IPC2021

16th INTERNATIONAL PEATLAND CONGRESS

3-6 May 2021 • Tallinn, Estonia

Oral presentations

Argo Argel • Suru bog, Estonia

ID 62654

NDVI AS A PROXY TO ESTIMATE THE CO2 FLUXES IN PEATLANDS: EXAMPLE OF ALKALINE FEN

*Raimo Pajula[1], Anna-Helena Purre[2]

[1] Institute of Ecology, Tallinn University, Tallinn, Estonia

[2] School of Natural Sciences and Health, Tallinn University, Tallinn, Estonia

raimo.pajula@tlu.ee

SUMMARY

Normalized Difference Vegetation Index (NDVI) is a widely used multispectral vegetation index to estimate vegetation health and its abundance. NDVI is based on the ratio of the red light and near infrared light that is reflected from the surface. Plants absorb red and reflect infrared light, so NDVI reflects density of vegetation. We aimed at relating CO_2 fluxes and NDVI measured by drone to investigate possibilities to upscale CO_2 fluxes to larger areas cost-efficiently, and provide more information about relations between CO_2 exchange and NDVI in peatlands.

In Estonia, the project "Life Peat Restore" aims at restoring natural water regime and carbon sequestration on large Läänemaa Suursoo mire, where among other measurements, greenhouse gas measurements and vegetation monitoring by drones are conducted. Automated drone SenseFly eBee applied with Parrot Sequoia multispectral sensor was used for NDVI mapping of the study area. Manual transparent chambers and infra-red gas analyser Li-6400 (Li-Cor) were used for CO_2 measurements. CO_2 measurements and drone monitoring were done simultaneously in May, July, August, September and October in 2019 on the monitoring transect located on near-natural alkaline fen.

NDVI maps reflect pattern of mire plant communities - higher NDVI values reflect higher cover of vegetation, especially sedges, and low values sparser vascular vegetation and higher brown moss cover. Both NDVI and CO_2 balance had seasonal pattern during the growing season with highest index values and highest carbon binding in mid-summer. Generally, no significant relation was found between NDVI and measured net ecosystem exchange (NEE) and photosynthesis at ambient light conditions. Whereas during sunny and warm monitoring days the NDVI explained over 30% of the variation in NEE. NDVI was generally positively correlated with ecosystem respiration ($r = 0.44$, $p < 0.01$). NDVI is useful indicator for analysing mires vegetation parameters but relations with CO_2 fluxes needs further investigations in different peatland ecosystems and conditions.

Keywords: *alkaline fen, boreal peatland, NDVI, carbon dioxide, NEE*

INTRODUCTION

Active mires as well drained peatlands play important role in global carbon budget and greenhouse gas (GHG) balances. Mires restoration is important task for climate changes mitigation. In light of this, GHG measurements continue to be an important activity in the study of natural, degraded and restored mires. Because GHG measurements are labor intensive and costly, there is a need to find indirect methods to estimate GHG balance of mires. One possibility is to use remote sensing methods based on the spectral properties of the vegetation. If smaller spatial resolution is sufficient, satellite monitoring is most suitable for remote monitoring of mires. But if greater spatial resolution is needed then drone monitoring is the most appropriate method. The GHG balance cannot be estimated directly by remote sensing, but can be done through vegetation, provided that vegetation reflects that.

Normalized Difference Vegetation Index (NDVI) is widely used multispectral vegetation index to estimate vegetation abundance and its health. NDVI is based on the ratio of the red light and near infrared light that is reflected from the surface. The standard formula for NDVI is "NDVI = (NIR – Red) / (NIR + Red)". Plants absorbred and reflect infrared light, so NDVI reflects density of vegetation i.e. cover of photosynthetically active parts of plants. In temperate and boreal zone, NDVI of most vegetation types has a clear seasonal pattern with highest values in summer and lower values in spring and autumn (Kross et al. 2013). This pattern reflects the growth of the leaves of grasses, sedges and deciduous plants in spring and summer and the die back in autumn. Carbon sequestration by plants have also similar seasonal pattern (Kross et al. 2014; Mikhaylov et al. 2019; Lees et al. 2021). Therefore, we expect that the NDVI index could reflect carbon sequestration by the plant cover.

Aim of the study is to relate CO_2 fluxes measured on field and NDVI measured by drone to investigate possibilitiesto upscale CO_2 fluxes to larger areas cost-efficiently, and through it provide more information about relations between CO_2 exchange and NDVI in peatlands.

MATERIALS AND METHODS

The international project "Life Peat Restore" aims at restoring natural water regime and carbon sequestration of peatlands in Estonia, Latvia, Lithuania, Poland and Germany. The project site in Estonia (Suursoo-Leidisoo project site) is eastern part of large Läänemaa Suursoo mire complex (Figure 1, 2). A comprehensive monitoring network has been established on the project area, where among other measurements, GHG measurements and vegetation monitoring by drones and on field are conducted. Monitoring transect containing 4 monitoring points and locatedon near-natural alkaline fen (Figure 2) in eastern part of the project area were selected for the current study. The alkaline fen is near treeless and dominated by *Schoenus ferrugineus*, *Carex davalliana*, *Myrica gale*, *Menyanthes trifoliata*, *Phragmites australis* and *Carex* species. Moss layer is sparse and composed of brown mosses. Shrub and grass layer cover is in the range of 25 % to 45 % and moss layer 10-40%. Water level is in vegetation period
-20 to +10 cm from the mire surface. There is no clear drainage gradient along the monitoring transect but grass layer and moss layer cover and dominant species vary between monitoring points. The site historical backgroundand species composition is described in detail by Truus et al. (2021) in this Congress abstract book.

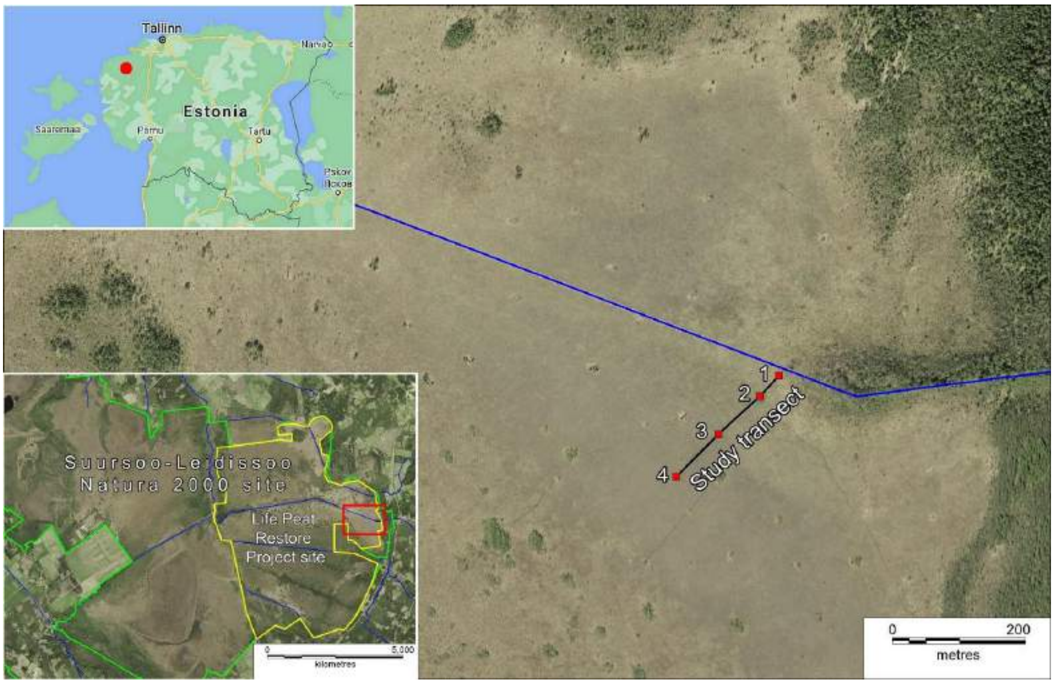

Figure 1. Location of the study area.

Automated survey drone SenseFly eBee with Parrot Sequoia multispectral sensor was used for NDVI mapping of the study area. Flights height was *ca* 65 m above ground and spatial resolution of NDVI output raster was ca 5 cm. Flights were performed around mid-day in same or close day with GHG measurements. In 2018 flights were done on August 13 and October 16, in 2019 on May 22, July 11, August 13, September 19 and October 30, and in 2020 on May 25, September 23 and November 6. Pix4Dmapper software was used for the data processing and NDVI maps creation. For the mire surface and vegetation located inside each 60 × 60 cm GHG measurement collars average NDVI values calculated for the area of ca 50 × 50 cm (0.25 m^2).

Manual transparent chambers (60 × 60 × 30 cm) and infra-red gas analyzer Li-6400 (Li-Cor) were used for CO_2 flux measurements. CO_2 measurements and drone monitoring were done simultaneously in all of the flight days on the monitoring transect located on near-natural alkaline fen. Here only CO_2 flux data calculated according to linear change in CO_2 concentrations inside the chambers and corrected according to the chamber volume and temperature is presented, and not the CO_2 fluxes reconstructed for the whole study period.


Figure 2. Drone photo of the study transect in alkaline fen. Study transect is indicated by red arrow.

RESULTS

NDVI values of the studied plots ranged 0.18 to 0.75 depending on date and study point. The index values are characterized by seasonal pattern with higher values in summer and lower values in spring and autumn (Figure 3). NDVI maps reflect well pattern of mire plant communities - higher NDVI values indicate higher cover of vegetation, especially sedges, and low values sparser vascular vegetation and higher brown moss cover. There was slight decrease in the NDVI values along the monitoring gradient moving from the ditch to the more pristine part of the fen. This trend can be explained by differences in cover of the grass layer which was denser near the ditch, while in autumn, NDVI values were higher on the most distant point from the ditch, where brown mosses had significant cover.

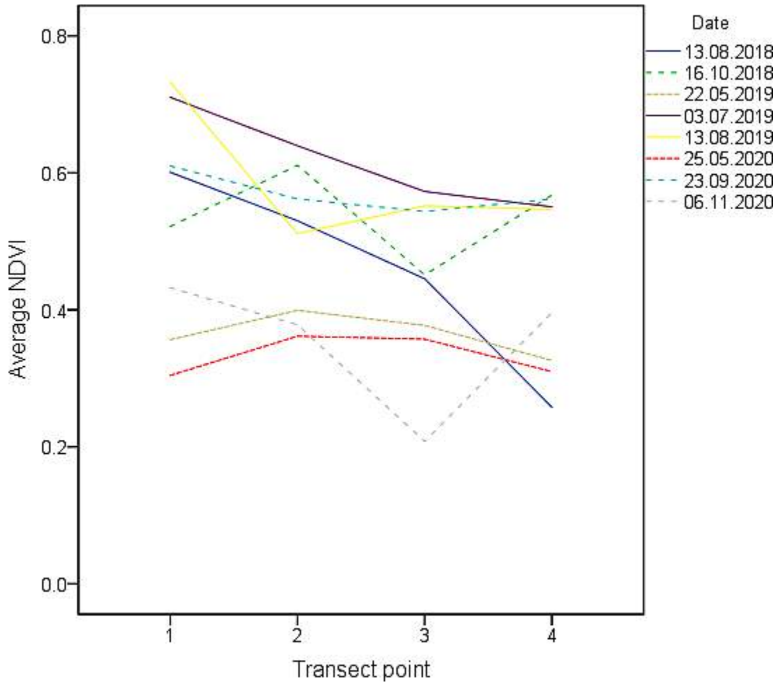

Figure 3. NDVI on study transect points on different measurement days. Solid lines indicate summer measurementdays (June-August), dotted lines indicate spring measurements (May), and dashed lines indicate autumn measurements (September-November).

Generally, plots with higher NDVI had also somewhat higher net ecosystem exchange (NEE) i.e. these plots were smaller CO_2 sinks during the measurements in ambient light conditions (Table 1). Stronger positive correlation was also between NDVI and ecosystem respiration (R_{eco}), whereas no correlation was found between NDVI and measured gross photosynthesis (P_g). On the three sunny and warm monitoring days (August 13s (2018 ($R^2 = 0.38$) and 2019 ($R^2 = 0.31$)), May 22 (2019; $R^2 = 0.31$)) when photosynthetically active radiation (PAR) was close to or exceeded 1 000 µmol m^{-2} s^{-1}, NDVI explained over 30% of variation of the NEE. In the August, 2018 the relationship was positive (higher NDVI led to somewhat higher NEE i.e. smaller CO2 uptake), whereas in both those dates in 2019, the relationship was negative, so higher NDVI led to higher CO2 uptake (Figure 4).

Table 1. Spearman correlations between NDVI, measured CO_2 flux variables (NEE and P_g measured under ambient light conditions), and environmental variables.

	NDVI	Transect point	Water level	NEE	P_g	R_{eco}
Transect point	-0,280**					
Water level	-0,331**	-0,096				
NEE	0,225*	0,132*	-0,298**			
P_g	-0,075	0,181**	0,089	0,901**		
R_{eco}	0,424**	-0,085	-0,546**	-0,226**	-0,585**	
LAI_{vasc}	0,636**	-0,059	0,006	0,282**	0,191	0,360**

*- correlation coefficient is statistically significant on level $p < 0.05$; **- correlation coefficient is statisticallysignificant on level $p <0.01$.

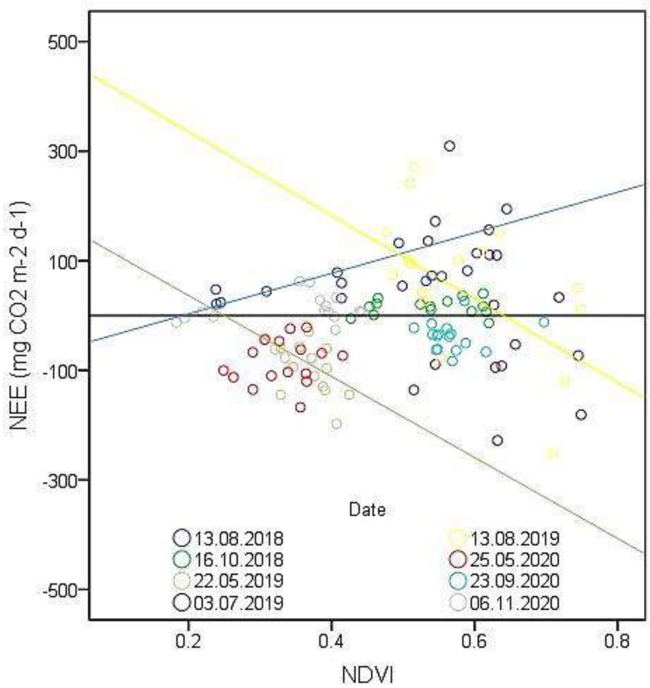

Figure 4. Relation between net ecosystem exchange (NEE) and NDVI. Solid lines indicate the linear regressionon dates when NDVI explained at least 30 % variation in NEE.

DISCUSSION

Our results support that NDVI has similar seasonal variations as CO_2 exchange as reported before (Lund et al. 2012; Kross et al. 2013). NDVI in this study in mildly disturbed fen ecosystem had weaker relationship with NEE than in restored milled peatlands in our previous study (Purre et al. 2019). Also the general direction of the relationship was reversed, when in restored milled peatlands higher NDVI values resulted in higher growing season CO_2 uptake and Pg (whereas no significant relationship was with Reco; Purre et al. 2019), in this study higher NDVI values were related with higher Reco and lower CO_2 uptake during the measurements, whereas Pg was not related significantly with NDVI. These differences between the studies are probably caused by different measurement periods. In Purre et al. (2019) NDVI was measured once after the CO_2 measurement period and was related with reconstructed growing season CO_2 fluxes while here NDVI was measured each time with CO_2 flux measurements and was also related with those. Differences also probably resulted from different peatland ecosystems, as restored milled peatlands have more patchy vegetation development with larger areas under bare peat (and therefore high heterotrophic respiration) or open water, and had higher cover of bryophytes, whereas fen ecosystem in this study had complete vegetation cover and herb layer dominated over sparser bryophyte layer. In initially bare peat areas such as restored milled peatlands development of any kind of vegetation is essential for carbon sequestration (Purre et al. 2019), whereas in undisturbed site, the carbon binding through Pg and also release by Reco depend on environmental conditions of the site and plant species and functional types. Site-type (nutrient availability and vegetation) specific differences in relations with CO_2 cycling and NDVI have been also reported before by Kross et al. (2013) in different undisturbed peatland ecosystems. Higher vascular cover characterized by higher summer NDVI and Reco values seems to reflect also higher soil respiration which can be caused by plants with aerenhyma.

Our measurements showed that NDVI and NEE related strongly during the more optimal light conditions (i.e. sunnier days), whereas no correlations were found during the clouded conditions. These results support the expectations of Boelman et al. (2003) who proposed that correlations between NDVI and CO_2 fluxes during the non-optimal light conditions are weaker than those correlations in optimal light conditions. Differences in NEE response to the differences in NDVI between the sunnier days in 2018 and 2019 could be result of differences in the study year conditions. In early-summer of 2018, heavy drought impacted the development of vegetation, which could have resulted in differences of CO_2 sequestration later that year. As reported by Lund et al. (2012) drought during the beginning of growing season impacts the CO_2 sequestration in greater extent than drought periods later in the summer. In sedge tundra, Boelman et al. (2003) measured CO_2 fluxes and NDVI during the peak of the growing season and at saturating PAR levels, finding that all three CO_2 flux components (Reco, Pg and NEE) had higher values (in case of Reco larger CO_2 emissions, in case of Pg and NEE larger CO_2 binding) on measurement plots with higher NDVI.

CONCLUSION

Our results show that NDVI can be used for describing temporal development, but also spatial distribution, of photosynthesizing biomass. Still, the relations between the CO_2 flux components and NDVI in fen-ecosystem differed from previous results in e.g. restored milled peatlands. Previously NDVI has been generally related with differences with gross photosynthesis, whereas in this study NDVI was more closely connected with ecosystem respiration. This topic should be further developed by relating measured NDVI with reconstructed growing season CO_2 fluxes in the future, and testing ways for using remotely measured vegetation indices for modelling and upscaling of CO_2 fluxes.

ACKNOWLEDGEMENTS

The study was conducted under LIFE Climate mitigation programme (2016-2021) project "Reduction of CO_2 emissions by restoring degraded peatlands in Northern European Lowland" (Life Peat Restore; LIFE15 CCM/DE/000138)

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