \cdot ha^{-1} \cdot yr^{-1}$ in naturally wet Norway spruce stands and clearcuts, accordingly (Fig. 3). The impact of drainage conditions (naturally wet or drained soil) on the total CO_2 emissions from soil with different dominant tree species and difference of the mean annual emission between the dominant tree species is not significant ($p < 0.05$).

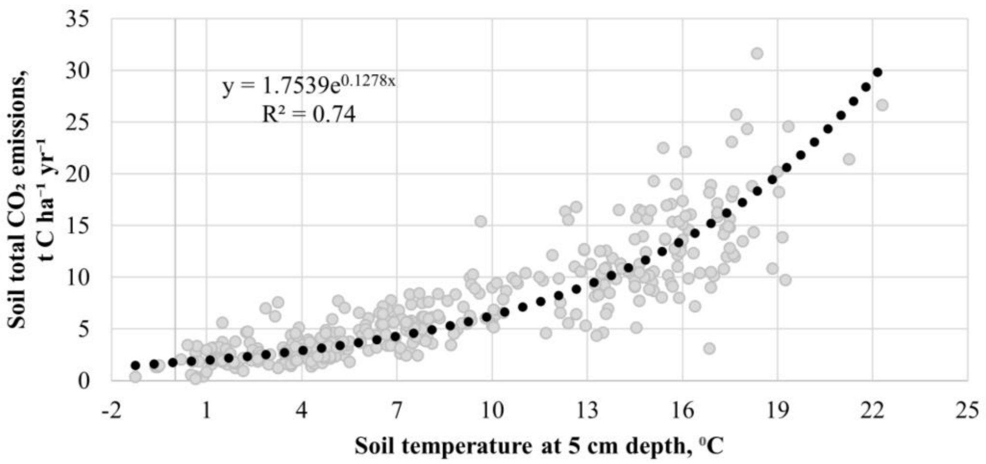

Fig. 2. **Relationship between soil total CO_2 emission and soil temperature**

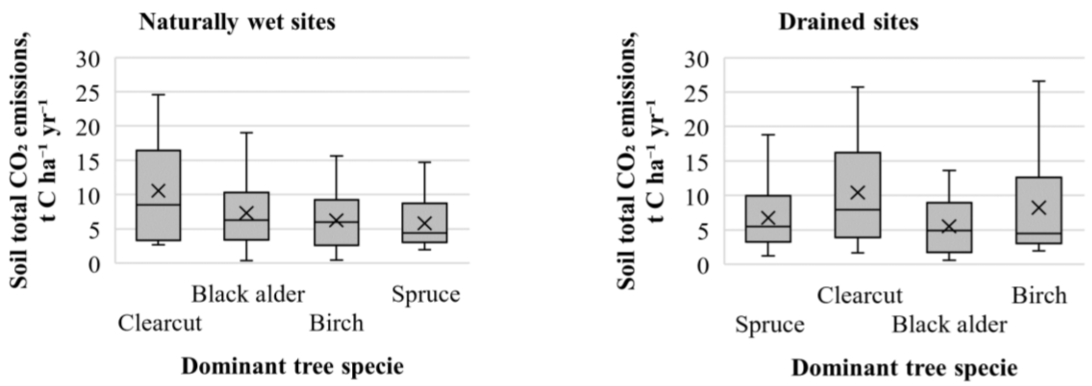

Fig. 3. **Intra annual variation of soil total CO_2 emissions in forest stands with different dominant tree species and soil drainage status**

Consequently, statistically significant differences between mean total CO_2 emissions from soil in different forest site types ($p > 0.05$) as well as in drained (7.35 ± 0.89 tC·ha^{-1}·yr^{-1}) and naturally wet (7.02 ± 0.96 tC·ha^{-1}·yr^{-1}) study sites ($p = 0.34$) were not found (Fig. 4). Intra annual total CO_2 emissions from soil in the study sites with tree cover ranged from 0.38 to 31.66 tC·ha^{-1}·yr^{-1}, while in clearcuts – from 0.17 to 25.74 tC·ha^{-1}·yr^{-1}. It was found that the CO_2 emissions above 22.13 tC·ha^{-1}·yr^{-1} are statistical outliers as indicated in Fig. 4 and differences between annual mean CO_2 emissions in forest stands (6.84 ± 0.56 tC·ha^{-1}·yr^{-1}) and clearcuts (10.08 ± 1.96 tC·ha^{-1}·yr^{-1}) are statistically significant ($p = 0.002$).

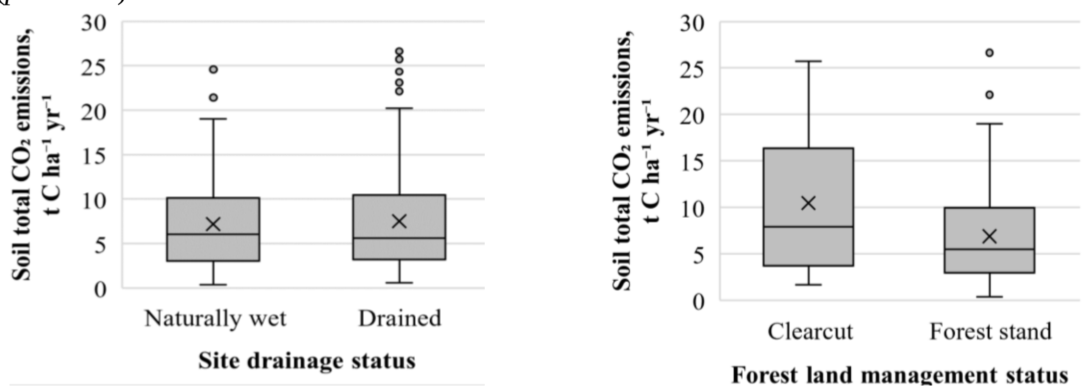

Fig. 4. **Intra annual variation of soil total CO_2 emissions in different forest site types and by drainage status and tree cover**

It is important to note that total reported CO_2 emissions from soil are gross soil emissions and include both soil heterotrophic and autotrophic respiration and do not consider soil C input by above-and belowground litter. It is reported in similar ecosystems studied that total CO_2 emissions from soil can be recalculated to heterotrophic respiration by the factor 0.5 [13-15]. It is estimated according to the NFI data on tree species and age distribution in Latvia that the weighted mean annual carbon input with above ground and belowground litter in drained organic soil is 0.27 ± 0.01 $tC \cdot ha^{-1} \cdot yr^{-1}$ and 0.65 ± 0.01 $tC \cdot ha^{-1} \cdot yr^{-1}$ in silver birch and Norway spruce stands, accordingly; while weighted average C annual input by fine roots is 1.43 ± 0.07 $tC \cdot ha^{-1} \cdot yr^{-1}$ in Norway spruce dominated stands and 1.70 ± 0.07 $tC \cdot ha^{-1} \cdot yr^{-1}$ in silver birch stands; and annual carbon input by tree foliar litter is 2.0 $tC \cdot ha^{-1} \cdot yr^{-1}$ and 1.86 $tC \cdot ha^{-1} \cdot yr^{-1}$ in silver birch and Norway spruce dominated stands with basal area of 20 m^2 ha^{-1} [16]. By combining the above mentioned data on soil CO_2 emissions an C input and estimating combined uncertainty, annual net soil CO_2 emissions are $-0.55 \pm 0{,}29$ $tC \cdot ha^{-1} \cdot yr^{-1}$ in silver birch stands and -0.52 ± 0.29 $tC \cdot ha^{-1} \cdot yr^{-1}$ in Norway spruce stands. To improve the net soil CO_2 emission estimate, additional national data on soil carbon input stratified by dominated tree species, soil fertility and drainage status as well as the proportion of heterotrophic and autotrophic respiration are necessary.

Conclusions

1. The study results show no significant impact of the forest site type, dominant tree species or drainage status on annual mean total CO_2 emissions from nutrient-rich organic soils (sum of soil heterotrophic and ground vegetation autotrophic respiration).
2. Differences between annual mean total CO_2 emissions from nutrient-rich organic soils in forest stands (6.84 ± 0 .56 $tC \cdot ha^{-1} \cdot yr^{-1}$) and clearcut areas ($10.08 \pm 1.96$ $tC \cdot ha^{-1} \cdot yr^{-1}$) are statistically significant.
3. Combining the study results on the CO_2 emissions from nutrient-rich organic soils with the estimates from earlier studies on the soil C input in forest sites with drained organic soils, the calculated net CO_2 emissions from the soil in the studied areas in silver birch stands are -0.55 ± 0.29 $tC \cdot ha^{-1} \cdot yr^{-1}$ and -0.52 ± 0.29 $tC \cdot ha^{-1} \cdot yr^{-1}$ in Norway spruce stands; respectively, they are net sinks of CO_2 removals.

Acknowledgements

The study is elaborated within the scope of the project of Forest sector competence centre "Modelling tools for evaluation of impact of groundwater level and other factors on GHG emissions from tree trunks" (agreement No. 1.2.1.1/18/A/004 P23).

Author contributions

Writing – original draft preparation, A.B.; field work, G.S.; writing – review and editing, I.L.; laboratory work – analysis of collected samples and data management, D.P.

References

[1] Jobbagy E. G., Jackson R. B. The Vertical Distribution of Soil Organic Carbon and Its Relation to Climate and Vegetation. Ecological Applications, vol. 10, no. 2, 2000, pp. 423-436.

[2] Lupikis A., Lazdins A. Soil carbon stock changes in transitional mire drained for forestry in Latvia: A case study. Research for Rural Development, vol. 1, no. May 17-19, 2017, Jelgava, Latvia, pp. 55-61.

[3] Valujeva K., Nipers A., Lupikis A., Schulte R. P. O. Assessment of Soil Functions: An Example of Meeting Competing National and International Obligations by Harnessing Regional Differences. Frontiers in Environmental Science, vol. 8, 2020, pp. 1–19.

[4] Skrebele A. et al., Latvia's National Inventory Report. Submission under UNFCCC and the Kyoto Protocol. Riga: Ministry of Environmental Protection and Regional Development of the Republic of Latvia, 2021. 545 p. [online] [03.05.2022]. Available at: https://unfccc.int/sites/default/files/resource/lva-2021-nir-13apr21_0.zip

[5] Bušs K. Meža ekoloģija un tipoloģija (Forest Ecology and Typology). Rīga: Zinātne, 1981. 64 p. (In Latvian)

[6] Eggleston H., Buendia L., Miwa K., Ngara T.,Tanabe K. (eds). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. Japan: IGES, 2006.

[7] Hiraishi T. et al. (eds). 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. Switzerland: IPCC, 2014.
[8] Bardule A., Lupikis A., Butlers A., Lazdins A. Organic carbon stock in different types of mineral soils in cropland and grassland in Latvia. Zemdirbyste, vol. 104, no. 1, 2017, pp 3-8.
[9] Lazdiņš A., Butlers A. Lupiķis A. Case study of soil carbon stock changes in drained and afforested transitional bog. In Foresst ecosystems and its management: towards understanding the complexity. Ilgas: Latvian State Forest Research Institute "Silava.," 2014. pp 40-41.
[10] Liepa I. et al. Latvijas meža tipoloģija (Latvian forest typlogy). Jelgava: Studentu biedrība "Šalkone", 2014. 119 p.
[11] Pavelka M. et al. Standardisation of chamber technique for CO2 , N2O and CH4 fluxes measurements from terrestrial ecosystems, International Agrophysics, vol. 32, no. 4, 2018, pp. 569-587.
[12] Loftfield N., Flessa H., Augustin J., Beese F. Automated Gas Chromatographic System for Rapid Analysis of the Atmospheric Trace Gases Methane, Carbon Dioxide, and Nitrous Oxide. Journal of Environment Quality, vol. 26, no. 2, 1997. pp. 560-564.
[13] Bond-Lamberty B., Wang C., and Gower S. T. A global relationship between the heterotrophic and autotrophic components of soil respiration?. Global Change Biology, vol. 10, no. 10, 2004, pp. 1756-1766.
[14] Comstedt D., Boström B., Ekblad A. Autotrophic and heterotrophic soil respiration in a Norway spruce forest: Estimating the root decomposition and soil moisture effects in a trenching experiment. Biogeochemistry, vol. 104, no. 1-3, 2011, pp. 121-132.
[15] Subke J. A., Inglima I., and Cotrufo M. F. Trends and methodological impacts in soil CO2 efflux partitioning: A metaanalytical review, Global Change Biology, vol. 12, no. 6, 2006, pp. 921–943.
[16] Bārdule A., Petaja G., Butlers A., Purviņa D., and Lazdiņš A. Estimation of litter input in hemi-boreal forests with drained organic soils for improvement of GHG inventories. Baltic Forestry, vol. 27, no. 2, 2021. pp. 1-15.