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Short Communication

Vegetation matters: Correcting chamber carbon flux measurements using plant volumes

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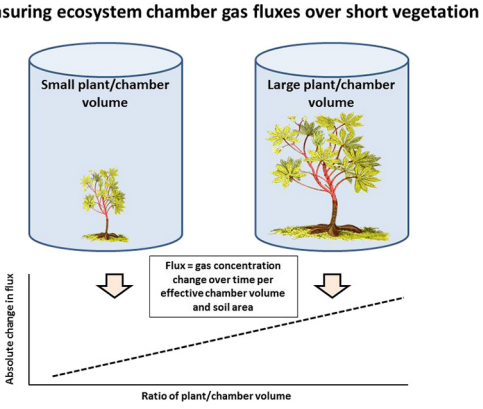
HIGHLIGHTS

- The effective chamber volume used in flux calculations is shown to be sensitive to plant volume.
- This effect is most pronounced when calculating fluxes from chambers containing proportionately larger plants.
- This can have important impacts on carbon cycle and carbon budget assessments when fluxes are upscaled.
- After an initial destructive laboratory validation, plant volumes can be visually assessed non-destructively in the field.

GRAPHICAL ABSTRACT



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ABSTRACT

Chamber carbon flux measurements are routinely used to assess ecosystem carbon sink/source dynamics. Often these point measurements enclose considerable vegetation biomass, with fluxes upscaled in space and time for each vegetation type. Here we assess the importance of including the volume of peatland dwarf shrub vegetation in chamber flux calculations and outline a simple but effective method of assessing plant volumes. We show that inclusion of plant volumes significantly affects fluxes and that this effect becomes greater as the proportion of chamber volume occupied by plants increases. Moreover, we demonstrate that, with an initial destructive laboratory assessment for each plant species and a little practice at volume estimation, plant volumes can be accurately assessed non-destructively in the field.

Globally, atmospheric carbon dioxide (CO_2) levels are rising; this exacerbates climate change and may lead to further CO_2 release (IPCC, 2014). Identifying ecosystems acting as either carbon (C) sinks (net CO_2 uptake) or C sources (net CO_2 release) requires accurate measurement of the net ecosystem exchange (NEE) CO_2 flux, which is the net balance between CO_2 uptake by photosynthesis and CO_2 losses from

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respiration by plants and soil (Chapin et al., 2006; Livingston and Hutchinson, 1995).

Peatlands represent a vast C store and, where intact and fully functioning, act as substantial C sinks (Bain et al., 2011). NEE based C accumulation measurements on northern hemisphere peatlands encompass values from −2 g C m^{-2} y^{-1} to −136 g C m^{-2} y^{-1} (Helfter et al., 2015; Nilsson et al., 2008; Roulet et al., 2007). Although the range of these NEE fluxes is large, the values represent a substantial C sink strength and demonstrate the potential of peatlands to mitigate rising atmospheric CO_2 concentrations, and hence regulate climate (Billett et al., 2010). This potential does however need balancing against the quantity of CH_4, a much more potent greenhouse gas than CO_2, released by peatlands (Bain et al., 2011).

Whilst NEE can be measured across a large area of peatland using eddy covariance flux towers, peatlands can be very heterogeneous environments, with each vegetation community exhibiting a different C balance (Poyatos et al., 2014). As climate change can alter the composition of vegetation communities (Bragazza et al., 2013), for accurate assessment and upscaling, NEE fluxes should therefore be measured for each community (Fox et al., 2008). This is typically achieved using ground-based chambers placed over the vegetation. As the chamber volume is used in calculating the NEE flux (Holland et al., 1999), large plant volumes reduce the effective chamber volume and may result in inaccurate fluxes. However, plant volumes are rarely, if ever, measured or included in NEE flux calculations.

In this study, plant volumes were estimated in the field and then validated in the laboratory. The aim was to verify whether including plant volumes in NEE flux calculations was necessary and, if so, whether volume estimates made in the field could be used as a proxy for volume measurements, without the need for destructive sampling. As NEE measured in the dark is ecosystem respiration (R_{eco}), R_{eco} measurements were used together with NEE measurements (those made in the light) to verify whether including the plant volumes was necessary. Whilst this study only considered NEE and R_{eco} fluxes from peatlands, the methods and findings detailed hereafter are applicable to any ecosystem and vegetation assemblage suitable for chamber measurements, and indeed chamber measurements of fluxes of any gas.

NEE fluxes were measured on three heather (*Calluna vulgaris*) dominated peatlands (Sites 1–3) in northwest England using a circular custom built clear Perspex chamber (Biology Mechanical Workshop, University of York, UK) with an internal diameter of 29.5 cm, a height of 60 cm and a volume of 39.6 L, which was connected to an infrared gas analyser (IRGA; Model 8100, Li-Cor, Lincoln, NE, USA). Each site had 24 permanent plots and fluxes were measured over three consecutive days (one day on each site) in July, October and December 2012. A PAR (photosynthetically active radiation) sensor (QS5 – PAR Quantum Sensor, Delta-T Devices, Cambridge, UK) was positioned free from shadows at c. 50 cm height within a demarcated circle on each plot and the chamber was carefully placed over the sensor and all plants rooted within this area. Wet *Sphagnum* moss was tucked around the base to seal the chamber to the atmosphere, thus avoiding issues related to entrenching soil collars (as demonstrated and highlighted in Heinemeyer et al., 2011).

The CO_2 concentration within the chamber was measured every second (s) for 45–90 s (the shorter times were used under warmer conditions) for periods of varying light conditions. Firstly, measurements were made in >90% of the total PAR (light reduction by the Perspex chamber was ~10%; A. Heinemeyer, unpublished data). Without removing the chamber, a shading mesh was placed over it (providing on average 30% of total PAR) and CO_2 concentrations recorded for another 45–90 s period. In July and October, a second shading mesh was placed over the first (resulting in 10% of total PAR on average) and another flux period was recorded. For the final flux period, ecosystem respiration was measured by placing a custom made cover (Environment Department, University of York, UK) over the chamber, blocking out all light. The *Sphagnum* moss seal was removed from plots after measurements. The internal chamber temperature increase was <3 °C during the light period and did not affect flux rates (i.e. the slope of CO_2 increase during the measurement period did not change).

During the October NEE flux measurements, the volume of *Calluna* plants was estimated in situ as a percentage of the chamber volume to the nearest 5%. The same two observers estimated volume at all sites by conferring. In March 2013, all plants within the NEE measurement circles were cut at the stem bases, bagged and sealed. Stems were cut so that the *Calluna* from each NEE circle fitted as compactly as possible into its bag. Using tongs, each bag was slowly submerged in a 20 L bucket, which was filled to the brim with water and inside a larger container. The bags were mainly sealed but one corner was left open to allow air to escape as it was forced up by the water pressure. The water displaced by the sample was measured and the bucket refilled. An empty bag was also measured five times in the same manner but using a 1 L beaker. The average of this was subtracted from each sample to give the *Calluna* volume.

LiCor Viewer software (version 1.3) was used to derive the CO_2 fluxes from the most linear 30–60 s portion (Li-Cor Biosciences, 2007) of each NEE measurement period under each light condition. The measured *Calluna* volume was subtracted from the chamber volume and all CO_2 fluxes were calculated using both this reduced (effective) and the original (uncorrected) chamber volume. All fluxes were expressed in μmol CO_2 m^{-2} s^{-1} where negative values represent NEE dominated by gross primary productivity (i.e. CO_2 uptake via photosynthesis) and positive values represent NEE dominated by ecosystem respiration (i.e. CO_2 release). The fluxes were calculated using a linear regression fit (with additional temperature, pressure, chamber volume and soil area adjustments performed by the software). The reduction in the effective chamber volume caused a proportional decrease in the corresponding plant volume corrected flux calculation based on:

$$F_{corr} = F_{raw} * V_{eff}/V_{raw}$$

where F is the uncorrected ($_{raw}$) or the corrected ($_{corr}$) flux and V is the uncorrected ($_{raw}$) or the plant volume adjusted effective ($_{eff}$) chamber volume.

A paired Student's *t*-test (using the function "*t*-test" in the R "stats" package; R Core Team, 2016) was used to determine whether subtracting the plant volume from the chamber volume significantly affected the NEE fluxes. A linear regression model test (employing the function "lm" in the R "stats" package; R Core Team, 2016) was used to determine the relationship between the estimated percentage volume and the measured volume of *Calluna* within the chamber. Separate linear regressions were also used on the same data split by site.

Across the different light conditions, NEE fluxes ranged from −14.48 μmol CO_2 m^{-2} s^{-1} to 12.67 μmol CO_2 m^{-2} s^{-1} with a mean of 1.53 μmol CO_2 m^{-2} s^{-1}. The difference between uncorrected fluxes and NEE fluxes corrected for *Calluna* volume ranged from −0.59 μmol CO_2 m^{-2} s^{-1} to 0.76 μmol CO_2 m^{-2} s^{-1} with a mean of 0.04 μmol CO_2 m^{-2} s^{-1}. Whilst this appears a relatively small change, the difference between the corrected and uncorrected fluxes was highly significant ($t_{791} = 10.0$, $p < 0.0001$), highlighting the importance of incorporating plant volumes into NEE flux calculations. The larger the NEE fluxes (i.e. the further from zero the fluxes were) and the larger the *Calluna* plants were, the greater the absolute change in NEE fluxes (Fig. 1). Therefore, the inclusion of plant volume becomes increasingly important as the proportion of the chamber occupied by vegetation increases, where fluxes from large mature vegetation are compared to fluxes from small or immature vegetation (e.g. as in Quin et al., 2015), and where NEE fluxes are upscaled, as any errors or inaccuracies in flux calculations would also be scaled (Holland et al., 1999).

Although there is a significant difference between the corrected and uncorrected fluxes, the mean of this difference was only 0.04 μmol CO_2 m^{-2} s^{-1}, just 2.6% of the mean of the uncorrected NEE fluxes