Supplementary Information for

Modeling relationships between water table depth and peat soil carbon loss in Southeast Asian plantations

Kimberly M Carlson\textsuperscript{1,2}, Lael K Goodman\textsuperscript{3} and Calen C May-Tobin\textsuperscript{3}

\textsuperscript{1} University of Minnesota Institute on the Environment, Saint Paul MN, USA
\textsuperscript{2} University of Hawai'i Mānoa Dept. of Natural Resources and Environmental Management, Honolulu HI, USA
\textsuperscript{3} Union of Concerned Scientists, Washington DC, USA

Supplementary Text
Supplementary References
Supplementary Table S1
Supplementary Figures S1-S3
SUPPLEMENTARY TEXT

1. Review of Subsidence Methods

In tropical peatlands, peat surface height loss the year following initial draining ranges from ~75-100 cm, with substantial height losses >15 cm yr⁻¹ possible during the first five years post-draining [1, 2]. Thereafter, subsidence rates decline to ~0.40-6.0 cm yr⁻¹, depending on peat properties including depth, dry bulk density (DBD, kg m⁻³), and mineral content, with higher subsidence rates recorded in deep fibric peats with low pre-drainage DBD and low mineral content [1, 3, 4]. Initial subsidence in peatlands planned for agricultural use may be enhanced by mechanical soil compaction. For example, in oil palm (Elaeis guineensis) plantations, compaction is undertaken to reduce leaning and improve yields [5]. However, not all plantations receive this treatment. As a result of subsidence, water tables in plantations must be constantly adjusted to maintain an appropriate water table depth for tree growth. Poles anchored into the mineral subsoil below the organic peat layer are typically used to assess subsidence rates.

Subsidence is a result of three processes: 1) Carbon loss from peat soil organic matter (SOM) decomposition; 2) Peat volume reduction above the water table (compaction and shrinkage); and 3) Compression of saturated peat below the water table (consolidation). In tropical peatlands, the cumulative contribution of decomposition to subsidence since the start of drainage has been estimated between 61% and 90% [3, 6]. Yet, the relative importance of decomposition, compaction, and consolidation changes with time. In the first years post-draining, most subsidence is ascribed to consolidation and compaction, with a greater proportion from decomposition in following years. For example, in acacia (Acacia crassicarpa) and oil palm plantations, Hooijer et al. [1] attribute ~92% of cumulative subsidence to decomposition in areas 18 years after drainage, compared to 75% only 6 years post-draining, and suggest that 100% of subsidence may be due to decomposition after the first 5 years. Although decomposition is a relatively less important contributor to subsidence rates in the first years following draining, decomposition rates may actually be higher in these initial years, because draining exposes a labile carbon pool that is rapidly decomposed on exposure to oxygen [1, 7].

Determining the relative contributions of decomposition, compaction, and consolidation is typically necessary for computing carbon loss rates from peat SOM using subsidence measurements [1, 8, 9]. For example, in an extensive subsidence-based study in Southeast Asia, Hooijer et al. [1] assumed that all consolidation occurred in the first year after draining. They further assumed that consolidation was the difference between the subsidence rate in the first year after draining and subsequent years. The relative contributions of compaction and decomposition to the remaining subsidence were then calculated from DBD and mean water table level before and after draining.

Researchers assess DBD by extracting, drying, and weighing a known volume of peat, typically at multiple depths in the soil profile. Dry bulk density in the lower peat layer of a drained peatland may be used as a proxy for pre-drained DBD [10, 11]. Alternatively, “control” DBD measurements may be collected from an intact reference system. However, because large differences in DBD have been recorded across small areas (e.g., intact Central Kalimantan peatlands [12]), adjacent systems may not always serve as good controls.

Carbon loss (kg m⁻²) can then be calculated from the proportion of subsidence due to decomposition (m), the carbon content of the soil (kg kg⁻¹) and DBD. Our review of research in Southeast Asian plantations indicates most studies do not directly measure carbon content, but derive values from the literature. Page et al. [13] find that published Southeast Asian peat carbon
contents range from ~0.42-0.62, and adopt a value of 0.56±0.03. Warren et al. [14] develop relationships between DBD and carbon content from a review of pan-tropical literature as well as Indonesian field-collected values. Farmer et al. [15] update this model for oil palm land use.

An alternative subsidence method assumes that managed land uses such as plantations have stable water tables controlled by water regulation in canals and periodic ditch deepening [11, 16]. Thus, the upper oxic peat layer remains in a steady state, enabling evaluation of carbon loss based solely on information about surface height loss, and lower peat layer DBD and carbon content. This method was developed by Kuikman et al. [16] and has been applied to drained peatlands in Europe and Southeast Asia [10, 11].

2. Review of Mass Balance Terms

Here, we review the state of knowledge regarding three mass balance terms: Land surface carbon loss in the form of CO₂ from heterotrophic soil respiration (C_H), fluvial export of carbon derived from SOM (C_H₂O), and carbon input from gross primary production (C_GPP).

2.1. Soil Respiration

Total soil respiration (C_S) measured with closed chambers consists of carbon loss from microbial SOM decomposition and microbial decomposition of dead plant remains (C_H), and additional SOM-derived emissions due to the rhizosphere priming effect, rhizomicrobial respiration, and root respiration [17].

A variety of field and laboratory techniques are available to partition among sources. Kuzyakov [17] presents a comprehensive review of the advantages and disadvantages of these techniques. From our reading of the tropical peat literature, we found that trenching, in which roots are severed prior to flux measurements, is frequently used to exclude root and rhizomicrobial respiration. Trenching is sometimes combined with clipping, where aboveground vegetation is cut. While these techniques have been criticized because they alter soil properties and may underestimate CO₂ emissions over the long term, while decomposition of dead roots must be considered [7], they may complement other techniques such as isotope analysis [18, 19]. In some ecosystems (e.g., plantations with trees spaced far apart), chambers can be installed far from trees and beyond the rooting zone to isolate heterotrophic respiration [20].

Jauhiainen et al. [19] measured CO₂ emissions under trenching and at different distances from trees in an acacia plantation, and found that root-related respiration composed 9-36% of total CO₂ flux. In an oil palm plantation, Dariah et al. [21] estimate that 14-29% of total area-weighted CO₂ emissions are root-related. Melling et al. [22] use a root exclusion technique and suggest that root respiration makes up 60% of total respiration in a Sarawak oil palm plantation. While such factors have been used to correct for the contribution of root-related respiration [23, 24], applying amendments may produce inaccurate results because this proportion varies widely over time and space.

A number of studies indicate that increasing temperature is correlated with increasing SOM decomposition rates [25, 26]. Temperature can vary widely depending on vegetative cover [25]. Since closed-chamber measurements are typically conducted during the daytime when soil surface temperatures can be up to 6 degrees higher than at night, failing to account for diurnal changes in soil temperature could result in overestimates of soil CO₂ emissions [25].

2.2. Fluvial Carbon Export
Fluvial carbon export ($C_{H_2O}$) from oil palm plantations is very uncertain because few studies cover this topic. For example, oil palm plantation fluvial carbon content measurements have been limited to a single dry season in 2008 [27] or include mixed upstream land uses with oil palm composing only ~1% of the total watershed [28]. Much fluvial carbon is likely exported as dissolved CO$_2$ and dissolved organic carbon (DOC) [29]. In Central Kalimantan, Moore et al. [27] found that annual total fluvial organic carbon flux was 40-68% greater in drained disturbed peat swamp forest compared to intact peat swamp forest, indicating that draining contributes to substantial fluvial carbon export from tropical peatlands. Yet, measuring only aquatic carbon content almost certainly underestimates $C_{H_2O}$. Jauhiainen and Silvennoinen [30] recorded substantial CO$_2$ (9.0-16 tC-CO$_2$ ha$^{-1}$ year$^{-1}$) and CH$_4$ (0.27-3.0 tC-CH$_4$ ha$^{-1}$ year$^{-1}$) emissions from water surfaces of drainage canals in Sumatra (acacia) and Borneo (abandoned peat). Currently, no other tropical studies present ditch carbon emissions, but the IPCC wetlands supplement [8] summarizes available temperate and boreal studies, and finds that CH$_4$ ditch emissions range from 0.011-2.0 tC-CH$_4$ ha$^{-1}$ yr$^{-1}$. These emissions are derived from photosynthesis of canal vegetation, gases formed during peat SOM decomposition, and gases produced within the canal from carbon originating from peat SOM. Until partitioning among production routes is undertaken, the contribution of peat decomposition to these fluxes will be unknown.

2.3. Carbon Input from Gross Primary Production

Primary producers contribute carbon inputs to peat soils through above- and below-ground pathways. When roots die and decompose, some of their carbon is released to the atmosphere, and some may be stored as SOM. Root mortality as well as root exudates – substances released into soil by healthy roots – represent potential carbon inputs to the soil. Leaf litter and wood also serve as inputs to peat substrates. These inputs vary widely with stand age, density, upkeep, genetic origins, soil type and management, climatic conditions, and local use of biomass. For example, Henson and Dolmat [31] found that total oil palm frond dry matter production increased more than three-fold over a 3-16 year period of palm maturation, while total frond biomass (t ha$^{-1}$) and root biomass turnover (kg palm$^{-1}$ yr$^{-1}$) were strongly dependent on palm density. Lamade and Bouillet [32] describe marked differences in carbon allocation to oil palm root systems between dry Ivory Coast soils and wet Indonesian soils. Moreover, removal of palm fronds from oil palm stands by local populations generates a notable decline in carbon input to plantation soils [32]. Inputs from roots are constrained to areas adjacent to the palm tree [21], while leaf litter is often stacked in windrows or piles between trees. In African mineral soils, 0-15 cm soil carbon content under frond piles was almost twice as high as carbon content in inter-rows cleared of leaf litter [33].

3. Data Collection and Analysis

In March 2015, we searched Google Scholar (scholar.google.com) and the Web of Science using terms such as “plantation”, “respiration,” and “subsidence” to generate a set of potential papers. With these papers, we used snowball techniques, adding papers from the citation lists of papers already in-hand. We considered peer-reviewed publications, white papers, dissertations, and published conference proceedings. Our search turned up 68 potential studies (Database 1). Once this list of potential papers was compiled, we selected literature reporting both water depth and chamber- or subsidence-based carbon loss from tropical peatland drained for plantation agriculture.
Forty-two studies were discarded because they were not relevant (i.e., did not include information about soil respiration or carbon loss via subsidence, did not report water table depth, were not located on peat, or did not include tropical plantation sites). Three publications were excluded because they did not include sufficient methodological detail. Three studies repeated other reported findings, which we used in our analysis. Seven studies were inaccessible, and consisted of conference proceedings, a white paper, a non-English language peer reviewed paper, and a dissertation.

We also filtered studies based on sampling timeframes. Soil respiration and depth must be measured over long time scales to detect significance relationships between these two variables. For example, while Jauhiainen et al. [19] detected a positive correlation between soil respiration rates and mean water depth measured over a 2-year period, instantaneous water table depth was uncorrelated with soil CO₂ emissions. One study [34] was rejected because flux measurements were conducted over only one month. The remaining twelve studies were used in our analysis (Database 2).

In cases where data were not provided in numeric format, we contacted authors for original data. If the authors did not respond, we estimated these values by extracting data from graphs. When necessary, composite standard deviation was calculated from sets of individual means and standard deviations, and mean values and standard deviations were weighted by sample size. We propagated uncertainty assuming no correlation between variables (covariance of 0). We recorded the length of time over which measurements were collected, identified measurements <5 years after initial peat draining, and flagged closed chamber studies excluding the root-related component of respiration. We assumed that chambers placed between or far from trees represented heterotrophic CO₂ emissions, while those placed close to trees were associated with total soil respiration rates. Ideally, all closed chamber studies would investigate whether ‘far from trees’ sites represent heterotrophic respiration by comparing CO₂ emissions pre- and post-trenching. Only Jauhiainen et al. [19] undertook this comparison; thus, there is some uncertainty regarding whether other heterotrophic CO₂ emissions estimates exclude all root-related respiration.

To calculate carbon density for all subsidence studies, we applied the model presented by Farmer et al. [15], which relates carbon density to DBD. We then followed Couwenberg and Hooijer’s [11] approach to calculate annual soil carbon loss (kg m⁻² yr⁻¹):

\[ f = S \times C \]  

(S1)

Where S is surface height loss (S, m yr⁻¹), and C is carbon density (kg m⁻³).

4. Selected Studies

Selected studies were published between 1996-2014 (Tables 1-2, Database 2). These studies report subsidence or closed chamber soil respiration measurements collected over 10 months to 7 years, and include oil palm, acacia, melaleuca (Melaleuca sp.), sago (Metroxylon sagu), and rubber (Hevea brasiliensis) land uses. Across sites, annual precipitation ranged from ~1700 mm yr⁻¹ to 3466 mm yr⁻¹, while peat depth spanned 2.5 to 9 m, and included a variety of peat types. Mean water table depth across all studies was 67±20 cm. Sago palm requires lower water table depths than other plantation species considered here; sago sites had mean water table depths of 27±5.8 cm (n = 3), versus oil palm (59±15 cm, n = 17), rubber (67 cm, n = 1), and acacia (75±16 cm, n = 36). Studies collected data over various periods from 1991 to 2012.
Comeau et al. [35] provided original data, and we included only samples for which water table depth and respiration rate were both available, so data presented here differ slightly from originally reported values.

Two studies – Melling et al. [22] and Melling et al. [36] – sampled chamber gas only two times, just before closure and at 6 minutes. Comeau et al. [35] used the same procedure and found that CO$_2$ flux plateaued after about 4 minutes. Thus, these studies may substantially underestimate emissions. Yet, removing these points altered mean soil respiration rate estimates at 70 cm water table depths by only 0-7% while reducing regression degrees of freedom, so we kept these sites in the study.
SUPPLEMENTARY REFERENCES

[1] Hooijer A, Page SE, Jauhiainen J, Lee WA, Lu XX, Idris A, et al. 2012 Subsidence and carbon loss in drained tropical peatlands Biogeosciences 9 1053-71
[2] Andriesse JP 1988 Nature and Management of Tropical Peat Soils FAO Rome
[3] Wösten. JH, Ismail AB, vanWijk ALM 1997 Peat subsidence and its practical implications: A case study in Malaysia Geoderma 78 25-36
[4] Murayama S, Bakar ZA 1996 Decomposition of tropical peat soils 2. Estimation of in situ decomposition by measurement of CO2 flux Jarp-Jpn Agr Res Q 30 153-8
[5] Lim KH, Lim SS, Parish F, Suharto R 2012 RSPO Manual on Best Management Practices (BMPs) for Existing Oil Palm Cultivation on Peat. Kuala Lumpur, Malaysia: Roundtable on Sustainable Palm Oil.
[6] Stephens JC, Allen LH, Chen E 1984 Organic soil subsidence Reviews in Engineering Geology 6 107-22
[7] Page SE, Morrison R, Malins C, Hooijer A, Rieley JO, Jauhiainen J 2011 Review of peat surface greenhouse gas emissions from oil palm plantations in Southeast Asia The International Council on Clean Transportation Washington, DC
[8] IPCC 2013 2013 Supplement to the 2006 IPCC guidelines for National Greenhouse Gas Inventories: Wetlands. Hiraishi T, Krug T, Tanabe K, Srivastava N, Baasansuren J, Fukuda M, et al., editors. Switzerland.
[9] DID, LAWOO 1996 Western Johore integrated agricultural development project, peat soil management study Department of Irrigation and Drainage (DID), Kuala Lumpur, Malaysia and Land and Water Research Group (LAWOO) Wageningen, The Netherlands
[10] Leifeld J, Muller M, Fuhrer J 2011 Peatland subsidence and carbon loss from drained temperate fens Soil Use and Management 27 170-6
[11] Couwenberg J, Hooijer A 2013 Towards robust subsidence-based soil carbon emission factors for peat soils in south-east Asia, with special reference to oil palm plantations Mires and Peat 12 1-13
[12] Kool DM, Buurman P, Hoekman DH 2006 Oxidation and compaction of a collapsed peat dome in Central Kalimantan Geoderma 137 217-25
[13] Page SE, Rieley JO, Banks CJ 2011 Global and regional importance of the tropical peatland carbon pool Global Change Biology 17 798–818
[14] Warren MW, Kauffman JB, Murdiyarso D, Anshari G, Hergoualc'h K, Kurnianto S, et al. 2012 A cost-efficient method to assess carbon stocks in tropical peat soil Biogeosciences 9 4477-85
[15] Farmer J, Matthews R, Smith P, Langan C, Hergoualc'h K, Verchot L, et al. 2014 Comparison of methods for quantifying soil carbon in tropical peats Geoderma 214-215 177-83
[16] Kuikman PJ, van den Akker JH, de Vries F 2005 Emissie van N2O en CO2 uit organische landbouwbodems (Emission of N2O and CO2 from Organic Agricultural Soils). Wageningen: Alterra; 66 p.
[17] Kuzyakov Y 2006 Sources of CO2 efflux from soil and review of partitioning methods Soil Biol Biochem 38 425-48
[18] Dorrepaal E, Toet S, van Logtestijn RSP, Swart E, van de Weg MJ, Callaghan TV, et al. 2009 Carbon respiration from subsurface peat accelerated by climate warming in the subarctic Nature 460 616-U79
[19] Jauhiainen J, Hooijer A, Page SE 2012 Carbon dioxide emissions from an Acacia plantation on peatland in Sumatra, Indonesia Biogeosciences 9 617-30
[20] Tang JW, Baldocchi DD, Xu L 2005 Tree photosynthesis modulates soil respiration on a diurnal time scale Global Change Biology 11 1298-304
[21] Dariah A, Marwanto S, Agus F 2014 Root- and peat-based CO2 emissions from oil palm plantations Mitig Adapt Strat Glob Change 19 831-43
[22] Melling L, Tan CSY, Goh KJ, Hatano R 2013 Soil microbial and root respiration from three ecosystems in tropical peatland of Sarawak, Malaysia J Oil Palm Res 25 44-57
[23] Agus F, Runtunuwu E, June T, Susanti E, Komara H, Syahbuddin H, et al. 2009 Carbon dioxide emission in land use transitions to plantation Jurnal Litbang Pertanian 28 119-26
[24] Hergoualc'h K, Verchot LV 2013 Greenhouse gas emission factors for land use and land-use change in Southeast Asian peatlands Mitig Adapt Strat Glob Change 19 789-807
[25] Jauhiainen J, Kerojoki O, Silvennoinen H, Limin S, Vasander H 2014 Heterotrophic respiration in drained tropical peat is greatly affected by temperature—a passive ecosystem cooling experiment Environmental Research Letters 9 105013
[26] Hirano T, Jauhiainen J, Inoue T, Takahashi H 2009 Controls on the Carbon Balance of Tropical Peatlands Ecosystems 12 873-87
[27] Moore S, Evans CD, Page SE, Garnett MH, Jones TG, Freeman C, et al. 2013 Deep instability of deforested tropical peatlands revealed by fluvial organic carbon fluxes Nature 493 660-4
[28] Lee KY, Syakir MI, Clark ID, Veizer J 2013 Isotope Constraints on the Aquatic Carbon Budget: Langat Watershed, Malaysia Aquatic Geochemistry 19 443-75
[29] Evans CD, Page SE, Jones TG, Moore S, Gauci V, Laiho R, et al. 2014 Contrasting vulnerability of drained tropical and high-latitude peatlands to fluvial loss of stored carbon Global Biogeochem Cy 28 1215-34
[30] Jauhiainen J, Silvennoinen H 2012 Diffusion GHG fluxes at tropical peatland drainage canal water surfaces Suo 63 93-105
[31] Henson IE, Dolmat MT 2003 Physiological Analysis of an Oil Palm Density Trial on a Peat Soil J Oil Palm Res 15 1-27
[32] Lamade E, Bouillet J-P 2005 Carbon storage and global change: the role of oil palm Oilseeds and fats, Crops and Lipids 12 154-60
[33] Lamade E, Djegui N, Leterme P 1996 Estimation of carbon allocation to the roots from soil respiration measurements of oil palm Plant and Soil 181 329-39
[34] Agus F, Handayani E, van Noordwijk M, Idris K, Sabiham S 2010 Root respiration interferes with peat CO2 emission measurement Proceedings of the 19th World Congress of Soil Science 1-6 August; Brisbane, Australia.
[35] Comeau L-P, Hergoualc'h K, Smith JU, Verchot L 2013 Conversion of intact peat swamp forest to oil palm plantation: Effects on soil CO2 fluxes in Jambi, Sumatra CIFOR Bogor, Indonesia
[36] Melling L, Chaddy A, Goh KJ, Hatano R 2013 Soil CO2 Fluxes from Different Ages of Oil Palm in Tropical Peatland of Sarawak, Malaysia as Influenced by Environmental and Soil Properties Acta Hortic 982 25-35
**SUPPLEMENTARY TABLES**

**Table S1.** Linear models weighted by sample size relating total peat soil carbon loss \( (f, \text{tC ha}^{-1} \text{yr}^{-1}) \), heterotrophic soil respiration \( (C_H, \text{tC-}CO_2 \text{ha}^{-1} \text{yr}^{-1}) \), and total soil respiration \( (C_S, \text{tC-}CO_2 \text{ha}^{-1} \text{yr}^{-1}) \) to water table depth (WT, cm) and vegetation age (Age, years) for plantations on drained peatlands in Southeast Asia. We report the measurement type, number of site data points \( (n) \), model specification, p-value, coefficient of determination \( (r^2) \), and AICc, as well as coefficient values, standard errors (SE), and p-values \( (p) \). We do not present subsidence and total respiration models with vegetation age because age is not a significant parameter \( (p > 0.05) \).

| Type                     | n    | Model                  | \( p \) (model) | \( r^2 \) | AICc | \( \alpha \) | SE | \( p \) | \( \beta \) | SE | \( p \) | \( \gamma \) | SE | \( p \) |
|-------------------------|------|------------------------|-----------------|----------|------|-------------|----|---------|-----------|----|---------|-----------|----|-------|
| Subsidence - Weighted   | 27   | \( f = \alpha + \beta \text{WT} \) | <0.01           | 0.39     | 159  | 6.3         | 3.2 | 0.063   | 0.20      | 0.049 | <0.01   |          |     |
| Heterotrophic           | 16   | \( C_H = \alpha + \beta \text{WT} \) | 0.14            | 0.15     | 115  | 7.1         | 7.3 | 0.35    | 0.14      | 0.092 | 0.14    |          |     |
| Respiration - Weighted  |      | \( C_H = \alpha + \beta \text{WT} + \gamma \text{Age} \) | <0.01           | 0.67     | 103  | 3.4         | 4.8 | 0.49    | 0.25      | 0.064 | <0.01   | -1.0      | 0.21 | <0.01 |
| Total                   | 16   | \( C_S = \alpha + \beta \text{WT} \) | <0.01           | 0.55     | 116  | -0.54       | 6.3 | 0.93    | 0.32      | 0.077 | <0.01   |          |     |
SUPPLEMENTARY FIGURES

Figure S1. Linear model weighted by sample size relating net carbon loss (tC ha\(^{-1}\) yr\(^{-1}\)) to water table depth (cm) in tropical peatlands drained for plantation agriculture. Regression was developed from published studies reporting carbon loss calculated from subsidence methods (four studies, \(n = 27\) sites). Solid lines represent the estimate of the population mean. Gray shaded areas indicate 95% CIs around the true population mean, while dashed lines denote 95% prediction intervals, which provide information about the potential value of future samples.
Figure S2. Linear models weighted by sample size relating soil respiration (tC-CO$_2$ ha$^{-1}$ yr$^{-1}$) to water table depth (cm) in tropical peatlands drained for plantation agriculture. Regressions were developed from published studies reporting: (a) heterotrophic soil respiration (six studies, $n = 16$ sites); and (b) total soil respiration (six studies, $n = 16$ sites) from closed chamber measurements. Emissions are corrected for temperature as described in the main text. Pulpwood plantations are indicated by circles, and consist of acacia (large circles) and melaleuca (small circles) vegetation. Solid lines represent the estimate of the population mean. Gray shaded areas indicate 95% CIs around the true population mean, while dashed lines denote 95% prediction intervals, which provide information about the potential value of future samples.
**Figure S3.** Relationships between predictor variables and carbon loss including net carbon loss (tC ha\(^{-1}\) yr\(^{-1}\)) measured from subsidence (red, S), as well as heterotrophic (black, H), and total (grey, T) respiration rates (tC-CO\(_2\) ha\(^{-1}\) yr\(^{-1}\)) measured with closed chambers in tropical plantations on peatlands. We assessed a) mean vegetation age (years), b) mean peat depth (m), and c) mean time since peat draining (years). Lines represent best-fit linear regressions for each measurement type. Chamber-based emissions are corrected for temperature as described in the main text. Pulpwood plantations are indicated by circles, and consist of acacia (large circles) and melaleuca (small circles) vegetation. Some studies did not report peat depth and time since draining, and are not included in these plots.