Emission Factor for Tropical Peatlands Drained for Oil Palm Cultivation

Peer-Review Report

United States Environmental Protection Agency

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Peer-Review Report

Transportation and Climate Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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NOTICE

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United States Environmental Protection Agency

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LIST OF ACRONYMS

C	carbon
CO_2	carbon dioxide
DIC	dissolved inorganic carbon
DOC	dissolved organic carbon
EPA	U.S. Environmental Protection Agency
$g\ cm^{-3}$	grams per cubic centimeter
GHG	greenhouse gas
ha^{-1}	hectare
$ha^{-1}\ yr^{-1}$	hectare per year
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
Pg	petagram
POC	particulate organic carbon
RFS	Renewable Fuel Standard
Tg	teragram

SECTION 1
INTRODUCTION

In January 2012, the U.S. Environmental Protection Agency (EPA) published an analysis of the life-cycle greenhouse gas (GHG) emissions associated with palm oil–based biodiesel and renewable diesel. The results of the analysis indicate that, when compared with the petroleum diesel baseline, palm oil–based biofuels reduce GHG emissions by 17% and 11%, respectively, and thus do not meet the statutory 20% GHG emissions reduction threshold for the Renewable Fuel Standard (RFS) program (EPA, 2012).

Based on EPA's analysis, one of the major sources of GHG emissions was emissions resulting from drained organic peat soils preceding the development of new palm oil plantations. The EPA used a peat soil emission factor of 95 tonnes of carbon dioxide (CO_2) per hectare of drained peat soil, based on Hooijer et al. (2012), to help estimate the total GHG emissions from the expansion of peat soil drainage.

To ensure that the EPA has taken into account the best available information on this important emissions factor for the life-cycle GHG analysis of palm oil–based biofuels, the Agency asked RTI International to facilitate an independent peer review. The purpose of this review was to request additional scientific input about the Agency's assessment of the average annual GHG emissions from tropical peatlands resulting from the development of the land for production of palm oil for use in EPA's life-cycle GHG analysis of palm oil–based biofuels. RTI selected five peer reviewers who are experts in GHG emissions from peat soils to review the EPA's application of the peat soil emissions factor and to provide feedback on the use of this factor. The following sections of this report summarize the peer-review process and the peer reviewers' responses to five questions that seek to address the relevance and appropriateness of the emission factor.

SECTION 2
OVERVIEW

In fall 2013, the EPA requested that RTI facilitate a peer review to be conducted of the peat soil emission factor that the Agency uses for life-cycle GHG assessment of palm oil biofuels for the RFS program. RTI, an independent contractor, supported the EPA by facilitating the peer review according to guidelines in the Agency's *Peer Review Handbook* (EPA, 2006).

The EPA requested recommendations for peer-review candidates from various organizations and agencies. Then, the EPA compiled the recommendations and submitted a list of 21 candidates to RTI. The Agency sought recommendations for qualified candidates from the following entities:

- Office of the Ambassador of Indonesia
- Clean Air Task Force
- Embassy of Malaysia
- International Council on Clean Transportation
- National Wildlife Federation
- National Resources Defense Council
- Union of Concerned Scientists
- World Wildlife Fund

Copies of the recommendation requests are included in **Appendix A** of this report.

Qualified candidates were those who have a doctoral degree in soil science or a related field and have published peer-reviewed journal articles about carbon cycling and tropical peat soils. Of the 21 recommended candidates, four were excluded from consideration because they were involved in the development of the Hooijer et al. (2012) publication on which EPA sought critical input, and there was considered to be an inherent conflict of interest in asking them to review the relevance and appropriateness of their own work. RTI also conducted a literature and online resources investigation for additional candidates and identified 10 more qualified candidates for consideration.

Thus, a total of 27 qualified candidates were identified and contacted to determine their interest in and availability for the peer review. Of the 27 candidates contacted, 18 of them said they were available, so they completed a Conflicts of Interest (COI) Disclosure Form. The COI forms requested information on any and all real or perceived COI or bias, including funding sources, employment, public statements, and other areas of potential conflict in accordance with EPA's *Peer Review Handbook* (EPA, 2006). A template of the COI form completed by the candidates is included in **Appendix B**. RTI staff supporting the peer review also underwent a COI investigation to corroborate the independence and a lack of bias across all components of the peer review.

Per the instructions from the EPA, RTI set out to select four or five reviewers from the candidate pool based on all of the following criteria:

- expertise, knowledge, and experience of each individual
- adherence to the COI guidance in the EPA *Peer Review Handbook*
- panel balance with respect to the expertise required to conduct the review and the diversity of relevant scientific and technical perspectives

Based on the candidates' availability and qualifications, the information provided in the completed COI Disclosure Forms, and an independent COI investigation conducted by RTI staff, RTI selected the following five candidates:

- Scott Bridgham, Ph.D., Professor, University of Oregon
- Kristell Hergoualc'h, Ph.D., Scientist, Center for International Forestry Research
- Monique Leclerc, Ph.D., Regents Professor, University of Georgia
- Supiandi Sabiham, Ph.D., Professor, Bogor Agricultural University
- Arina Schrier, Ph.D., Owner, Climate and Environmental International Consultancy

Three of the selected peer reviewers (i.e., Drs. Bridgham, Hergoualc'h, and Leclerc) reported no COI on the disclosure form. Dr. Sabiham stated that although he does not have any actual or potential COI or bias impeding his ability to independently evaluate the peat soil emissions factor used by the EPA, he did note that government and palm oil industry funding has been provided to the university where he is employed to support ecological and sociological research on land-use changes from peat swamp forest to agricultural uses, from which Dr. Sabiham and his graduate students receive funding. Dr. Sabiham also noted his roles as President of the Indonesian Peat Society and as an independent expert developing scientific reviews for entities such as the Intergovernmental Panel on Climate Change (IPCC), the Indonesian Government, and the Roundtable on Sustainable Palm Oil. Similarly, Dr. Schrier noted her roles as an independent expert developing scientific reviews for the IPCC, the International Council on Clean Transportation, and the Roundtable on Sustainable Palm Oil.

It is important to note that these five candidates were specifically selected to develop a balanced, independent panel with various backgrounds from academia, nongovernmental organizations, and private consulting. No more than one candidate was selected from the recommendations provided by a single EPA-contacted entity (one each from the Ambassador of Indonesia, the Embassy of Malaysia, and International Council on Clean Transportation, and two independently identified by RTI).

The EPA reviewed and approved the list of candidates selected by RTI as appropriate choices from the candidate pool to form an independent and balanced panel. Copies of the selected candidate resumes are included in **Appendix C** of this report.

RTI staff provided the peer reviewers with the EPA-developed Technical Work Product and Peer-Review Charge (both in **Appendix D** of this report), which guided the evaluations. RTI requested that the reviewers refrain from discussing the subject of the review with other parties during the review period. Although RTI was available to address any questions that reviewers had during the review, all peer reviewers were asked to respond to the charge independently and without consult from the other peer reviewers. The panel was not asked to reach a consensus.

RTI staff members have summarized the panel's responses below. The peer reviews from each panel member are included in **Appendix E** of this report.

Three out of the five reviewers agreed that the emission factor used in EPA's analysis of palm oil–based biofuels is an appropriate coefficient to use based on current scientific understanding, but emphasized that the emission factor should be reevaluated as meta-analyses of existing research are conducted and/or as additional research becomes available. Two reviewers stated that the EPA has likely overestimated the carbon emissions. One of those two reviewers recommended using the peat soil emission factors published by the IPCC (Drösler et al., 2013), while the other reviewer recommended using the peat soil emission factors published by Melling et al. (2007).

SECTION 3
SUMMARY OF PEER-REVIEW RESPONSES

All five peer reviewers examined the EPA–developed Technical Work Product and Peer Review Charge. This section of the report provides the charge questions (in italics) followed by summaries of the peer reviewers' comments. **Appendix E** includes the full responses from each peer reviewer.

3.1 Overarching Charge Question

Given the three criteria outlined in the Technical Work Product and the estimates available in the literature, did the EPA choose the most appropriate value for the peat soil emission factor? If not, please provide a recommendation on the most appropriate peat soil emission factor to use in EPA's analysis, with a detailed explanation.

Three out of the five peer reviewers (Drs. Bridgham, Schrier, and Leclerc) stated that the peat soil emissions factor used by the EPA is the most appropriate emission factor based on current available literature. Both Drs. Schrier and Leclerc emphasized that the emission factor should be reevaluated as meta-analyses of existing research are conducted and/or as additional research becomes available. Reevaluating the emission factor will help reduce the uncertainty associated with any factors that have not been considered, have not been based on oil palm on peat measurements, or have been based on a small sample size (spatial, temporal, or numerical). Dr. Schrier discussed the uncertainties associated with the following:

- short-term nature of the available literature
- separation between CO_2 and methane emissions related to the drainage of peat
- assumptions required for the soil subsidence method, including bulk density and carbon fraction
- initial pulse emissions versus base emissions rates
- dissolved organic carbon (DOC) and ditch fluxes
- fire emissions
- water-table fluctuations and averages

Dr. Leclerc recommended that the emissions factor be considered temporary and conditional because it likely underestimates emissions. Dr. Leclerc noted the following areas for further investigation: the role of root respiration and differences between peat swamp forests, oil palm, and acacia; non-CO_2 GHG emissions; and acknowledgement and identification of heterogeneous peat depths through additional sample locations. Dr. Leclerc also mentioned these additional areas for further investigation: the effect of management practices, the occurrence of peat fires following the establishment of oil-palm plantations on peat land, and the duration of carbon monoxide and CO_2 emissions with smoldering fires.

Drs. Hergoualc'h and Sabiham disagreed with EPA's emission factor choice. Dr. Hergoualc'h stated that EPA's emission factor is not representative of Southeast Asia and recommended the emission factors published by the IPCC (Drösler et al., 2013):

- on-site CO_2 emissions: 40 tonnes of CO_2 per hectare per year (ha^{-1} yr^{-1})
- off-site CO_2 emissions via waterborne carbon losses: 3 tonnes of CO_2 (ha^{-1} yr^{-1})
- CO_2 from prescribed fires: 264 tonnes of CO_2 per hectare (ha^{-1})
- CO_2 from wildfires: 601 tonnes CO_2 ha^{-1}

Dr. Hergoualc'h further noted that the initial pulse emissions following drainage are not directly included in EPA's emissions factor, but rather indirectly added through the carbon loss estimate.

Dr. Sabiham stated that the emissions factor is not an appropriate choice because of Hooijer et al.'s (2012) exclusion of root respiration and the assumptions regarding peat soil bulk density, peat organic carbon content, and groundwater table depth. Dr. Sabiham noted that these assumptions likely overestimate the emissions and, therefore, recommended an emissions factor consistent with the Melling et al. (2007) study, which includes root respiration and a shallower groundwater level.

3.2 Potential Adjustment of Emission Factor from Hooijer et al. (2012)

Some commenters have raised questions about particular values used in the Hooijer et al. (2012) study (e.g., organic carbon content, peat bulk density). Would you recommend that EPA use the overall approach and data published in Hooijer et al. (2012), but use a different value for the following: (a) organic carbon content, (b) peat bulk density, (c) the percentage of subsidence due to oxidation, or (d) another parameter (please specify)? Please explain your recommendation and provide supporting documentation.

In response to the second charge question, the panel was fairly split. Two peer reviewers (i.e., Drs. Sabiham and Bridgham) agreed with the overall approach used by the EPA and presented by Hooijer et al. (2012). One peer reviewer (i.e., Dr. Hergoualc'h) did not agree with the overall approach. One peer reviewer (i.e., Dr. Leclerc) stated that there was not enough information available on the key components of the approach to determine its appropriateness. One peer reviewer (i.e., Dr. Schrier) suggested that a meta-analysis be performed that incorporates both the soil subsidence- and chamber-based research. Regarding the values used in the approach, two panel members (i.e., Drs. Schrier and Bridgham) agreed with EPA's decision to use the Hooijer et al. (2012) values, and one panel member (Dr. Sabiham) disagreed. Two members (Drs. Hergoualc'h and Leclerc) asserted that not enough information was available to lessen the uncertainty regarding the values.

Dr. Hergoualc'h recommended that the EPA not use the approach by Hooijer et al. (2012) because it is too sensitive to parameter values that require long-term monitoring and baseline information (e.g., organic carbon content, peat bulk density, the percentage of subsidence because of oxidation). Because no reference site information or long-term data are available, the approach must, therefore, be based on assumptions, which introduces high levels of uncertainty.

Dr. Sabiham stated that a subsidence-based technique performs better than a closed-chamber measurement regarding the long-term effect of drainage on carbon stock depletion of peat. However, Dr. Sabiham questioned the values used by the EPA for organic carbon content, peat bulk density, and the percentage of subsidence because of oxidation. Therefore, Dr. Sabiham made the following recommendations for emission factor estimates developed for oil palm plantations on peat soil:

- The value of organic carbon content should not exceed 45% .

- The value of peat bulk density should range between 0.07 and 0.1 grams per cubic centimeter (g cm^{-3}) at the start of drainage and between 0.18 and 0.22 g cm^{-3} once subsidence has begun.
- An oxidation/subsidence ratio of 44%, as supported by Couwenberg et al. (2010), should be used.

Dr. Bridgham agreed with the overall approach and values used by Hooijer et al. (2012) but noted that the values used by the approach may be limited by the geographically limited study area. However, Dr. Bridgham stated that it is likely that this level of uncertainty leads to an underestimation of emissions because of higher bulk density and soil carbon measurements, which are observed in other literature.

Dr. Schrier recommended that the EPA continue to use the current values published in Hooijer et al. (2012) because the carbon fraction and bulk density estimates are representative of the literature and because the study is the most robust investigation specifically designed to determine soil subsidence due to oxidation. However, Dr. Schrier recommended that the overall approach be amended to consider other studies through a meta-analysis of soil subsidence and chamber-based research.

Dr. Leclerc stated that the effects of peat characteristics (including bulk density, organic carbon content, and depth) and other variables (e.g., management techniques) on GHG emissions must be assessed before selecting an approach. Therefore, once additional studies have been conducted and more data are available for analysis, the approach should be refined. Dr. Leclerc further asserted that the composition of peat varies regionally; therefore, this will create large variations in the values required for the subsidence technique. Thus, one emissions factor may not be sufficient.

3.3 Directionality of Estimate

The EPA recognizes that the Hooijer et al. (2012) study that forms the foundation of our estimate of peat soil emissions was conducted under specific circumstances. For example, it was conducted in a limited number of plantations on the island of Sumatra. For the reasons listed in the Technical Work Product, we believe this is the best available estimate of peat soil emissions, but we recognize that numerous factors could cause this estimate to be higher or lower than the average emission factor for peat soils drained for oil palm across Southeast Asia. Please discuss whether the emission factor value used by the EPA (95 tCO_2e/ha/yr) is likely to overestimate or underestimate (and if so, by how much) or provide a plausible estimate of average GHG emissions from peat soil drainage for oil palm across Southeast Asia. In particular, please discuss whether the following factors are likely to make EPA's emission factor an overestimate or an underestimate:

a. *Variation in the type of peat soil (e.g., mineral content, carbon content, depth, extent of degradation)*
b. *Precipitation regime (e.g., annual rainfall, timing of rainfall)*
c. *Differing water management practices at plantations*
d. *Different types of plantations (e.g., oil palm versus acacia)*
e. *The approach used by Hooijer et al. (2012) to estimate emissions during the first 5 years after drainage*
f. *Omission of methane and nitrous oxide emissions*
g. *Omission of emissions due to fire (as discussed in the Technical Work Product, omission of this factor will cause EPA's emission factor to underestimate emissions, but we welcome comments about how large this underestimation may be.)*
h. *Omission of incidentally drained peat swamps adjoining the plantations.*

Overall, two peer reviewers (Drs. Sabiham and Hergoualc'h) responded that the previously mentioned factors are likely to overestimate the average GHG emissions from peat soil drainage under oil palm plantations. Two peer reviewers (Drs. Leclerc and Schrier) stated that the factors are likely to underestimate the average GHG emissions. One peer reviewer responded that the GHG emissions are likely to be fairly represented. Table 3-1 summarizes the panel members' responses to each of the individual factors.

Table 3-1. Summary of Peer-Review Response to Charge Question #3

Topic Areas	Dr. Bridgham	Dr. Hergoualc'h	Dr. Leclerc	Dr. Sabiham	Dr. Schrier
a. Variation in the type of peat soil	This is a representative estimate.	Additional research is needed. Peat properties and duration of consolidation will likely affect the carbon loss rate after conversion.[a]	This likely underestimates the emissions from sapric peat more than for fibric and hemic, but more research is needed.	Additional information is needed, but this is likely overestimated because of low organic carbon in high ash–content soils.	This is a representative estimate or a slight overestimate because of spatial and temporal variability.
b. Precipitation regime	This is a representative estimate, as long as regional water table and drainage are consistent.	There is no scientific evidence that rainfall patterns can influence peat carbon losses in converted tropical peatlands.	This is expected to affect the emissions because it modifies the water content in the peat. Its importance has yet to be examined.	This is likely overestimated because plantations can manage groundwater level.	This is a representative estimate or a slight overestimate because of variations in climate.
c. Differing water management practices at plantations	This is a representative estimate because of the nitrogen fertilization effect.	Differences in laboratory and field measurements suggest that additional research is needed.	This is underestimated. CO_2 emissions rise when methane emissions fall and vice versa due to microbial populations. Thus, customary water table management should be revised to decrease the total GHGs and not just CO_2.	This is likely overestimated because optimum groundwater level is shallower than the Hooijer et al. (2012) estimate.	This is a representative estimate or a slight overestimate. Maintaining water tables according to best management practices is generally not feasible with most current drainage systems. If drainage systems are optimized, then lower emissions are possible.
d. Different types of plantations	If drainage is similar, then this is a representative estimate.	This is likely overestimated.	More research is needed on root respiration, fertilizer applications, plantation age, and non-CO_2 GHGs to determine whether there are underestimates or overestimates.	This is likely overestimated.	This is a representative estimate based on new research.[b]

(continued)

Table 3-2. Summary of Peer-Review Response to Charge Question #3

Topic Areas	Dr. Bridgham	Dr. Hergoualc'h	Dr. Leclerc	Dr. Sabiham	Dr. Schrier
e. The approach during the first 5 years after drainage	This is a representative estimate.	This is likely an overestimate because of the assumptions made on baseline conditions using acacia plantations with different locations and management.	Additional research is needed to accurately represent emissions.	This is likely an overestimate because of the peat bulk density, organic carbon, and subsidence estimates used.	The recommendation was made that an annual emission factor be used with a multiplier of 2.6 for the first 5 years to account for increased emissions initially.
f. Omission of methane and nitrous oxide emissions	This is a slight underestimate (relative to CO_2 emissions).	This is an underestimate that should include IPCC values.	This is an underestimate, and it should be included.	This is a representative estimate.	This is an underestimate, and it should include IPCC values.
g. Omission of emissions due to fire	This is an underestimate, and it should be included. The literature ranges from 86 to 387 teragrams of carbon per year.[c]	This is an underestimate that should include IPCC values.	This is an underestimate, and it should be included. The literature suggests average CO_2 emissions from fires from 2000–2006 of 6.5 petagrams of carbon per year.[d]	This is an underestimate, but regulations prohibit burning, so future estimates should omit fire emissions.	This is an underestimate, and it should include IPCC values. Fire frequency and intensity have increased because of drainage of peat.
h. Omission of incidentally drained peat swamps adjoining the plantations	This is an underestimate, and it should be included.	The current scientific knowledge on tropical peatlands allows for integrating this impact in the emission factor.	This is an underestimate, and it should be quantified.	This is a representative estimate because regulations prohibit new plantations on peat soil and forests.	This is an underestimate, but more research is needed before these emissions can be considered.

[a] Othman et al., 2011.

[b] Husnain et al., 2012.

[c] Couwenberg et al., 2010; Hooijer et al., 2012; van der Werf et al., 2008.

[d] Murdiyarso et al., 2010.

3.4 *Intergovernmental Panel on Climate Change Report*

The IPCC (2014) lists a Tier 1 emission factor of 40 tCO_2/ha/yr for tropical drained oil palm plantations. This value does not include emissions for the first 6 years after drainage. However, studies have shown that a pulse of higher emissions occurs right after drainage. The IPCC report also gives a default DOC emission factor of 3 tCO_2/ha/yr. In addition, the IPCC gives guidance on quantifying emissions from fires. The report gives a default emission factor of 1,701 gCO_2/(kilograms [kg]of dry matter burned) for tropical organic soil and a default dry matter consumption value of 155 t/ha for prescribed fires in the tropics.

a. Would it be appropriate for the EPA to use the IPCC Tier 1 default emission factor of 40 tCO_2/ha/yr, or is it scientifically justified to use a different number based on more detailed information?

Two peer reviewers (i.e., Drs. Hergoualc'h and Sabiham) stated that the IPCC Tier 1 emission factor is appropriate to use. Dr. Sabiham indicated it would be appropriate for the Agency to use values as high as 44 tonnes of CO_2 ha^{-1} yr^{-1}, which accounts for groundwater levels up to 60 centimeters below the soil surface.

Three peer reviewers (i.e., Drs. Bridgham, Leclerc, and Schrier) stated that the Hooijer et al. (2012) estimate is more scientifically justified. Dr. Bridgham further stated that the Hooijer et al. (2012) estimate is inherently clearer and more scientifically defensible because of the uncertainties associated with scaling up the chamber-based method and estimating litter inputs. Additionally, Drs. Leclerc and Schrier noted that the development of the IPCC emission factor is not based on more recent literature that indicates that the emission factor is closer to the Hooijer et al. (2012) estimate.

b. Should the emission factor that the EPA uses include the emissions pulse that occurs in the first several years immediately following drainage?

Two peer reviewers (i.e., Drs. Bridgham and Leclerc) agreed that the EPA should include the emissions pulse. Dr. Bridgham stated that further data, in addition to the Hooijer et al. (2012) emissions pulse data, would be preferable for comparison.

Dr. Sabiham stated that the EPA should exclude the emissions pulse because the analysis may have confused oil palm and acacia subsidence results. Similarly, Dr. Hergoualc'h stated that the pulse demonstrated in Hooijer et al. (2012) was observed in an acacia plantation and only demonstrates a pulse in subsidence, not emissions; therefore, the emissions pulse is not scientifically supported. Dr. Hergoualc'h also proposed that consolidation may be more important than currently estimated.

Dr. Schrier stated that a multiplication factor for the first 5 years of drainage would increase the certainty and robustness of the emission factor more appropriately than including an emissions pulse.

c. *Should the EPA include DOC and fire emission factors in the overall emission factor? If so, are the IPCC emission factors appropriate to use, or are there better estimates for EPA's purpose?*

Three reviewers (i.e., Drs. Hergoualc'h, Leclerc, and Schrier) agreed that the EPA should include the IPCC fire emission and DOC factors. Dr. Hergoualc'h stated that the Agency could eventually merge the IPCC emission factors for DOC, but that the emission factors for prescribed fires and wildfires should be kept apart to acknowledge site-specific land-use history. Dr. Schrier also asserted that the EPA should include non-CO_2 emissions. Dr. Leclerc stated that DOCs are a "hot spot" of GHGs and that advection from neighboring regions caused by land-use conversion should also be taken into account for robust emission factors to be determined.

Dr. Bridgham stated that a fire emission factor should be included, but this will require more investigation to suggest an appropriate factor. Dr. Bridgham further stated that DOC fluxes may or may not need to be included separately, depending on the method used. If the subsidence method is used, then it is not necessary to include DOC fluxes because they are already accounted for in the loss of soil carbon and mass. If the soil respiration method is used, then it is necessary to include DOC fluxes (IPCC, 2006).

Dr. Sabiham recommended that DOC and fire emission factors not be included in EPA's approach because DOC fluxes are off site and relatively insignificant, and best management practices of oil palm plantation require zero burning.

d. *There are also erosion losses of particulate organic carbon (POC) and waterborne transport of dissolved inorganic carbon (primarily dissolved CO_2) derived from autotrophic and heterotrophic respiration within the organic soil. The IPCC concluded that, at present, the science and available data are not sufficient to provide guidance on CO_2 emissions or removals associated with these waterborne carbon fluxes. Do you agree that the science on these factors is not sufficient for EPA to consider losses of POC and dissolved inorganic carbon in its peat soil emission factor?*

Three peer reviewers (i.e., Drs. Hergoualc'h, Leclerc, and Schrier) agreed that the science is not sufficient yet and should be omitted from the emission factor until further information is available.

Dr. Bridgham stated that it is not necessary to account for POC and dissolved inorganic carbon losses if a stock-based approach is used such as the subsidence method. Dr. Bridgham also iterated the reasons why a gain–loss approach of the IPCC is inappropriate for estimating the peat soil emission factor, such as the uncertainties associated with scaling up and estimating litter inputs and root respiration.

Dr. Sabiham stated that there is no need to include POC loss in the overall emission factor for peat soil under oil palm plantation, but for different reasons. Dr. Sabiham noted that for drained peat soil under oil palm plantations that follow best management practices (e.g., zero burning method during land preparation, maintaining groundwater at a certain level to avoid drying of peat materials during dry season), POC should generally be a negligible component.

In addition, Dr. Sabiham agreed that research on dissolved inorganic carbon is still not sufficient to warrant inclusion in the peat soil emission factor, although he noted that several research results (Dariah et al., 2013; Sabiham et al., 2014) indicate that the contribution of root respiration could be considered as the correction factor for closed-chamber technique evaluations.

3.5 Additional Input

Please provide any additional scientific information that you believe the EPA should consider regarding the Agency's assessment of the average annual GHG emissions from draining tropical peatlands for palm oil cultivation for use in EPA's lifecycle GHG analysis of palm oil–based biofuels.

Two peer reviewers (i.e., Dr. Bridgham and Leclerc) stated that they had no more information to provide outside of the responses and references previously provided. Dr. Schrier added that the meta-analysis of Carlson et al. (in preparation) should be considered as soon as it becomes available.

Dr. Hergoualc'h stated that the literature review carried out by the EPA appeared to be incomplete. For example, a number of soil respiration studies and the soil carbon flux approach applied in Hergoualc'h and Verchot (2013) were not included in the analyses. Furthermore, Dr. Hergoualc'h stated that it was not clear whether the EPA firmly understands the approach for calculating an emission factor using peat carbon fluxes.

Dr. Sabiham noted that Indonesian peat soils contain mostly fibric peat, in which subsidence occurs quickly after drainage, and this is particularly important to know when calculating carbon emissions for the first 5 years after drainage. Dr. Sabiham also noted that fibric peat reaches an irreversible drying condition rapidly, at which point carbon loss because of peat oxidation does not exist but is highly susceptible to fire.

SECTION 4
REFERENCES

Couwenberg, J. and A. Hoosier. 2013. Towards robust subsidence based and soil carbon factors for peat soils in South-East Asia, with special reference to oil palm plantations. *Mires and Peat 12*:1–13.

Couwenberg, J., R. Dommain, and H. Joosten. 2010. Greenhouse gas fluxes from tropical peatlands in Southeast Asia. *Global Change Biology 16*(6):1715–1732.

Dariah, A., S. Marwanto, and F. Agus. 2013. Root- and peat-based CO_2 emission from oil palm plantations. *Mitigation and Adaptation Strategies for Global Change 19*(6):831–843.

Drösler, M., L.V. Verchot, A. Freibauer, G. Pan, C.D. Evans, R.A. Bourbonniere, J.P. Alm, S. Page, F. Agus, K. Hergoualc'h, J. Couwenberg, J. Jauhiainen, S. Sabiham, C. Wang, N. Srivastava, L. Borgeau-Chavez, A. Hooijer, K. Minkkinen, N. French, T. Strand, A. Sirin, R. Mickler, K. Tansey, and N. Larkin. 2014. Drained inland organic soils. Chapter 2 in the *2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands*. Edited by T. Hiraishi, T. Krug, K. Tanabe, N. Srivastava, B. Jamsranjav, M. Fukuda, and T. Troxler. IPCC: Switzerland.

EPA (U.S. Environmental Protection Agency). 2014. Technical Work Product for Peer Review: Emission Factor for Tropical Peatlands Drained for Palm Oil Cultivation. May 15, 2014.

EPA (U.S. Environmental Protection Agency). 2012. Notice of Data Availability Concerning Renewable Fuels Produced from Palm Oil under the RFS Program. January 27, 2012. 77 FR 4300.

EPA (U.S. Environmental Protection Agency). 2006. *Peer Review Handbook*. Third Edition. EPA/100/B-06/002. Available at www.epa.gov/peerreview/pdfs/peer_review_handbook_2012.pdf

Hergoualc'h, K., and L.V. Verchot. 2013. Greenhouse gas emission factors for land use and land-use change in Southeast Asian peatlands. *Mitigation and Adaptation Strategies for Global Change 19 (6)*:789-807. doi 10.1007/s11027-013-9511-x.

Hooijer, A., S. Page, J. Jauhiainen, W.A. Lee, X.X. Lu, A. Idris, and G. Anshari. 2012. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences 9*:1053–1071.

Husnain, H.F. Agus, P. Wigena, A. Maswar, Dariah, and S. Marwanto. 2012. Peat CO_2 emissions from several land-use types in Indonesia. To be submitted to *Mitigation and Adaptation Strategies for Global Change*.

IPCC (Intergovernmental Panel on Climate Change). 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Institute for Global Environmental Strategies (IGES), Hayama, Japan.

IPCC (Intergovernmental Panel on Climate Change). 2014. *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. Edited by T. Hiraishi, T. Krug, K. Tanabe, N. Srivastava, J. Baasansuren, M. Fukuda, and T.G. Troxler. IPCC: Switzerland.

Jauhiainen, J., A. Hooijer, and S.E. Page. 2012. Carbon dioxide emissions from an acacia plantation on peatland in Sumatra, Indonesia. *Biogeosciences 9*:617–630.

Melling, L., R. Hatano, and K.J. Goh. 2007. Nitrous oxide emissions from three ecosystems in tropical peatland of Sarawak, Malaysia. *Soil Science and Plant Nutrition 53*:792–805.

Murdiyarso, D., K. Hergoualc'h, and L.V. Verchot. 2010. Opportunities for reducing greenhouse gas emissions in tropical peatlands. *PNAS 107*:19655–19660.

Othman, H., A.T. Mohammed, F.M. Darus, M.H. Harun, and M.P. Zambri. 2011. Best management practices for oil palm cultivation on peat: Ground water-table maintenance in relation to peat subsidence and estimation of CO_2 emissions at Sessang, Sarawak. *Journal of Oil Palm Research 23*:1078–1086.

Page, S.E., R. Morrison, C. Malins, A. Hooijer, J.O. Rieley, and J. Jauhiainen. 2011. Review of peat surface greenhouse gas emissions from oil palm plantations in Southeast Asia. International Council on Clean Transportation. White Paper Number 15, Indirect Effects of Biofuel Production Series.

Sabiham, S., S. Marwanto, T. Watanabe, S. Furukawa, U. Sudadi, and F. Agus. 2014. Estimating the relative contributions of root respiration and peat decomposition to the total CO_2 Flux from peat soil at an oil palm plantation in Sumatra, Indonesia. *Journal of Tropical Agriculture and Development*. (In press).

van der Werf, G.R., J.T. Randerson, G.J. Collatz, L. Giglio, P.S. Kasibhatla, A.F. Arellano, S.C. Olsen, and E.S. Kasischke. 2004. Continental-scale partitioning of fire emissions during the 1997 to 2001 El Nino/La Nina period. *Science 303*:73–76.

APPENDIX A
RECOMMENDATION REQUESTS

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 1 3 2013

OFFICE OF
AIR AND RADIATION

His Excellency Dino Patti Djalal
Ambassador of Indonesia
2020 Massachusetts Avenue, N.W.
Washington, D.C. 20036

Dear Mr. Ambassador:

I wish to extend to you my great appreciation for your visit in September to express your thoughtful congratulations and wishes for success to the Administrator of the U.S. Environmental Protection Agency. As you know, the EPA and Indonesia have long shared an interest in advancing environmental-protection and public-health initiatives that will benefit people in both our countries. We look forward to continuing our discussions with Indonesia.

I am also writing to provide more information about the peer review that was briefly discussed at the September meeting. The EPA is supporting a third-party independent peer review to gather additional input about the science relevant to determining an appropriate peat soil emissions factor for use in EPA's analysis of the lifecycle GHG emissions associated with palm oil-based biofuels, for purposes of determining qualifying biofuels under the U.S. Renewable Fuel Standard (RFS) program. This letter provides background about EPA's assessment; explains the scope of the peer review; outlines how the peer review process will work; and provides further details about what type of candidate recommendations EPA is seeking.

I. Background

In January 2012, the EPA released a Notice of Data Availability (NODA) Concerning Renewable Fuels Produced from Palm Oil under the Renewable Fuel Standard (RFS) Program.[1] As part of this NODA, the EPA sought comment on its analysis of lifecycle greenhouse gas (GHG) emissions analysis from palm oil-based biodiesel and renewable diesel, which estimated that these biofuels had lifecycle GHG emission reductions of 17% and 11%, respectively versus the petroleum diesel baseline. Based on the Agency's analysis, these biofuels would not meet the statutory 20% GHG emissions reduction threshold and thus, with limited exceptions,[2] would not qualify as renewable fuel for the RFS program.[3]

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[3] EPA's evaluation will not affect palm oil exports to the United States for food or other purposes. This determination also will not restrict the ability of palm oil biofuels to be imported to the United States. It will only help to determine whether such fuels are eligible under United States law to be used to comply with the RFS program.

One of the major sources of GHG emissions in EPA's analysis was emissions from development of palm oil plantations on drained tropical peat soils. For the analysis in the NODA, the EPA used a peat soil emissions factor of 95 tonnes of carbon dioxide-equivalent per hectare per year (tCO_2e/ha/yr) over the first thirty years following draining of the land, based primarily on the study by Hooijer et al. (2012).[4,5] The EPA chose this emissions factor after a thorough survey of the literature. The EPA has received over 70,000 public comments on the January 2012 NODA, including a number with substantive comments on the peat soil emissions factor used in the Agency's assessment. The commenters cited various studies and proposed emissions factors ranging from 26 to 103 tCO_2e/ha/yr.

II. Scope of the Peer Review

The EPA is conducting further review of the scientific literature to determine if new information warrants revisiting our choice of emissions factor, considering the comments received on the NODA and other information published or provided to the Agency. Because this emissions factor is an important piece of our lifecycle GHG analysis, we are supporting a peer review process to gather additional input from the scientific community about whether the emissions factor used by the EPA in the January 2012 NODA is the most appropriate for our final assessment. The scope of this peer review is limited to the specific technical issue of the peat soil emissions factor used in EPA's lifecycle GHG analysis for the RFS program. The information gathered as part of this review will be considered as part of EPA's ongoing review of the lifecycle GHG emissions related to palm oil biofuels.

III. The Peer Review Process

EPA's *Peer Review Handbook* provides guidance on conducting peer reviews.[6] A third-party contractor will be tasked with independently selecting the reviewers and managing this technical review. An important goal of these procedures is to maintain an impartial process.

Once the contractor has selected the qualified reviewers, the peer review will likely take several months. The reviewers will receive charge questions asking a range of technical questions about the peat soil emissions factor used in EPA's lifecycle GHG analysis of palm oil biofuels. The charge questions will include information provided by the public commenters, including a summary of comments that were critical of EPA's assumptions, along with references and internet links to the original comments. Furthermore, the charge will provide a list of studies cited by commenters, because the EPA would like the reviewers to consider the range of relevant scientific literature as they formulate their responses.

The reviewers will be instructed to work independently and will not be asked to reach consensus. They will send their responses to the contractor, who will summarize the results and compile a peer review record document. The peer review record will include the charge questions,

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the contractor's summary of the reviewers' responses as well as unedited copies of the reviewers' comments. The peer review record will be made public in its entirety and posted on the public docket with this rulemaking. This is the same type of peer review process that was used to gather scientific input on EPA's lifecycle GHG emissions analysis of other types of biofuels (e.g., corn ethanol, soybean oil biodiesel, sugarcane ethanol) for the March 2010 RFS rule (75 FR 14669).[7]

IV. Peer Review Candidate Recommendations

One way to participate in this process would be to advise the EPA of qualified candidates to serve as peer reviewers. Each candidate should have recognized expertise that bears on the subject matter of GHG emissions from drained tropical peat soil. In determining the most qualified candidates for the review, the contractor will be instructed to consider each candidate's expertise, knowledge, skills and experience related to the subject matter. For example, qualified candidates will be expected to have a doctoral degree in soil science or a related field and publication of peer reviewed journal articles related to carbon cycling in tropical peat soils. All candidate recommendations will be considered by a third-party contractor who will independently select the final reviewers based on criteria described in the *Peer Review Handbook*, such as: (a) qualifications, (b) independence and appearance of impartiality, and (c) balance with respect to diversity of scientific and technical perspectives.

Because the reviewers will be selected independently by a third-party contractor, the EPA cannot make any guarantees about the selection of review candidates that you recommend, but in general highly qualified candidates who do not have any conflicts of interest[8] or appearance of a lack of impartiality[9] related to this subject matter should have a higher probability of selection. As such, we welcome all candidate recommendations that you may have, but we ask that you limit such recommendations to candidates who will have a high probability of selection based on the criteria described above. The EPA will forward all of the candidate recommendations that are received to the third-party contractor for consideration. In order to initiate the peer review in a timely manner we request that you submit any candidate recommendations by December 13, 2013.

V. Conclusion

We appreciate your interest in EPA's assessment of palm oil-based biofuels under the RFS program. The Agency recognizes there are many complex issues involved in this analysis. We seek to gather relevant scientific information from a range of perspectives, and will consider all input carefully before making any final determinations. The peer review discussed above is an important part of this process and we welcome your recommendations regarding qualified peer review candidates. We also welcome any additional information that you wish to submit in a timely manner for consideration by the peer reviewers. Such information will be added to the public docket and

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referenced for the reviewers' consideration. If you have any questions about this process please do not hesitate to contact Aaron Levy of my staff at levy.aaron@epa.gov.

Sincerely,

Christopher Grundler, Director
Office of Transportation and Air Quality

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 1 3 2013

OFFICE OF
AIR AND RADIATION

Mr. Jonathan Lewis
Clean Air Task Force
18 Tremont Street, Suite 530
Boston, Massachusetts 02108

Dear Mr. Lewis:

I am writing inform you that the U.S. Environmental Protection Agency is supporting a third-party independent peer review to gather additional input about the science relevant to determining an appropriate peat soil emissions factor for use in EPA's analysis of the lifecycle greenhouse gas (GHG) emissions associated with palm oil-based biofuels, for purposes of determining qualifying biofuels under the U.S. Renewable Fuel Standard (RFS) program. This letter provides background about EPA's assessment; explains the scope of the peer review; outlines how the peer review process will work; and provides further details about what type of candidate recommendations the EPA is seeking.

I. Background

In January 2012, EPA released a Notice of Data Availability (NODA) Concerning Renewable Fuels Produced from Palm Oil under the Renewable Fuel Standard (RFS) Program.[1] As part of this NODA, the EPA sought comment on its analysis of lifecycle GHG emissions analysis from palm oil-based biodiesel and renewable diesel, which estimated that these biofuels had lifecycle GHG emission reductions of 17% and 11%, respectively versus the petroleum diesel baseline. Based on the Agency's analysis, these biofuels would not meet the statutory 20% GHG emissions reduction threshold and thus, with limited exceptions,[2] would not qualify as renewable fuel for the RFS program.[3]

One of the major sources of GHG emissions in EPA's analysis was emissions from development of palm oil plantations on drained tropical peat soils. For the analysis in the NODA, the EPA used a peat soil emissions factor of 95 tonnes of carbon dioxide-equivalent per hectare per year (tCO_2e/ha/yr) over the first thirty years following draining of the land, based primarily on the study by Hooijer et al. (2012).[4,5] The EPA chose this emissions factor after a thorough survey of the literature. The EPA has

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II. Scope of the Peer Review

The EPA is conducting further review of the scientific literature to determine if new information warrants revisiting our choice of emissions factor, considering the comments received on the NODA and other information published or provided to the Agency. Because this emissions factor is an important piece of our lifecycle GHG analysis, we are supporting a peer review process to gather additional input from the scientific community about whether the emissions factor used by the EPA in the January 2012 NODA is the most appropriate for our final assessment. The scope of this peer review is limited to the specific technical issue of the peat soil emissions factor used in EPA's lifecycle GHG analysis for the RFS program. The information gathered as part of this review will be considered as part of EPA's ongoing review of the lifecycle GHG emissions related to palm oil biofuels.

III. The Peer Review Process

EPA's *Peer Review Handbook* provides guidance on conducting peer reviews.[6] A third-party contractor will be tasked with independently selecting the reviewers and managing this technical review. An important goal of these procedures is to maintain an impartial process.

Once the contractor has selected the qualified reviewers, the peer review will likely take several months. The reviewers will receive charge questions asking a range of technical questions about the peat soil emissions factor used in EPA's lifecycle GHG analysis of palm oil biofuels. The charge questions will include information provided by the public commenters, including a summary of comments that were critical of EPA's assumptions, along with references and internet links to the original comments. Furthermore, the charge will provide a list of studies cited by commenters, because the EPA would like the reviewers to consider the range of relevant scientific literature as they formulate their responses.

The reviewers will be instructed to work independently and will not be asked to reach consensus. They will send their responses to the contractor, who will summarize the results and compile a peer review record document. The peer review record will include the charge questions, the contractor's summary of the reviewers' responses as well as unedited copies of the reviewers' comments. The peer review record will be made public in its entirety and posted on the public docket with this rulemaking. This is the same type of peer review process that was used to gather scientific input on EPA's lifecycle GHG emissions analysis of other types of biofuels (e.g., corn ethanol, soybean oil biodiesel, sugarcane ethanol) for the March 2010 RFS rule (75 FR 14669).[7]

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IV. Peer Review Candidate Recommendations

One way to participate in this process would be to advise the EPA of qualified candidates to serve as peer reviewers. Each candidate should have recognized expertise that bears on the subject matter of GHG emissions from drained tropical peat soil. In determining the most qualified candidates for the review, the contractor will be instructed to consider each candidate's expertise, knowledge, skills and experience related to the subject matter. For example, qualified candidates will be expected to have a doctoral degree in soil science or a related field and publication of peer reviewed journal articles related to carbon cycling in tropical peat soils. All candidate recommendations will be considered by a third-party contractor who will independently select the final reviewers based on criteria described in the *Peer Review Handbook*, such as: (a) qualifications, (b) independence and appearance of impartiality, and (c) balance with respect to diversity of scientific and technical perspectives.

Because the reviewers will be selected independently by a third-party contractor, the EPA cannot make any guarantees about the selection of review candidates that you recommend, but in general highly qualified candidates who do not have any conflicts of interest[8] or appearance of a lack of impartiality[9] related to this subject matter should have a higher probability of selection. As such, we welcome all candidate recommendations that you may have, but we ask that you limit such recommendations to candidates who will have a high probability of selection based on the criteria described above. The EPA will forward all of the candidate recommendations that are received to the third-party contractor for consideration. In order to initiate the peer review in a timely manner we request that you submit any candidate recommendations by December 13, 2013.

V. Conclusion

We appreciate your interest in EPA's assessment of palm oil-based biofuels under the RFS program. The Agency recognizes there are many complex issues involved in this analysis. We seek to gather relevant scientific information from a range of perspectives, and will consider all input carefully before making any final determinations. The peer review discussed above is an important part of this process and we welcome your recommendations regarding qualified peer review candidates. We also welcome any additional information that you wish to submit in a timely manner for consideration by the peer reviewers. Such information will be added to the public docket and referenced for the reviewers' consideration. If you have any questions about this process please do not hesitate to contact Aaron Levy of my staff at levy.aaron@epa.gov.

Sincerely,

Christopher Grundler, Director
Office of Transportation and Air Quality

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 1 3 2013

OFFICE OF
AIR AND RADIATION

Mr. Shahril Essendi Ghany
Chargé d'Affaires
Embassy of Malaysia
3516 International Court N.W.
Washington, D.C. 20008

Dear Mr. Chargé:

I am writing inform you that the U.S. Environmental Protection Agency is supporting a third-party independent peer review to gather additional input about the science relevant to determining an appropriate peat soil emissions factor for use in EPA's analysis of the lifecycle greenhouse gas (GHG) emissions associated with palm oil-based biofuels, for purposes of determining qualifying biofuels under the U.S. Renewable Fuel Standard (RFS) program. This letter provides background about EPA's assessment; explains the scope of the peer review; outlines how the peer review process will work; and provides further details about what type of candidate recommendations the EPA is seeking.

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II. Scope of the Peer Review

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Sincerely,

Christopher Grundler, Director
Office of Transportation and Air Quality

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 13 2013

OFFICE OF
AIR AND RADIATION

Dr. Chris Malins
The International Council on Clean Transportation
1225 I Street, N.W.
Suite 900
Washington, D.C. 20005

Dear Dr. Malins:

I am writing inform you that the U.S. Environmental Protection Agency is supporting a third-party independent peer review to gather additional input about the science relevant to determining an appropriate peat soil emissions factor for use in EPA's analysis of the lifecycle greenhouse gas (GHG) emissions associated with palm oil-based biofuels, for purposes of determining qualifying biofuels under the U.S. Renewable Fuel Standard (RFS) program. This letter provides background about EPA's assessment; explains the scope of the peer review; outlines how the peer review process will work; and provides further details about what type of candidate recommendations the EPA is seeking.

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Sincerely,

Christopher Grundler, Director
Office of Transportation and Air Quality

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 13 2013

OFFICE OF
AIR AND RADIATION

Mr. Ben Larson
National Wildlife Federation
P.O. Box 1583
Merrifield, Virginia 22116

Dear Mr. Larson:

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Sincerely,

Christopher Grundler, Director
Office of Transportation and Air Quality

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 1 3 2013

OFFICE OF
AIR AND RADIATION

Mr. Brian Siu
Natural Resources Defense Council
1152 15th Street N.W., Suite 300
Washington, D.C. 20005

Dear Mr. Siu:

I am writing inform you that the U.S. Environmental Protection Agency is supporting a third-party independent peer review to gather additional input about the science relevant to determining an appropriate peat soil emissions factor for use in EPA's analysis of the lifecycle greenhouse gas (GHG) emissions associated with palm oil-based biofuels, for purposes of determining qualifying biofuels under the U.S. Renewable Fuel Standard (RFS) program. This letter provides background about EPA's assessment; explains the scope of the peer review; outlines how the peer review process will work; and provides further details about what type of candidate recommendations the EPA is seeking.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 1 3 2013

OFFICE OF
AIR AND RADIATION

Dr. Jeremy Martin
Union of Concerned Scientists
1825 K Street N.W., Suite 800
Washington, D.C. 20006

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 1 3 2013

OFFICE OF
AIR AND RADIATION

Dr. Craig Kirkpatrick
World Wildlife Fund
1250 24th Street, N.W.
Washington, D.C. 20037

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I am writing inform you that the U.S. Environmental Protection Agency is supporting a third-party independent peer review to gather additional input about the science relevant to determining an appropriate peat soil emissions factor for use in EPA's analysis of the lifecycle greenhouse gas (GHG) emissions associated with palm oil-based biofuels, for purposes of determining qualifying biofuels under the U.S. Renewable Fuel Standard (RFS) program. This letter provides background about EPA's assessment; explains the scope of the peer review; outlines how the peer review process will work; and provides further details about what type of candidate recommendations the EPA is seeking.

I. Background

In January 2012, EPA released a Notice of Data Availability (NODA) Concerning Renewable Fuels Produced from Palm Oil under the Renewable Fuel Standard (RFS) Program.[1] As part of this NODA, the EPA sought comment on its analysis of lifecycle GHG emissions analysis from palm oil-based biodiesel and renewable diesel, which estimated that these biofuels had lifecycle GHG emission reductions of 17% and 11%, respectively versus the petroleum diesel baseline. Based on the Agency's analysis, these biofuels would not meet the statutory 20% GHG emissions reduction threshold and thus, with limited exceptions,[2] would not qualify as renewable fuel for the RFS program.[3]

One of the major sources of GHG emissions in EPA's analysis was emissions from development of palm oil plantations on drained tropical peat soils. For the analysis in the NODA, the EPA used a peat soil emissions factor of 95 tonnes of carbon dioxide-equivalent per hectare per year ($tCO_2e/ha/yr$) over the first thirty years following draining of the land, based primarily on the study by Hooijer et al. (2012).[4,5] The EPA chose this emissions factor after a thorough survey of the literature. The EPA has

[1] 77 FR 4300, http://www.gpo.gov/fdsys/pkg/FR-2012-01-27/pdf/2012-1784.pdf

[2] Biofuel facilities that commenced construction prior to December 19, 2007 and completed construction prior to December 19, 2010 (domestic and foreign) are not required to meet the 20% GHG threshold to qualify as renewable fuel– such facilities are "Grandfathered." See 40 CFR 80.1403 for details.

[3] EPA's evaluation will not affect palm oil exports to the United States for food or other purposes. This determination also will not restrict the ability of palm oil biofuels to be imported to the United States. It will only help to determine whether such fuels are eligible under United States law to be used to comply with the RFS program.

[4] Hooijer, A., Page, S. E., Jauhiainen, J., Lee, W. A., Idris, A., & Anshari, G. (2012) Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences, 9,* 1053-1071.

received over 70,000 public comments on the January 2012 NODA, including a number with substantive comments on the peat soil emissions factor used in the Agency's assessment. The commenters cited various studies and proposed emissions factors ranging from 26 to 103 $tCO_2e/ha/yr$.

II. Scope of the Peer Review

The EPA is conducting further review of the scientific literature to determine if new information warrants revisiting our choice of emissions factor, considering the comments received on the NODA and other information published or provided to the Agency. Because this emissions factor is an important piece of our lifecycle GHG analysis, we are supporting a peer review process to gather additional input from the scientific community about whether the emissions factor used by the EPA in the January 2012 NODA is the most appropriate for our final assessment. The scope of this peer review is limited to the specific technical issue of the peat soil emissions factor used in EPA's lifecycle GHG analysis for the RFS program. The information gathered as part of this review will be considered as part of EPA's ongoing review of the lifecycle GHG emissions related to palm oil biofuels.

III. The Peer Review Process

EPA's *Peer Review Handbook* provides guidance on conducting peer reviews.[6] A third-party contractor will be tasked with independently selecting the reviewers and managing this technical review. An important goal of these procedures is to maintain an impartial process.

Once the contractor has selected the qualified reviewers, the peer review will likely take several months. The reviewers will receive charge questions asking a range of technical questions about the peat soil emissions factor used in EPA's lifecycle GHG analysis of palm oil biofuels. The charge questions will include information provided by the public commenters, including a summary of comments that were critical of EPA's assumptions, along with references and internet links to the original comments. Furthermore, the charge will provide a list of studies cited by commenters, because the EPA would like the reviewers to consider the range of relevant scientific literature as they formulate their responses.

The reviewers will be instructed to work independently and will not be asked to reach consensus. They will send their responses to the contractor, who will summarize the results and compile a peer review record document. The peer review record will include the charge questions, the contractor's summary of the reviewers' responses as well as unedited copies of the reviewers' comments. The peer review record will be made public in its entirety and posted on the public docket with this rulemaking. This is the same type of peer review process that was used to gather scientific input on EPA's lifecycle GHG emissions analysis of other types of biofuels (e.g., corn ethanol, soybean oil biodiesel, sugarcane ethanol) for the March 2010 RFS rule (75 FR 14669).[7]

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[5] EPA's emissions factor for drained tropical peat soil only includes heterotrophic respiration of CO_2, i.e., from decomposition of organic matter in the soil. Carbon stock changes from clearing of above and below-ground biomass, such as trees and roots, were considered separately.

[6] U.S. EPA. *Peer Review Handbook*, 3rd Edition, EPA/100/B-06/002, http://www.epa.gov/peerreview/pdfs/peer_review_handbook_2012.pdf

[7] For more information about the peer review conducted for the March 2010 RFS rule see http://www.epa.gov/fedrgstr/EPA-AIR/2009/August/Day-17/a19466.pdf and http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm

IV. Peer Review Candidate Recommendations

One way to participate in this process would be to advise the EPA of qualified candidates to serve as peer reviewers. Each candidate should have recognized expertise that bears on the subject matter of GHG emissions from drained tropical peat soil. In determining the most qualified candidates for the review, the contractor will be instructed to consider each candidate's expertise, knowledge, skills and experience related to the subject matter. For example, qualified candidates will be expected to have a doctoral degree in soil science or a related field and publication of peer reviewed journal articles related to carbon cycling in tropical peat soils. All candidate recommendations will be considered by a third-party contractor who will independently select the final reviewers based on criteria described in the *Peer Review Handbook*, such as: (a) qualifications, (b) independence and appearance of impartiality, and (c) balance with respect to diversity of scientific and technical perspectives.

Because the reviewers will be selected independently by a third-party contractor, the EPA cannot make any guarantees about the selection of review candidates that you recommend, but in general highly qualified candidates who do not have any conflicts of interest[8] or appearance of a lack of impartiality[9] related to this subject matter should have a higher probability of selection. As such, we welcome all candidate recommendations that you may have, but we ask that you limit such recommendations to candidates who will have a high probability of selection based on the criteria described above. The EPA will forward all of the candidate recommendations that are received to the third-party contractor for consideration. In order to initiate the peer review in a timely manner we request that you submit any candidate recommendations by December 13, 2013.

V. Conclusion

We appreciate your interest in EPA's assessment of palm oil-based biofuels under the RFS program. The Agency recognizes there are many complex issues involved in this analysis. We seek to gather relevant scientific information from a range of perspectives, and will consider all input carefully before making any final determinations. The peer review discussed above is an important part of this process and we welcome your recommendations regarding qualified peer review candidates. We also welcome any additional information that you wish to submit in a timely manner for consideration by the peer reviewers. Such information will be added to the public docket and referenced for the reviewers' consideration. If you have any questions about this process please do not hesitate to contact Aaron Levy of my staff at levy.aaron@epa.gov.

Sincerely,

Christopher Grundler, Director
Office of Transportation and Air Quality

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[8] A conflict of interest is generally concerned with matters of financial interest and/or professional standing and status. For more details see Section 3.4.5 in the EPA *Peer Review Handbook*.

[9] In general, lack of impartiality arises when the circumstances would cause a reasonable person with knowledge of the relevant facts to question a candidate's impartiality in the matter. For more details see Section 3.4.5 in the EPA *Peer Review Handbook*.

APPENDIX B
CONFLICT OF INTEREST ANALYSIS AND BIAS QUESTIONNAIRE

Instructions

The following questions have been developed to help identify any conflicts of interest and other concerns regarding each candidate reviewer's ability to independently evaluate the peat soil emissions factor used by EPA for lifecycle greenhouse gas (GHG) assessment of palm oil biofuels for the Renewable Fuel Standard (RFS) program (hence referred to as the peat soil emissions factor). Please answer Yes, No or Unsure in response to each question to the best of your knowledge and belief. If you answer Yes or Unsure to any of the questions, please provide a detailed explanation on a separate sheet of paper.

Answering Yes or Unsure to any of the questions will not result in disqualification. The responses to the questionnaire will only be used to help RTI International select a balanced, unbiased group of peer reviewers. Responses will not be publicly released without consent of the candidate and all information will be kept anonymous to EPA during the selection process.

It is expected that the candidate make a reasonable effort to obtain the answers to each question. For example, if you are unsure whether you or a relevant associated party (e.g., spouse, dependent, significant other) has a relevant connection to the peer review subject, a reasonable effort such as calling or emailing to obtain the necessary information should be made.

1. Have you had previous involvement with the development of the peat soil emissions factor under review? Yes/No/Unsure

2. Is there any connection between the palm oil industry and any of your and/or your spouse's (or other relevant associated party's):

    a. Compensated or non-compensated employment, including government service, during the past 24 months? Yes/No/Unsure
    b. Sources of research support and project funding, including from any government, during the past 24 months? Yes/No/Unsure
    c. Consulting activities during the past 24 months? Yes/No/Unsure
    d. Expert witness activity during the past 24 months? Yes/No/Unsure
    e. Financial holdings (excluding well-diversified mutual funds and holdings, with a value less than $15,000) Yes/No/Unsure

3. To the best of your knowledge and belief, is there any direct or significant financial benefit that might be gained by you or your spouse (or other relevant associated party) as a result of the outcome of EPA's decision on the eligibility of biofuel made from palm oil feedstock under the RFS? Yes/No/Unsure

4. Have you made any public statements (written or oral) or taken positions that would indicate to an observer that you have taken a position on the peat soil emissions factor or a closely related topic under review? Yes/No/Unsure

5. Have you served on previous advisory panels, committees or subcommittees that have addressed the peat soil emissions factor under review or addressed a closely related topic? Yes/No/Unsure

6. Do you know of any reason that you might be unable to provide impartial advice on the matter under review or any reason that your impartiality in the matter might be questioned? Yes/No/Unsure

7. To the best of your knowledge and belief, is there any other information that might reasonably raise a question about whether you have an actual or potential personal conflict of interest or bias regarding the matter under review? Yes/No/Unsure

Please sign below to certify that:

1. You have fully and to the best of your ability completed this disclosure form,
2. You will update your disclosure form promptly by contacting the RTI International peer review facilitator if relevant circumstances change,
3. You are not currently arranging new professional relationships with, or obtaining new financial holdings in, an entity (related to the peer review subject) which is not yet reported, and
4. The certification below, based on information you have provided, and your CV may be made public for review and comment.

Signature ____

Date____

(Print name)______________________________________

APPENDIX C
PEER REVIEWER RESUMES

updated as of 7/10/2014

Curriculum Vitae—SCOTT D. BRIDGHAM

ADDRESS

Department of Biology
1210 University of Oregon
Eugene, Oregon 97403-1210
(541) 346-1466; Fax: (541) 346-2364
E-mail: bridgham@uoregon.edu
Web pages: http://ie2.uoregon.edu/faculty_pages/Bridgham.php and https://sites.google.com/site/bridghamlab/

EDUCATION

Ph.D. 1991, School of Forestry and Environmental Studies (now Nicholas School of the Environment), Duke University, Durham, NC
Dissertation: Mechanisms Controlling Soil Carbon Cycling in North Carolina Peatlands
Advisor: Curtis Richardson

M.S. 1986, Department of Ecology, Evolution and Behavior, University of Minnesota, Minneapolis, MN.
Thesis: Effects of Low Levels of 2,2'-Dichlorobiphenyl on *Daphnia pulicaria*
Advisor: Donald McNaught

B.A. 1982, Zoology, University of Maine, Orono, with Highest Honors

B.A. 1980, English with emphasis in creative writing, University of Maine, Orono, with Highest Honors

RESEARCH INTERESTS

Ecosystem ecology and biogeochemistry, climate change impacts on ecosystems, carbon and nutrient cycling, wetland ecology, trace gas production, plant community ecology, microbial and plant community structure/ecosystem function interactions, restoration

PROFESSIONAL EXPERIENCE

Director, Environmental Science Institute, University of Oregon, 2012 – present.

Acting Director, Center for Ecology and Evolutionary Biology, University of Oregon, summer 2006.

Professor, Department of Biology and Environmental Studies Program, University of Oregon, 2008 - present.

Associate Professor, Department of Biology and Environmental Studies Program, University of Oregon, 2003 – 2008.

Associate Professor, Department of Biological Sciences, University of Notre Dame, 2001 – 2002.

Assistant Professor, Department of Biological Sciences, University of Notre Dame, 1994 – 2001.

Research Associate, Natural Resources Research Institute, University of Minnesota, Duluth, 1992 – 1994.

Postdoctoral Research Associate, Natural Resources Research Institute, University of Minnesota, Duluth, 1991 – 1992. Advisors: Carol Johnston and John Pastor.
Research Assistant, School of the Environment, Duke University, 1986 – 1991.
Research and Teaching Assistant, Department of Ecology, Evolution and Behavioral Biology, University of Minnesota, 1983 – 1986.
Field Research Technician, USDA Forest Service, Orono, ME, 1978 – 1979.

HONORS AND AWARDS

Milton Ellis Award for Academic Distinction in English – 1980, University of Maine
Eugene A. Jordan Memorial Scholarship for Outstanding Academic Achievement in Zoology – 1982, University of Maine
National Science Foundation Grant for Improving Doctoral Dissertation Research, 1988 – 1991
Department of Energy Global Change Distinguished Postdoctoral Fellowship, 1991 – 1993
National Science Foundation CAREER Award, 1996 – 2001
Editorial Board of *Soil Science Society of America Journal*, 1994 – 1997
Editorial Board of *Wetlands*, 1997 – 2000.
Chair of the Division S-10, Wetland Soils, Soil Science Society of America, 2001 – 2002
Editorial Board of *Biogeochemistry*, 2004 – 2008
West Eugene Wetlands Appreciation Award, 2006
Chair, Global Change Section of the Society of Wetland Scientists, 2012
Fellow of the Society of Wetland Scientists, 2012
Two papers chosen for 30-year Commemorative Issue of journal *Wetlands* (http://www.springer.com/life+sciences/ecology/journal/13157?detailsPage=press)

PROFESSIONAL ORGANIZATIONS

Ecological Society of America
Soil Science Society of America
Society of Wetland Scientists

GRANTS

Controls over methane cycling in tropical wetlands. Research, Innovation, and Graduate Education Office, University of Oregon, $5,000 (matched by $2,000 from Gabon-Oregon Transnational Research Center), 5/2014-4/2015. (Principal Investigator)
How do Temperature and Soil Organic Matter Inputs Mediate the Organic Molecular Composition of Soils? Environmental Molecular Sciences Laboratory, Pacific Northwest National Laboratory, Department of Energy, 2013. EMSL to provide instrumentation and technical expertise. (Principal Investigator, with PhD student Lorien Reynolds)
Understanding the Mechanisms Underlying Heterotrophic CO_2 *and* CH_4 *Fluxes in a Peatland with Deep Soil Warming and Atmospheric* CO_2 *Enrichment*, Department of Energy, $1,047,425, 8/2012 – 7/2015. (Principal Investigator, subcontracts to Chapman Univ. and Purdue Univ.)
Dissertation Research: Microbial Community Structure and Ecosystem Function: Linking Methanogen Community Composition to Methane Production Rates in Wetland Soils, National Science Foundation Doctoral Dissertation Improvement Grant to Steven A. McAllister and co-advisors. $14,967, 6/2012 – 5/2014.

University of Oregon College of Arts and Sciences Program Grant to assist in the establishment of an Environmental Sciences Institute. $5,000, 2011. (Principal Investigator)

Climate Effects on Plant Range Distributions and Community Structure of Pacific Northwest Prairies, Department of Energy, $1,835,510, 1/2009 – 12/2013. (Principal Investigator)

Collaborative Research: Why Does Methane Production Vary Dramatically Among Wetlands?, National Science Foundation, $890,000, 8/2008 – 10/2012. (Principal Investigator) 3 Research for Experience for Undergraduates Supplements, $22,000.

Collaborative Research: The Interactions of Climate Change, Land Management Policies and Forest Succession on Fire Hazard and Ecosystem Trajectories in the Wildland-Urban Interface, National Science Foundation, $1,133,152, 8/2008- 1/2013. (Co-Principal Investigator). 1 Research for Experience for Undergraduates Supplement, $15,850.

Linking the FlamMap and Envision Simulation Models, Pacific Northwest Research Station, U.S. Forest Service, $45,000, 5/2009 – 4/2011. (Co-Principal Investigator).

Beyond the Monod Equation: Developing a New Theory of Geomicrobial Kinetics, National Science Foundation, $300,000, 9/2008 – 8/2012. (Co-Principal Investigator)

A Landscape-Level Approach to Fuels Management Through Ecological Restoration: Developing a Knowledge Base for Application to Historic Oak-Pine Savanna, Joint Fire Science Program, $393,110, 5/2004 – 7/2008. (Co-Principal Investigator)

The Role of Salmon-Derived Nutrients in Managed U.S. Forests. USDA National Research Initiative Competitive Grants Program, $497,041, 1/2006 – 12/2008. (Collaborator, no money comes directly to Univ. of Oregon)

The Effects of the Invasive Grasses Phalaris arundinacea and Zostera japonica on Ecosystem Processes in the South Slough National Estuarine Research Reserve, Oregon, USA, National Oceanic and Atmospheric Administration, $60,000, 6/2004 – 5/2008. (Fellowship for graduate student, Lisa Turnbull)

Plant and Soil Responses to Experimental Restoration Techniques in the West Eugene Wetlands, Environmental Protection Agency (through Lane Community Council of Governments), $78,762, 1/2004 – 9/2007. (Principal Investigator)

Interactive Effects of Climate Change, Wetlands, and Dissolved Organic Matter on UV Damage to Aquatic Foodwebs, Environmental Protection Agency, $937,009, 7/2002 – 6/2006. (Principal Investigator, subcontracts to Univ. of Notre Dame and South Dakota State Univ.)

Collaborative Research: Interactions Among Global Change Stressors In Northern Fens: Atmospheric CO_2, Temperature, And Hydrology, National Science Foundation, $20,454, 6/2003 – 6/2004. (Co-Principal Investigator)

Hydro-Bio-Geochemical Controls on the Dissolved Organic Matter Content in UNDERC Wetlands, University of Notre Dame, $11,900, 4/2001 – 3/2002. (Co-Principal Investigator)

*Biocomplexity—Incubation Activity on Biocomplexity in Peatland*s, National Science Foundation, $99,540, 9/2000 – 8/2004. (Principal Investigator)

Retention of Soluble Organic Nutrients in Ecosystems During Primary Succession and Soil Development, National Science Foundation, $224,628, 10/1999 – 9/2003. (Co-Principal Investigator, subcontract from Univ. of Nevada-Reno)

Effects of Climate Change and Plant Community Composition on Methane Cycling in Peatlands, National Science Foundation, $11,026, 7/1998 – 6/2002. (Co-Principal Investigator, subcontract from Univ. of Indiana)

Carbon and Energy Flow and Plant Community Response to Climate Change in Peatlands, National Science Foundation, $1,200,000, 8/1997 – 7/2003. Five Research for Experience for Undergraduates Supplements, $40,500. (Principal Investigator, subcontracts to Univ. of Minnesota and Univ. of Toledo)

Multiple Environmental Gradients Structuring Peatland Communities, National Science Foundation CAREER award, $420,000, 9/1996 – 8/2003. 1 Research for Experience for Undergraduates Supplement, $6,000. (Principal Investigator)

Environmental Stress in Ecosystems: Linking Ecology and Engineering, Graduate Research Training Program In Environmental Biology, National Science Foundation, $537,500, 8/1995 – 7/2000. (Co-Principal Investigator with 11 others)

Direct and Indirect Effects of Climate Change on Boreal Peatlands: A Mesocosm Approach, National Science Foundation, $800,000, 7/1993 – 12/1997. 4 Research for Experience for Undergraduates Supplements, $28,650. (Principal Investigator, subcontracts to Univ. of Minnesota and Michigan Technological Univ.)

Constructed Wetlands for Treating Aquaculture Wastes, Minnesota Technology Inc./Iron Range Resources and Rehabilitation Board, $257,852, 9/1993 – 8/1995. (Co-Principal Investigator)

Spatial Dynamics of Nutrient and Sediment Removal by Riverine Wetlands, USDA National Research Initiative Competitive Grants Program, $200,000, 10/1992 – 9/1994. (Co-Principal Investigator)

U.S. Department of Energy Global Change Distinguished Postdoctoral Fellowship, $77,000, 9/1991 – 9/1993.

Mechanisms Controlling Decomposition Dynamics along a Phosphorus Availability Gradient in Freshwater Wetlands, National Science Foundation Grant for Improving Doctoral Dissertation Research, $10,000, 1988 – 1991.

REVIEWER FOR JOURNALS

Agricultural Systems; American Midland Naturalist; American Naturalist; Archives of Environmental Contamination and Toxicology; Biogeochemistry; Canadian Journal of Botany; Climate Change; Earth-Science Reviews; Ecology; Ecological Applications; Ecological Engineering; Écoscience; Ecosystems; Environmental Pollution; Functional Ecology; Global Biogeochemical Cycles; Global Change Biology; Journal of Environmental Quality; Journal of Geophysical Research; Journal of Great Lakes Research; Landscape Ecology; Landscape Ecology; Nature; New Phytologist; Plant and Soil; Proceedings of the National Academy of Sciences, U.S.A.; Restoration Ecology; Scandinavian Journal of Forest Research; Soil Biology and Biochemistry; Soil Science; Soil Science Society of America Journal; Water, Air, and Soil Pollution; Wetlands; Wetlands Ecology and Management

ASSOCIATE EDITOR FOR JOURNALS

Soil Science Society of America Journal, 1994 – 1997.
Wetlands, 1997 – 2000.
Biogeochemistry, 2004 – 2008.

AD HOC REVIEWER FOR GRANTING AGENCIES

Cottrell College Science Awards, Research Corporation for Science Advancement

Department of Agriculture, National Research Initiative Competitive Grants Program:
Ecosystems, Soils and Soil Biology, Watershed Processes and Water Resources Programs
Department of Defense Strategic Environmental Research and Development Program
Department of Energy – Terrestrial Carbon Processes Program, National Institute for Climatic Change Research Program
Environmental Protection Agency – Wetland's Program
Leverhulme Trust, United Kingdom
Maine Agricultural and Forest Experiment Station
Minnesota Environment and Natural Resources Trust Fund
National Aeronautics and Space Administration – Ecosystem Dynamics and Biogeochemical Processes Program
National Environment Research Council, United Kingdom
National Fish and Wildlife Foundation
National Sciences and Engineering Research Council, Canada
National Science Foundation – Atmospheric Chemistry, Ecosystems, Ecological Studies, Hydrologic Sciences, Environmental Geochemistry and Biogeochemistry, Office of Polar Programs, Arctic Natural Sciences and Visiting Professorship for Women Programs, Biocomplexity Program, International Program, Integrated Research Challenges in Environmental Biology, Frontiers in Integrative Biological Research, Marine Geology and Geophysics, Microbial Observatories, Geobiology and Low Temperature Geochemistry
Netherlands Geosciences Foundation
NSF/DOE/NASA/USDA Joint Program on Terrestrial Ecology and Global Change
NSF/EPA Partnership for Environmental Research, Water and Watersheds
USDA Forest Service – Southern Forest Experimental Station

OTHER PROFESSIONAL SERVICE AND ACTIVITIES

Wetlands Ecologist Search Committee member, Environmental Research Laboratory – Duluth, Environmental Protection Agency, 1991.
National Science Foundation Workshop on *Soil-Warming Experiments in Global Change Research*, Woods Hole, MA, Sept. 27-28, 1991, participant.
National Institute of Health Summer Minority High School Student Research Apprentice Program, sponsored students in 1992 – 1993.
Chairperson for session, *Dynamics of Aquatic and Terrestrial Ecosystems*, 1993 Annual Meeting of Ecological Society of America, Madison, WI.
Judge for Buell Award for best student oral presentation, 1993, 1995, 1999 Annual Meeting of Ecological Society of America.
Judge for best student oral presentation, 1994 – 1995, 1998, 2000 Annual Meetings of the Society of Wetland Scientists.
Review of aquatics program for Ottawa, Nicolet, and Chequamegon National Forests, Sept. 19, 1994.
Panel member for NSF/DOE/NASA/USDA Joint Program on Terrestrial Ecology and Global Change, June 1995.
Panel member for NSF/EPA Partnership for Environmental Research, Water and Watersheds, July 1996.

Invited participant for the *Upper Great Lakes Regional Climate Change Impacts Workshop*, US Global Change Research Program, University of Michigan, Ann Arbor, MI, May 4-7, 1998.
Steering Committee of the Indiana Grand Kankakee Marsh Restoration Project, 1998 – 2002.
Invited participant at the *National Science Foundation CAREER Program Principal Investigator Meeting*, Washington, DC, Jan. 10-12, 1999.
Invited participant at workshop titled *A Cross Biome Synthesis of Ecosystem Response to Global Warming* held at the National Center for Ecological Analysis and Synthesis, Santa Barbara, CA, Feb. 1-5, 1999.
Leader of Minnesota peatlands site in the initiative Terrestrial Ecosystem Response to Atmospheric and Climate Change (TERACC), under the auspices of the International Geosphere-Biosphere Programme (IGBP).
Invited participant at workshop titled *Synchotron Environmental Science* held at Advance Photon Source of the Argonne National Laboratory, Chicago, IL, April 19-21, 1999.
Hosted sabbatical of Dr. Danilo Lopez-Hernandez from the Universidad Central de Venezuela from 1/99 through 5/99.
Chair of the Division S-10, Wetland Soils, of the Soil Science Society of America, 2001 – 2002.
Chairperson for session, *Wetland Greenhouse Gases*, in INTECOL International Wetland Conference VI and the annual meeting of the Society of Wetland Scientists, Quebec, Canada, Aug. 6-12, 2000.
Chairperson and organizer for session, *Carbon Cycling and Sequestration in Wetlands*, Seventh International Symposium on the Biogeochemistry of Wetlands, Duke University, Durham, NC, June 17-20, 2001.
Invited participant at workshop titled Regulation of Organic Matter in Soils and Sediments, Virginia Institute of Marine Science, July 27-28, 2001.
Panel member for Soils and Soil Biology Program, National Research Initiative Competitive Grants Program (NRICGP), USDA, 4/2002.
Interviewed on local news, WSBT, on Jan. 14, 2002 on climate change impacts on US. Other occasional interviews with radio and newspaper media.
Tenure reviews for Cornell University (2001), Indiana University (2002), University of Tennessee (2002).
Reviewer for Confronting Climate Change In The Great Lakes Region: Impacts on Our Communities and Ecosystems, report by the Ecological Society of America and Union of Concerned Scientists, 10/02.
Invited participant at a scientific roundtable to discuss carbon sequestration as a mechanism of wetland restoration in Eastern North Carolina peatlands, US Fish and Wildlife Service and the Conservation Fund, Raleigh, NC, Nov. 18, 2002.
Attended workshop on "Interactions between increasing CO_2 and temperature in terrestrial ecosystems," Terrestrial Ecosystem Response to Atmospheric & Climate Change (TERACC), International Geosphere-Biosphere Program, Lake Tahoe, April 27-30, 2003.
Assessment team for research program of Kachemak Bay National Estuarine Reserve in Homer, AK, June 23-26, 2003.
Chairperson for session "Wetland Microbial Processes," annual meeting of the Soil Science Society of America, Nov. 2-6, 2003 Denver, CO.
External examiner for Ph.D. thesis at the University Waikato, New Zealand, 2005.
Requested letter in support of chaired position for faculty member at the University of Wales,

Bangor, 2005.
Lead author on wetlands chapter in *The First State of the Carbon Cycle Report (SOCCR): North American Carbon Budget and Implications for the Global Carbon Cycle*. Synthesis and Assessment Report 2.2 (SAR 2.2) by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, 2005-2007.
Participated in panel discussion for "Advocates for the Land: Photography in the American West" at the Jordan Schnitzer Museum of Art, University of Oregon, Sept. 7, 2005.
Evaluator for faculty member for promotion to full professor, University of Nevada at Reno, Sept. 2006.
Panel member for EPA STAR graduate fellowship program (microbiology panel), March 2007.
Reviewed 41 pre-proposals for DOE National Institute for Climatic Research (NICCR), Midwest region, 2007.
Panel member of EPA STAR solicitation on Ecological Impacts from the Interaction of Climate Change, Land Use Change, and Invasive Species: Aquatic Ecosystems, Oct. 1-3, 2007.
Panel member for U.S. DOE National Institute for Climate Change Research, Midwest region, 2007, 2008.
On Oregon University System screening committee for the Director of the Oregon Climate Change Research Institute, 2008.
Invited participant to PEATNET workshop on "Why Is There Peat?", Villanova University, March 27-28, 2008.
Invited participant for U.S. DOE sponsored workshop on "Exploring Science Needs for the Next Generation of Climate Change and Elevated CO_2 Experiments in Terrestrial Ecosystems," Crystal City, VA, April 14-18, 2008.
Invited participant in Upper Willamette Watershed Climate Futures Workshop, Eugene, OR, Sept. 23, 2008.
Evaluator for faculty promotion to full professor, York University, Canada, 2009.
Chairperson for session "Wetland Vegetation Dynamics" in annual meeting of the Society of Wetland Scientists, Madison, WI, June 22-26, 2009.
Invited participant in Expert Workshop: Achieving Carbon Offsets through Mangroves and other Wetlands, IUCN/Ramsar/Danone, Gland, Switzerland, Nov. 9-11, 2009.
Board of Advisors for SPRUCE experiment (large manipulative climate change treatment in a Minnesota peatland) of the U.S. DOE Oak Ridge National Laboratory, Environmental Sciences Division, 2009 - 2012.
Member of Integrated Network for Terrestrial Ecosystem Research on Feedbacks to the Atmosphere and Climate (INTERFACE): Linking experimentalists, ecosystem modelers, and Earth system modelers. 2011 - present.
Invited participant in workshop on How Do We Improve Earth System Models: Integrating Earth System Models, Ecosystem Models, Experiments and Long-Term Data, organized by Integrated Network for Terrestrial Ecosystem Research on Feedbacks to the Atmosphere and Climate (INTERFACE), Captiva Island, FL, Feb. 28-March 3, 2011.
Invited speaker on Challenges and Opportunity for Carbon Sequestration in the Restoration of Wetlands, Department of Interior Natural Resource Damage Assessment and Restoration Program Meeting, Phoenix, AZ, March 24, 2011.
Hosted high school student for summer research internship for Saturday Academy Apprenticeships in Science & Engineering Program, 2011, 2012.
Interviewed by NPR reporter for Oregon and Washington concerning DOE-funded manipulative

climate change experiment, June 10, 2011.

Chair, Global Change Section of the Society of Wetland Scientists, 2012.

Evaluator for faculty promotion to associate professor and tenure, Michigan Technological University, 2012.

Co-authored an invited resolution concerning wetlands and climate change at INTECOL International Wetlands Conference, Orlando, FL June 3-8, 2012.

Co-Moderator and organizer of session "Methane Dynamics in Peatland Ecosystems" at INTECOL International Wetlands Conference, Orlando, FL June 3-8, 2012.

Member of site visit committee for Industrial Research Chair and Collaborative Research and Development Grant at Université Laval, Quebec City for Natural Sciences and Engineering Research Council, Canada, Nov. 12, 2012.

Technical team for freshwater indicators of climate change as part of the U.S. National Climate Assessment, 2013 – current.

Invited panel member of workshop "Belowground Carbon Cycling Processes at the Molecular Scale," Environmental Molecular Science Laboratory, Dept. of Energy, Feb. 19-21, 2013.

Invited participant in Dept. of Energy Terrestrial Ecosystem/Subsurface Biogeochemical Research Joint Investigators Meeting, Potomac, MD, May 13-15, 2013.

Co-Moderator and organizer of session "Peatlands and Global Change" at Society of Wetland Scientists meeting, Duluth, MN, June 3-7, 2013.

Evaluator for faculty member for promotion to full professor, Louisiana State University, 2013.

Co-Moderator and organizer of session, "Trace Gas Emissions and Carbon Sequestration in Wetlands and Lakes" at Joint Aquatic Sciences meeting, Portland, OR, May 18-23, 2014.

Quoted in news article in Frontiers in Ecology and the Environment concerning the launching the Global Freshwater Biodiversity Atlas, Feb. 2014.

PEER-REVIEWED JOURNAL PUBLICATIONS

(* = undergraduate student, # = graduate student, ^ = postdoctoral associate, † = technician)

1) Bridgham, S. D. 1988. Chronic effects of 2,2'-dichlorobiphenyl on reproduction, mortality, growth, and respiration of *Daphnia pulicaria*. Archives of Environmental Contamination and Toxicology 17: 731-740.

2) Bridgham, S. D., S. P. Faulkner#, and C. J. Richardson. 1991. Steel rod oxidation as a hydrologic indicator in wetland soils. Soil Science Society of America Journal 55:856-862.

3) Bridgham, S. D., C. J. Richardson, E. Maltby, and S. P. Faulkner#. 1991. Cellulose decay in natural and disturbed peatlands in North Carolina, U.S.A. Journal of Environmental Quality 20:695-701.

4) Bridgham, S. D. and C. J. Richardson. 1992. Mechanisms controlling soil respiration (CO_2 and CH_4) in southern peatlands. Soil Biology and Biochemistry 24:1089-1099.

5) Bridgham, S.D. and C. J. Richardson. 1993. Hydrology and nutrient gradients in North Carolina peatlands. Wetlands 13:207-218.

6) Bridgham, S. D., J. Pastor, C. A. McClaugherty, and C. J. Richardson. 1995. Nutrient-use efficiency: a litterfall index, a model, and a test along a nutrient availability gradient in North Carolina peatlands. American Naturalist 145:1-21.

7) Updegraff, K.†, J. Pastor, S. D. Bridgham, and C. A. Johnston. 1995. Environmental and substrate controls over carbon and nitrogen mineralization in northern wetlands. Ecological Applications 5:151-163.

8) Bridgham, S. D., C. A. Johnston, J. Pastor, and K. Updegraff†. 1995. Potential feedbacks of northern wetlands on climate change. BioScience 45:262-274.

9) Bridgham, S. D., J. Pastor, J. A. Janssens, C. Chapin#, and T. J. Malterer. 1996. Multiple limiting gradients in peatlands: A call for a new paradigm. Wetlands 16:45-65. **(One of 30 papers chosen for 30-yr commemorative issue of journal: http://www.springer.com/life+sciences/ecology/journal/13157?detailsPage=press**)

10) Bridgham, S. D., K. Updegraff†, and J. Pastor. 1998. Carbon, nitrogen, and phosphorus mineralization in northern wetlands. Ecology 79:1545-1561.

11) Updegraff, K.†, S. D. Bridgham, J. Pastor, and P. Weishampel†. 1998. Hysteresis in the temperature response of carbon dioxide and methane production in peat soils. Biogeochemistry 43:253-272.

12) Pastor, J., and S. D. Bridgham. 1999. Nutrient efficiency along nutrient availability gradients. Oecologia 118:50-58.

13) Bridgham, S. D., J. Pastor, K. Updegraff†, T. J. Malterer, K. Johnson†, C. Harth†, and J. Chen. 1999. Ecosystem control over temperature and energy flux in northern peatlands. Ecological Applications 9: 1345-1358.

14) Weltzin, J. F.^, J. Pastor, C. Harth†, S. D. Bridgham, K. Updegraff†, and C. T. Chapin#. 2000. Response of bog and fen plant communities to warming and water-table manipulations. Ecology 81: 3464-3478.

15) Updegraff, K.†, S. D. Bridgham, J. Pastor, P. Weishampel†, and C. Harth†. 2001. Response of CO_2 and CH_4 emissions in peatlands to warming and water-table manipulation. Ecological Applications 11: 311-326.

16) Bridgham, S. D., K. Updegraff†, and J. Pastor. 2001. A comparison of nutrient availability indices along an ombrotrophic—minerotrophic gradient in Minnesota wetlands. Soil Science Society of America 65:259-269.

17) Johnston, C. A., S. D. Bridgham, and J. P. Schubauer-Berigan. 2001. Nutrient dynamics in relation to geomorphology of riverine wetlands. Soil Science Society of America Journal 65:557-577.

18) Bridgham, S. D., C. A. Johnston, J. P. Schubauer-Berigan, and P. Weishampel†. 2001. Phosphorus sorption dynamics in soils and coupling with surface and pore water in riverine wetlands. Soil Science Society of America Journal 65: 577-588.

19) Weltzin, J. F.^, C. Harth†, S. D. Bridgham, J. Pastor, and M. Vonderharr#. 2001. Production and microtopography of bog bryophytes: response to warming and water-table manipulations. Oecologia 128: 557-565.

20) Rustad, L. E., J. L. Campbell, G. M. Marion, R. J. Norby, M. J.Mitchell, A. E. Hartley, J. H. C. Cornelissen, J. Gurevitch and GCTE-NEWS. 2001. Meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. Oecologia 126:243-262 (I was part of the workshop, 'GCTE-NEWS',

that formulated this paper, and am acknowledged as such on the paper.

21) Kellogg, C. H.#, and S. D. Bridgham. 2002. Colonization during early succession of restored freshwater marshes. Canadian Journal of Botany 80: 176-185.

22) Pastor, J., B. Peckham, S. Bridgham, J. Weltzin^, and J. Chen. 2002. Plant dynamics, nutrient cycling, and multiple stable equilibria in peatlands. American Naturalist 160:553-568.

23) Bridgham, S. D. 2002. Commentary: nitrogen, translocation, and *Sphagnum* mosses. New Phytologist 156:140-141.

24) Weltzin, J. F.^, S. D. Bridgham, J. Pastor, J. Chen, and C. Harth†. 2003. Potential effects of warming and drying on peatland plant community composition. Global Change Biology 9:1-11.

25) Pastor, J., J. Solin#, S. D. Bridgham, K. Updegraff†, C. Harth†, P. Weishampel†, and B. Dewey†. 2003. Global warming and the export of dissolved organic carbon from boreal peatlands. Oikos 100: 380-386.

26) Kellogg, L. E.# and S. D. Bridgham. 2003. Phosphorous retention and movement compared across an ombrotrophic-minerotrophic gradient in Michigan. Biogeochemistry 63:299-315.

27) Kellogg, C. H.#, S. D. Bridgham, and S. A. Leicht*. 2003. Effects of water level, shade and time on germination and growth of freshwater marsh plants along a simulated successional gradient. Journal of Ecology 91:274-282.

28) Vile, M. A.#, S. D. Bridgham, R. K. Wieder, and M. Novák. 2003. Atmospheric sulfur deposition alters pathways of gaseous carbon production in peatlands. Global Biogeochemical Cycles 17:1058-1064.

29) Vile, M. A.#, S. D. Bridgham, and R. K. Wieder. 2003. Response of anaerobic carbon mineralization rates to sulfate amendments in a boreal peatland. Ecological Applications 13:720-734.

30) Bridgham, S. D., and C. J. Richardson. 2003. Endogenous versus exogenous nutrient control over decomposition in North Carolina peatlands. Biogeochemistry 65:151-178.

31) Xenopoulos, M. A.^, D. M. Lodge, J. Frentress#, T. A. Kreps#,S. D. Bridgham, E. Grossman*, and C. J. Jackson*. 2003. Regional comparisons of watershed determinants of dissolved organic carbon in temperate lakes from the Upper Great Lakes region and selected regions globally. Limnology and Oceanography 48:2321-2334.

32) Chapin, C. T.#, S. D. Bridgham, J. Pastor, and K. Updegraff†. 2003. Nitrogen, phosphorus, and carbon mineralization in response to nutrient and lime additions in peatlands. Soil Science 168:409-420.

33) Bauer, C. R.#, C. H. Kellogg#, S. D. Bridgham, and G. A. Lamberti. 2003. Mycorrhizal colonization across hydrologic gradients in restored and reference freshwater wetlands. Wetlands 23:961-968.

34) Lilienfein, J.^, R. G. Qualls, S. M. Uselman#, and S. D. Bridgham. 2003. Soil formation and organic matter accretion in a young andesitic chronosequence at Mt Shasta, California. Geoderma 116:249-264.

35) Keller, J. K.#, J. R. White, S. D. Bridgham, and J. Pastor. 2004. Climate change effects on carbon and nitrogen mineralization in peatlands through changes in soil quality. Global Change Biology 10:1053-1064.

36) Lilienfein, J.^, R. G. Qualls, S. M. Uselman#, and S. D. Bridgham. 2004. Adsorption of dissolved organic and inorganic phosphorus in soils of a weathering chronosequence. Soil Science Society of America Journal 68:620-628.

37) Lilienfein, J.^, R. G. Qualls, S. M. Uselman#, and S. D. Bridgham. 2004. Adsorption of dissolved organic carbon and nitrogen in soils of a weathering chronosequence. Soil Science Society of America Journal 68:292-305.

38) Chapin, C. T.#, S. D. Bridgham, and J. Pastor. 2004. pH and nutrient effects on above-ground net primary production in a Minnesota, USA bog and fen. Wetlands 24:186-201.

39) Kellogg, C. H.#, and S. D. Bridgham. 2004. Effects of disturbance, seed bank, and herbivory on dominance of an invasive grass. Biological Invasions 6(3):319-329.

40) Noormets, A.^, J. Chen, S. D. Bridgham, J. F. Weltzin^, J. Pastor, B. Dewey†, and J. LeMoine#. 2004. The effects of infrared loading and water table on soil energy fluxes in northern peatlands. Ecosystems 7:573-582.

41) Pendall, E., S. Bridgham, P. J. Hanson, B. Hungate, D. W. Kicklighter, D. W. Johnson, B. E. Law, Y. Luo, J. P. Megonigal, M. Olsrud, M. G. Ryan, and S. Wan. 2004. Below-ground process responses to elevated CO_2 and temperature: a discussion of observations, measurement methods, and models. New Phytologist 162:311-322.

42) Young, K. C.#, P. A. Maurice, K. M. Docherty#, and S. D. Bridgham. 2004. Bacterial degradation of dissolved organic matter from two northern Michigan streams. Geomicrobiology Journal 21:521-528.

43) Keller, J. K.#, S. D. Bridgham, C. T. Chapin#, and C. M. Iversen#. 2005. Limited effects of six years of fertilization on carbon mineralization dynamics in a Minnesota fen. Soil Biology and Biochemistry 37(6):1197-1204.

44) Frost, P. C.^, J. H. Larson#, L. E. Kinsman*, G. A. Lamberti, and S. D. Bridgham. 2005. Attenuation of ultraviolet radiation in streams of northern Michigan. Journal of the North American Benthological Society 24(2):246-255.

45) Weltzin, J. F.^, J. K. Keller#, S. D. Bridgham, J. Pastor, P. B. Allen#, and J. Chen. 2005. Litter controls plant community composition in a northern fen. Oikos 110:537-546.

46) Young, K. C.# , K. M. Docherty#, P. A. Maurice, and S. D. Bridgham. 2005. Degradation of surface-water dissolved organic matter: influences of DOM chemical composition and microbial populations. Hydrobiologia 539:1-11.

47) Qualls, R. G. and S. D. Bridgham. 2005. Mineralization rate of ^{14}C labeled dissolved organic matter from leaf litter in soils from a weathering chronosequence. Soil Biology and Biochemistry 37:905-916.

48) Frost, P. C.^, J. H. Larson#, C. A. Johnston, K. C. Young#, P. A. Maurice, G. A. Lamberti, and S. D. Bridgham. 2006. Landscape predictors of stream dissolved organic matter concentration and physicochemistry in a Lake Superior river watershed. Aquatic Sciences 68:40-51.

49) Kellogg, L. E.#, S. D. Bridgham, and D. López-Hernández. 2006. A comparison of four methods of measuring gross phosphorus mineralization. Soil Science Society of America Journal 70:1349-1358.

50) Keller, J. K.#, A. K. Bauers#, S. D. Bridgham, L. E. Kellogg#, and C. M. Iversen#. 2006. Nutrient control of microbial carbon cycling along an ombrotrophic-minerotrophic peatland gradient. Journal of Geophysical Research—Biogeosciences 111, G03006, doi:10.1029/2005JG000152.

51) Frost, P. C.^, A. Mack*, J. H. Larson#, S. D. Bridgham, and G. A. Lamberti. 2006. Environmental controls of UV radiation in forested streams of northern Michigan. Photochemistry and Photobiology 82:781–786.

52) Bridgham, S. D., J. P. Megonigal, J. K. Keller^, N. B. Bliss, and C. Trettin. 2006. The carbon balance of North American wetlands. Wetlands 26:889-916. **(selected for Faculty of 1000 Biology and one of 30 papers chosen for 30-yr commemorative issue of the journal: http://www.springer.com/life+sciences/ecology/journal/13157?detailsPage=press)**

53) Docherty, K. M.#, K. C. Young#, P. A. Maurice, and S. D. Bridgham. 2006. Dissolved organic matter concentration and quality influences upon structure and function of freshwater microbial communities. Microbial Ecology 52:378-388.

54) Frost, P. C.^, C. T. Cherrier†, J. H. Larson, S. Bridgham, and G. A. Lamberti. 2007 Effects of dissolved organic matter and ultraviolet radiation on the accrual, stoichiometry, and algal taxonomy of stream periphyton. Freshwater Biology 52:319-330.

55) Keller, J. K.# and S. D. Bridgham. 2007. Pathways of anaerobic carbon cycling across an ombrotrophic-minerotrophic peatland gradient. Limnology and Oceanography 52:96-107.

56) Larson, J. H.#, P. C. Frost^, Z. Zheng, C. A. Johnston, S. D. Bridgham, D. M. Lodge, and G. A. Lamberti. 2007. Effects of upstream lakes on dissolved organic matter in streams. Limnology and Oceanography 52:60-69.

57) Pfeifer-Meister#, L. and S. D. Bridgham. 2007. Seasonal and spatial controls over nutrient cycling in a Pacific Northwest prairie. Ecosystems 10:1250-1260.

58) Pfeifer-Meister, L.#, E. Cole*, B. A. Roy, and S. D. Bridgham. 2008. Abiotic constraints on the competitive ability of exotic and native grasses in a Pacific Northwest prairie. Oecologia 155:357-366.

59) White, J. R., R. D. Shannon, J. F. Weltzin^, J. Pastor, and S. D. Bridgham. 2008. Effects of soil warming and drying on methane cycling in a northern peatland mesocosm study. Journal of Geophysical Research—Biogeosciences, *113,* G00A06, doi:10.1029/2007JG000609.

60) Chen, J., S. Bridgham, J. Keller†, J. Pastor, A. Noormets^, and J. F. Weltzin^. 2008. Temperature responses to infrared-loading and water table manipulations in peatland mesocosms. Journal of Integrative Plant Biology 50:1484-1496.

61) Johnston, C. A., B. A. Shmagin, P. C. Frost^, C. Cherrier†, J. H. Larson#, G. A. Lamberti, and S. D. Bridgham. 2008. Wetland types and wetland maps differ in ability to predict dissolved organic carbon in streams. Science of the Total Environment 404:326-334.

62) Bridgham, S. D., J. Pastor, B. Dewey†, J. F. Weltzin^, and K. Updegraff†. 2008. Rapid carbon response of peatlands to climate change. Ecology 89:3041-3048.

63) Iversen#, C. M., S. D. Bridgham, and L. E. Kellogg#. 2010. Scaling nitrogen use and uptake efficiencies in response to nutrient additions in peatlands. Ecology 91:693-707.

64) D'Amore, D. V., N. Bonzey†, J. Berkowitz†, J. Rüegg#, and S. Bridgham. 2010. Holocene soil-geomorphic surfaces influence the role of salmon-derived nutrients in the coastal temperate rainforest of southeast Alaska. Geomorphology doi:10.1016/j.geomorph.2010.04.014.

65) Bachelet, D., B. R. Johnson, S. D. Bridgham, P. V. Dunn, H. E. Anderson, and B. M. Rogers. 2011. Climate change impacts on Western Pacific Northwest prairies and savannas. Northwest Science 85:411-429. (http://www.bioone.org/doi/full/10.3955/046.085.0224)

66) Yospin#, G. I., S. D. Bridgham, J. Kertis, and B. R. Johnson. 2012. Ecological correlates of fuel dynamics and potential fire behavior in former upland prairie and oak savanna. Forest Ecology and Management 266:54-65.

67) Ye, R.^, Q. Jin, B. Bohannan, J. K. Keller, S. A. McAllister#, and S. D. Bridgham. 2012. pH controls over anaerobic carbon mineralization, the efficiency of methane production, and methanogenic pathways in peatlands across an ombrotrophic-minerotrophic gradient. Soil Biology and Biochemistry 54:36-47.

68) Pfeifer-Meister^, L., B. R. Johnson, B. A. Roy, S. Carreño#, J. L. Stuart#, and S. D. Bridgham. 2012. Restoring wetland prairies: tradeoffs among native plant cover, community composition, and ecosystem functioning. Ecosphere 3(12): art 121 (http://dx.doi.org/10.1890/ES12-00261.1).

69) Pfeifer-Meister^, L., B. A. Roy, B. R. Johnson, J. Kruger, and S. D. Bridgham. 2012. Dominance of native grasses leads to community convergence in wetland restoration. Plant Ecology 213:637-647.

70) Bridgham, S. D., H. Cadillo-Quiroz, J. K. Keller, and Q. Zhuang. 2013. Methane emissions from wetlands: biogeochemical, microbial, and modeling perspectives from local to global scales. Global Change Biology 19:1325-1346. (one of 20 most downloaded papers in Wiley Online Library in 2013)

71) Pfeifer-Meister^, L., S. D. Bridgham, T. Tomaszewski^, C. J. Little†, L. L. Reynolds#, M. E. Goklany#, and B. R. Johnson. 2013. Pushing the limit: Experiment evidence of climate effects on plant range distributions. Ecology 94 (10):2131-2137.

72) Ye^, R., Q. Jin, B. Bohannan, J. K. Keller, and S. D. Bridgham. 2014. Homoacetogenesis: A potentially underappreciated carbon pathway in peatlands. Soil Biology and Biochemistry 68:385-391.

73) Ye^, R. J. K. Keller, Q. Jin, B. J. M. Bohannan, and S. D. Bridgham. *Submitted*. Mechanisms for the suppression of methane production in peatland soils by a humic substance analog. Biogeosciences Discuss 11:1739-1771 (http://www.biogeosciences-discuss.net/11/1739/2014/).

74) Yospin#, G. I., S. D. Bridgham, R. P. Neilson, J. P. Bolte, D. M. Bachelet, P. J. Gould, C. A. Harrington, J. K. Kertis, C. Evers†, and B. R. Johnson. *In revision*. A new model to simulate climate change impacts on forest succession for local land management. Ecological Applications.

PEER-REVIEWED BOOK CHAPTERS/PROCEEDINGS

(* = undergraduate student, # = graduate student, ^ = postdoctoral associate, † = technician)

1) Bridgham, S. D., D. C. McNaught, C. Meadows†. 1988. Effects of complex effluents on photosynthesis in Lake Erie and Lake Huron. Pages 74-84 in Functional Testing of Aquatic Biota for Estimating Hazards of Chemicals, J. Cairns, Jr. and J. R. Pratt, eds. American Society for Testing and Materials, Philadelphia, PA.
2) McNaught, D. C., S. D. Bridgham, and C. Meadows†. 1988. Effects of complex effluents from the River Raisin on zooplankton grazing in Lake Erie. Pages 128-137 in Functional Testing of Aquatic Biota for Estimating Hazards of Chemicals, J. Cairns, Jr. and J. R. Pratt, eds. American Society for Testing and Materials, Philadelphia, PA.
3) Johnston, C.A., K. Updegraff†, S. Bridgham, and J. Pastor. 1992. Influence of beaver and bogs on greenhouse gases at Voyageurs National Park. Pages 471-479 in Managing Water Resources During Global Change, American Water Resources Association Conference & Symposia, November 1-5, 1992, Reno, NV, R. Herman, ed.
4) Updegraff, K.†, S. D. Bridgham, J. Pastor, and C. A. Johnston. 1994. A method to determine long-term anaerobic carbon and nutrient mineralization in soils. Pages 209-219 in Defining Soil Quality for a Sustainable Environment, J. Doran, D. Bezdicek, and D. Coleman, eds., Soil Science Society of America, Madison, WI.
5) Johnston, C. A., J. P. Schubauer-Berigan and S. D. Bridgham. 1997. The potential role of riverine wetlands as buffer zones. Pages 155-170 in Buffer Zones: Their Processes and Potential in Water Protection, N. E. Haycock, T.P. Burt, K.W.T. Goulding, and G. Pinay, eds. Quest Environmental, Harpenden, UK.
6) Bridgham, S. D., C.-L. Ping , J. L. Richardson, and K. Updegraff†. 2001. Soils of Northern Peatlands: Histosols and Gelisols. Pages 343-370 in Wetland Soils: Genesis, Hydrology, Landscapes, and Classification, J. L. Richardson and M. J. Vepraskas, eds., Lewis Publishers, Boca Raton, FL.
7) Wu, K.^, C. Johnston, C. Cherrier†, S. Bridgham, and B. Shmagin. 2006. Hydrologic calibration of the SWAT model in a Great Lakes coastal watershed. Pages 15-28 in Coastal Hydrology and Processes, V.P. Singh and Y. Jun Xu, eds., Proceedings of the American Institute of Hydrology 25th Anniversary Meeting & International Conference, "Challenges in Coastal Hydrology and Water Management." Water Resources Publications, Highlands Ranch, CO.
8) Ogram, A., S. Bridgham, R. Corstanje, H. Drake, K. Küsel, A. Mills, S. Newman, K. Portier, and R. Wetzel. 2006. Linkages between microbial community composition and biogeochemical processes across scales. Pages 239-270 in Wetlands and Natural Resource Management, J. T. A. Verhoeven, B. Beltman, R. Bobbink, and D. F. Whigham, eds., Springer, New York.
9) Bridgham, S. D., J. P. Megonigal, J. K. Keller^, C. Trettin, and N. B. Bliss. 2007. Wetlands. The North America carbon budget past and present. Pages 139 – 148 in The First State of the Carbon Cycle Report (SOCCR): North American Carbon Budget and Implications for the

Global Carbon Cycle. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, A. W. King, L. Dilling. G. P. Zimmerman, D. M. Fairman, R. A. Houghton, G. H. Marland, A. Z. Rose, and T. J. Wilbanks, eds., National Climatic Data Center, Asheville, NC, 242 pp.

10) Pacala, S., R. Birdsey, S. Bridgham, R. T. Conant, K. Davis, B. Hales, R. Houghton, J. C. Jenkins, M. Johnston, G. Marland, K. Paustian, and S. C. Wofsy. 2007. The North America carbon budget past and present. Pages 29 – 36 in The First State of the Carbon Cycle Report (SOCCR): North American Carbon Budget and Implications for the Global Carbon Cycle. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, A. W. King, L. Dilling. G. P. Zimmerman, D. M. Fairman, R. A. Houghton, G. H. Marland, A. Z. Rose, and T. J. Wilbanks, eds., National Climatic Data Center, Asheville, NC, 242 pp.

11) Bridgham, S. D. and G. A. Lamberti. 2009. Decomposition in wetlands. Pages 326 -- 345 in The Wetlands Handbook, E. Maltby and T. Barker, eds., Wiley-Blackwell Publishing, Oxford, United Kingdom.

12) Dise, N., N. J. Shurpali, P. Weishampel, S. Verma, S. Verry, E. Gorham, P. Crill, R. Harriss, C. Kelly, J. Yavitt, K. Smemo, R. Kolka, K. Smith, J. Kim, R. Clement, T. Arkebauer, K. Bartlett, D. Billesbach, S. Bridgham, A. Elling, P. Flebbe, J. King, C. Martens, D. Sebacher, C. Williams, K. Wieder. 2011. Carbon emissions in peatlands. In Peatland Biogeochemistry and Watershed Hydrology at the Marcel Experimental Forest, eds. R. Kolka, S. Sebestyen, S. Verry, and K. Brooks. Taylor and Francis Group, LLC, Oxford, United Kingdom.

13) Kerns, B. K., M. A. Hemstrom, D. Conklin, G. I. Yospin#, B. Johnson,, D. Bachelet, and S. Bridgham. 2012**.** Approaches to incorporating climate change effects in state and transition models of vegetation. Pages 161-172 in Proceedings of the First Landscape State-and-Transition Simulation Modeling Conference, eds. B. K. Kerns, A. J. Shlisky, and C. J. Daniels, June 14-16, 2011, Portland, OR, Gen. Tech. Rep. PNW-GTR-869, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

14) Bridgham, S. D. and R. Ye^. 2013. Organic matter mineralization and decomposition. Pages 253-274 in Methods in Biogeochemistry of Wetlands, eds. R. D. DeLaune, K. R. Reddy, C. J. Richardson, and J. P. Megonigal. Soil Science Society of America, Madison, WI.

15) Bridgham, S. D. 2014. Carbon dynamics and ecosystem processes. In Ecology of Freshwater and Estuarine Wetlands (edited texbook), eds. D. P. Batzer and R. R. Sharitz, University of California Press, Berkeley, CA.

16) Kolka, R., S. D. Bridgham, and C.-L. Ping. *In press*. Soils peatlands: Histosols and Gelisols. In Wetland Soils: Genesis, Hydrology, Landscapes, and Classification, 2nd Edition, M. J. Vepraskas and C. Craft, eds., Lewis Publishers, Boca Raton, FL.

OTHER PUBLICATIONS

1) Bridgham, S. D. 1986. *The Effects of PCBs on the Physiology of* Daphnia pulicaria. M.S. thesis, Department of Ecology, Evolution, and Behavior, University of Minnesota, St. Paul, MN.
2) Bridgham, S. D. 1991. *Mechanisms Controlling Soil Carbon Cycling in North Carolina Peatlands.* Ph.D. dissertation, Nicholas School of the Environment & Earth Sciences, Duke University, Durham, NC.
3) Bridgham, S. D. and C. J. Richardson. 1991. Freshwater peatlands on the southeastern Coastal Plain of the USA: Community description, nutrient dynamics, and disturbance. Pages 1 - 15 in Proceedings of the International Peat Symposium, August 19-23, Duluth, MN, D.N. Grubich and T.J. Malterer, eds.
4) Bridgham, S. D. 1994. Review of Wetlands: Guide to Science, Law, and Technology, M. S. Dennison and J. F. Berry, eds., Noyes Publications. Journal of Environmental Quality 23:1119-1120.
5) Axler, R. P., J. Henneck†, S. Bridgham, C. Tikkanen†, D. Nordman†, A. Bamford†, and M. McDonald. 1996. Constructed wetlands in northern Minnesota for treatment of aquacultural wastes. In Proceedings from the Constructed Wetlands in Cold Climates, June 4-5, 1996, Niagara-on-the-Lake, Ontario, Canada.
6) Bridgham, S. D. 1998. The role of agriculture in phosphorus eutrophication of surface water. Review of Phosphorus Loss from Soil to Water, H. Tunney, O. T. Carton, P. C. Brookes, and A. E. Johnston, eds., CAB International. Ecology 79:2215-2216.
7) Bridgham, S. D. 1999. Meeting review of "How nutrient cycles constrain carbon balances in boreal forests and arctic tundra." A conference organized on behalf of the GCTE (Global Change and Terrestrial Ecosystems) core project of the IGBP (International Geosphere Biosphere Programme) in Abisko, Sweden on June 15-19, 1999. Bulletin of the Ecological Society of America 80:244-245.
8) Bridgham, S. D. 1999. How nutrient cycles constrain carbon balances in boreal forests and arctic tundra. GCTE (Global Change and Terrestrial Ecosystems) Newsletter.
9) Pfeifer-Meister, L. S. Bridgham, B. Roy, and B. Johnson. 2007. Testing the effectiveness of site preparation techniques for wetland prairie restoration. Final report to West Eugene Wetland Partnership (http://www.lcog.org/Site%20Prep%20Presentation_May%202007.pdf).

INVITED SEMINARS (last 4 years)

1) Climate change effects on plant range distribution in (and the restoration of) prairies. Web seminar to The Nature Conservancy personnel in Washington and Oregon. March 12, 2010.
2) Experimental determination of climate change effects on native prairies in the Pacific Northwest. Public talk at Deer Creek Center, Selma, OR, April 8, 2010.
3) Climate change effects on terrestrial ecosystems. Public talk at Eugene Natural History Society, March 18, 2011.
4) Challenges and opportunity for carbon sequestration in the restoration of wetlands. Department of Interior Natural Resource Damage Assessment and Restoration Program

Meeting, Phoenix, AZ, March 24, 2011.

5) Climate effects on plant Range distributions and ecosystem function in Mediterranean grasslands: A manipulative experiment embedded in a natural climate gradient in the Pacific Northwest. Center on Global Change, Duke University, Oct. 25, 2012.

INVITED SYMPOSIA (last 4 years)

1) Bridgham, S., J. Keller, J. White, and M. Vile. 2010. Biogeochemical controls over methane production and emissions from peatlands. Society of Wetland Scientists, Salt Lake City, June 27 – July 2.
2) Megonigal, P., S. Bridgham, V. Gauci, M. Finlayson, C. Lloyd, S. Luchessa, M. McCartney, N. Pettorelli, S. Page. 2010. Misconceptions about wetland management for carbon sequestration. Society of Wetland Scientists, Salt Lake City, June 27 – July 2.
3) Bridgham, S. D., R. Ye, J. K. Keller, S. McAllister, Q. Jin, and B. Bohannan. 2012. Controls over Anaerobic carbon cycling and methane production in peatlands. INTECOL Wetlands, Orlando, FL, June 3-8.
4) McAllister, S. A., S. D. Bridgham, Q. Jin, and B. Bohannan. 2012. Linking methane production rate to methanogen community structure in peatland soils. INTECOL Wetlands, Orlando, FL, June 3-8.
5) Bridgham, S. D. 2013. Rhizosphere processes and the role of humic substances in driving peatland carbon dynamics. Workshop on Belowground Carbon Cycling Processes at the Molecular Scale, Environmental Molecular Science Laboratory, Pacific Northwest National Laboratory, Richland, WA, Feb. 19-21.
6) Pfeifer-Meister, L., S. D. Bridgham, T. Tomaszewski, L. Reynolds, M. E. Goklany, C. J. Little, H. E. Wilson. 2013. Climate change impacts on biodiversity in Pacific Northwest prairies: Shifts in plant range distributions and functional group composition. Cascadia Prairie-Oak Partnership and Northwest Scientific Association, Portland, OR, Mar. 20-23.

OTHER PRESENTATIONS AND POSTERS (last 4 years)

1) White, J. R., R. D. Shannon, J. F. Weltzin, J. Pastor, and S. D. Bridgham. 2010. Stable isotopic evidence of climate-driven changes in methane cycling in northern peatlands. Goldschmidt Conference on Earth, Energy and the Environment, Knoxville, TN, June.
2) Bridgham S., B. Johnson., L. Pfeifer-Meister, T. Tomaszewski, L. Reynolds, and M. Goklany. 2010. How will climate change affect the range distributions of native prairie plants and the viability of restored prairies in the Pacific Northwest? Pacific NW Climate Science Conference, June 15-16, Portland, OR.
3) Johnson, B. R., R. G. Ribe, D. W. Hulse, J. P. Bolte, S. D. Bridgham, T. Sheehan, M. Nielson-Pincus, G. I. Yospin[1], A. A. Ager, J. A. Kertis, D. Bachelet, R. P. Neilson, D. Conklin, C. A. Harrington, and P. J. Gould. 2010. Modeling the potential for surprise in coupled human and natural systems under future climate change, population growth and

wildfire hazard in the Willamette Valley Ecoregion. Pacific NW Climate Science Conference, June 15-16, Portland, OR.

4) McAllister, S., B. Bohannan, S. Bridgham, and Q. Jin. 2010. Microbial community structure and ecosystem function: linking methane production rate to methanogen community structure in wetland soils. International Symposium on Microbial Ecology, Aug. 23-27, Seattle, WA.

5) Bridgham, S. D., B. Johnson, T. Tomaszewski, L. Pfeifer-Meister, M. Goklany, L. Reynolds, and H. Wilson. 2011. Poster: Temperature and Precipitation Effects on Plant Range Distributions, Community Structure, and Ecosystem Function across a Natural Climate Gradient in Prairie Ecosystems. Invited participant in workshop on How Do We Improve Earth System Models: Integrating Earth System Models, Ecosystem Models, Experiments and Long-Term Data, organized by Integrated Network for Terrestrial Ecosystem Research on Feedbacks to the Atmosphere and Climate (INTERFACE), Feb. 28-Mar. 3, Captiva Island, FL.

6) Eisenhut, N., R. Ye, B. Bohannan, Q. Jin, and S. Bridgham. 2011. pH effects on carbon mineralization to CO_2 and CH_4 in peatlands across an ombrotrophic-minerotrophic gradient. Annual meeting of the Ecological Society of America, Aug. 7-12, Austin, TX.

7) Goklanay, M., B. Johnson, L. Pfeifer-Mesiter, T. Tomaszewski, and S. Bridgham. 2011. How climate change affect the physiology and productivity of perennial grasses in Pacific Northwest prairies? Annual meeting of the Ecological Society of America, Aug. 7-12, Austin, TX.

8) McAllister, S. A., S. D. Bridgham, Q. Jin, and B. J. M. Bohannon. 2011. Linking methane production rate to methanogen community structure in wetland soils. Annual meeting of the Ecological Society of America, Aug. 7-12, Austin, TX.

9) Bridgham, S. D., L. Pfeifer-Meister, T. Tomaszewski, L. Reynolds, M. Goklany, H. Wilson, and B. R. Johnson. 2011. Climate impacts on terrestrial ecosystems and managed resources. Pacific Northwest Climate Science Conference, Sept. 13-14, Seattle, WA.

10) Pfeifer-Meister, L., B. R. Johnson, T. Tomaszewski, M. Goklany, L. Reynolds, H. Wilson, and S. D. Bridgham. 2011. Natural and experimental climatic effects on native plant range distributions in the Pacific Northwest. Pacific Northwest Climate Science Conference, Sept. 13-14, Seattle, WA.

11) Wilson, H., B. Johnson, and S. Bridgham. 2011. Increased experimental heating decreases arbuscular mycorrhizal abundance across a latitudinal gradient in annual prairie forbs. Pacific Northwest Climate Science Conference, Sept. 13-14, Seattle, WA.

12) Reynolds, L., B. Johnson, L. Pfeifer-Meister, T. Tomaszewski, and S. Bridgham. 2011. The response of soil respiration to simulated climate change along a latitudinal climate gradient in Pacific Northwest prairies. Pacific Northwest Climate Science Conference, Sept. 13-14, Seattle, WA.

13) Ye, R., S.D. Bridgham, Q. Jin, and B. Bohannan. 2011. pH controls over anaerobic carbon mineralization to CO_2 and CH_4 in peatlands across an ombrotrophic-minerotrophic gradient. Annual meeting of the Soil Science Society of America, Oct. 16-19, San Antonio, TX.

14) Ye, R., Q. Jin, B. Bohannan, J. Keller, and S.D. Bridgham. 2011. pH controls over carbon mineralization to CO_2 and CH_4 in peatlands across an ombrotrophic-minerotrophic gradient. Annual meeting of the American Geophysical Union, Dec. 5-9, San Francisco, CA.

15) Cadillo-Quiroz, H., S. Maguffin, S. Bridgham, B. Bohannan, and Q. Jin. 2012. Methanogenic community and kinetics of methane production from acetate in contrasting ecosystems. Annual meeting of the American Society of Microbiology, June 16-19, San Francisco, CA.

16) Bridgham, S. D., L. Pfeifer-Meister, T. Tomaszewski, M. E. Goklany, L. L. Reynolds, C. J. Little, and Bart R. Johnson. 2012. Pushing limits: Altered temperature and precipitation differentially affect plant species inside and beyond their current ranges. Poster presented at the U.S. DOE Terrestrial Ecosystem Science Principal Investigators Meeting, Washington, DC, Apr. 23-24.

17) Reynolds, L. L., B. R. Johnson, L. Pfeifer-Meister, T. Tomaszewski, and S. D. Bridgham. 2012. Response of soil respiration to experimental warming and increased precipitation intensity depends upon a latitudinal climate gradient in Pacific Northwest grasslands. Poster presented at the U.S. DOE Terrestrial Ecosystem Science Principal Investigators Meeting, Washington, DC, Apr. 23-24.

18) Bridgham, S. D., R. Ye, J. K. Keller, S. McAllister, Q. Jin, and B. Bohannan. 2012. Controls over anaerobic carbon cycling and methane production in peatlands. Biogeomon International Symposium on Ecosystem Behavior, Northport, ME, July 15-20.

19) Vandegrift, A. W. B. A. Roy, L. E. Pfeifer-Meister, T. E. Tomaszewski, B. R. Johnson, and S. D. Bridgham. 2012. Climate change and *Epichloë* endophyte infection influences arbuscular mycorrhizal colonization rates in grasses. Annual Meeting of the Ecological Society of America, Portland, OR, Aug. 5-10.

20) Bridgham, S. D., R. Ye, J. K. Keller, S. McAllister, Q. Jin, and B. Bohannan. 2012. Why does the efficiency of methane production vary so much among peatlands? Annual Meeting of the Ecological Society of America, Portland, OR, Aug. 5-10.

21) Wilson, H. E. B. R. Johnson, R. C. Mueller, L. Pfeifer-Meister, T. Tomaszewski, B. J. M. Bohannan, and S. D. Bridgham. 2012. Experimental warming across a natural climate gradient reverses soil nutrient effects on arbuscular mycorrhizal abundance in prairie plants. Annual Meeting of the Ecological Society of America, Portland, OR, Aug. 5-10.

22) Yospin, G. I., S. D. Bridgham, R. P. Neilson, J. P. Bolte, D. M. Bachelet, P. J. Gould, C. A. Harrington, J. A. Kertis, J. Merzenich, C. Evers, and B. R. Johnson. 2012. Projections of climate change impacts on forest succession for local land management using a new vegetation model, CV-STM. Annual Meeting of the Ecological Society of America, Portland, OR, Aug. 5-10.

23) Johnson. B. R., J. P. Bolte, S. D. Bridgham, D. W. Hulse, R. P. Neilson, R. G. Ribe, , A. A. Ager, M. Nielsen-Pincus, T. Sheehan, G. I. Yospin, J. A. Kertis, C. A. Harrington, and P. J. Gould. 2012. Addressing uncertainties in climate change adaptation planning by using an integrated suite of mechanistic simulation models within an alternative futures planning framework. Annual Meeting of the Ecological Society of America, Portland, OR, Aug. 5-10.

24) McAllister, S. A., S. D. Bridgham, Q. Jin, and B. J. M. Bohannan. 2012. Microbial community structure and ecosystem function: Linking methane production rate to methanogen community structure in peatland soils. Annual Meeting of the Ecological Society of America, Portland, OR, Aug. 5-10.

25) Pfiefer-Meister, L., S. D. Bridgham, T. Tomaszewski, M. E. Goklany, L. L. Reynolds, C. J. Little, and B. R. Johnson. Pushing Limits: Altered temperature and precipitation differentially affect plant species inside and outside their current ranges.. Annual Meeting of the Ecological Society of America, Portland, OR, Aug. 5-10.

26) Reynolds, L. L., B. R. Johnson, L. Pfeifer-Meister, T. E. Tomaszewski, and S. D. Bridgham. 2012. Response of soil efflux to experimental warming and increased precipitation intensity depends upon latitudinal climate gradient in Pacific Northwest grasslands. Annual Meeting of the Ecological Society of America, Portland, OR, Aug. 5-10.

27) Tomaszewski, T., B. R. Johnson, L. Pfeifer-Meister, M. E. Goklany, L. L. Reynolds, H. E. Wilson, and S. D. Bridgham. 2012. Site-dependent versus regionally consistent effects of increased temperature and precipitation on plant community composition, productivity, and soil nutrient availability in restored Pacific Northwest prairies. Annual Meeting of the Ecological Society of America, Portland, OR, Aug. 5-10.

28) Reynolds, L. L., K. Lajtha, R. D. Bowden, B. Johson, and S. Bridgham. 2012. The DIRT on Q_{10}: Differential temperature response of soils depleted of labile inputs. Poster at Long-Term Ecological Research (LTER) All Scientists Meeting, Estes Park, CO, Sept. 10-13.

29) Pfeifer-Meister, L., S. D. Bridgham, T. Tomaszewski, L. Reynolds, M. E. Goklany, C. J. Little, H. E. Wilson. 2013. Climate change impacts on biodiversity in Pacific Northwest prairies: Shifts in plant range distributions and functional group composition. Annual meeting of the Northwest Science Association and Cascadia Prairie-Oak Partnership, Portland, OR, March 20-23.

30) Bridgham, S. 2013. Rhizospheric processes and the role of humic substances in driving peatland carbon dynamics. Workshop on "Belowground Carbon Cycling Processes at the Molecular Scale," Environmental Molecular Science Laboratory, Dept. of Energy, Feb. 19-21, 2013.

31) Pfeifer-Meister, L., S. D. Bridgham, T. Tomaszewski, M. E. Goklany, L L. Reynolds, C. J. Little, and B. R. Johnson. 2013. Pushing the limit: Experimental evidence of climate effects on plant range distributions. Dept. of Energy Terrestrial Ecosystem/Subsurface Biogeochemical Research Joint Investigators Meeting, Potomac, MD, May 13-15, 2013.

32) Pfeifer-Meister, L., S. D. Bridgham, T. Tomaszewski, L L. Reynolds, M. E. Goklany, C. J. Little, H. E. Wilson, and B. R. Johnson. 2013. Consistent shifts in the community composition and diversity in response to experimental climate manipulations across a latitudinal gradient in Pacific Northwest prairies. Dept. of Energy Terrestrial Ecosystem/Subsurface Biogeochemical Research Joint Investigators Meeting, Potomac, MD, May 13-15, 2013.

33) Reynolds, L. L., B. R. Johnson, L. Pfeifer-Meister, T. Tomaszewski, and S.D. Bridgham. 2013. Response of soil respiration to experimental warming and increased precipitation intensity depends upon a latitudinal climate gradient in Pacific Northwest grasslands.

Dept. of Energy Terrestrial Ecosystem/Subsurface Biogeochemical Research Joint Investigators Meeting, Potomac, MD, May 13-15, 2013.

34) Bridgham, S.D., J. Pastor, J. Keller, J. White, and R. D. Shannon. 2013. A retrospective analysis of a Minnesota peatland manipulative climate change study. Annual Meeting of the Society of Wetland Scientists, Duluth, MN, June 2-6.

35) Keller, S. D. and S. D. Bridgham. 2013. Rethinking the role of soil organic matter in peatland decomposition. Annual Meeting of the Society of Wetland Scientists, Duluth, MN, June 2-6.

36) Pfeifer-Meister, L., L. G. Gayton, S. D. Bridgham. 2013. Controls of trace gas emissions in natural, restored, and agricultural seasonal wetlands. Annual Meeting of the Society of Wetland Scientists, Duluth, MN, June 2-6.

37) Reynolds, L. L., K. Lajtha, R. D. Bowden, B. Johnson, and S. Bridgham. 2013. Depletion of labile-inputs does not increase temperature sensitivity in a laboratory incubation but does this imply no change in the molecular nature of the decomposed organic carbon? Users Meeting for Environmental Molecular Science Laboratory, Pacific Northwest National Laboratory, Department of Energy, Richland, WA, July 30-31.

38) Reynolds, L. L., K. Lajtha, R. D. Bowden, B. Johnson, and S. Bridgham. 2013. The DIRT on Q_{10}: Depletion of labile-inputs does not increase temperature sensitivity in a laboratory incubation. Annual Meeting of the American Geophysical Union, San Francisco, CA, Dec. 9-13.

39) Kostka, J. E., X. Lin, M. M. Tfaily, J. P. Chanton, W. Cooper, S. Bridgham, and J. Keller. 2014. The abundance and expression of genes for methanogenesis and methanotrophy in northern peatlands. Annual Meeting of American Society of Microbiology, Boston, MA, May 17-20.

Biographical sketch: MONIQUE Y. LECLERC

Regents Professor and D. W. Brooks Distinguished Research Professor
Atmospheric BioGeosciences Group (www.biogeosciences.uga.edu), The University of Georgia

Education

1980 B.Sc. Sciences McGill University, Canada
1982 M.Sc. Land Resource Science University of Guelph, Canada
1987 Ph.D. Land Resource Science University of Guelph, Canada

Professional Experience

2009-Present Regents' Professor, University of Georgia
2000-Present Professor, Lab for Environmental Physics, Univ. of Georgia
2007-Present Honorary Professor, Peking Univ., State Key Laboratory, Beijing, China
2003-Present Honorary Professor, Chiang Mai Univ., Chiang Mai, Thailand
1995-2000 Associate Professor, Laboratory for Environ. Physics, Univ. Georgia
1990-1995 Associate Professor, Department of Physics, Univ.Quebec at Montreal
1991- Adjunct Professor, Dept. Atmos. and Ocean. Sci., McGill Univ.
1991-1995 Adjunct Professor, Dept. of Environ. Sci., Univ. Quebec at Montreal
1987-1990 Assistant Professor, Dept. of Soils and Biometeorology, Utah State University
1987-1991 Associate Faculty, Center for Theoretical Hydrology, Utah State University
1987-1992 Associate Faculty, Ecology Center, Utah State University

Recent Selected Recognitions

- Distinguished Professor. King Mongkut University. Bangkok. Thailand 2013
- Scientific Advisory Committee. Oil Palm Board. Kuala Lumpur. Malaysia 2014-
- D. W. Brooks Award of Excellence in Global Programs. 2012;
- Advisory Board.Integrated Carbon Observation System (ICOS) Sweden 2012-2015
- The American Meteorological Society 'The Award for Outstanding Achievement in Biometeorology' for 'Pioneering Research that has advanced our understanding of temporal and spatial patterns of local and regional

carbon exchanges, and for global leadership in advancement of biometeorology.' 2008. Nota Bene: THIS AWARD WAS GIVEN TO THE YOUNGEST SCIENTIST AND THE FIRST FEMALE;

- National Advisory Board. CAST, Wash. DC 2007-2010;
- Advisory Board to the President of the University of Georgia 2014-
- Member of evaluation panels at USDA, DOE, NSF, NSERC, Italian Research Council, etc.
- D. W. Brooks Distinguished Professor Award for Excellence in Research 2009;
- Advisor to the Government of Bhutan on Climate Change. Thimphu, Bhutan. 2009;
- Guest Professor. State Key Laboratory. Dept. of Atmospheric Sciences. Peking University. 2008-
- University of Oxford, 20th Anniv., Oxford Annual Round Table. St-Anne's College. England. 2008;
- Marquis Who's Who in America. Global Marquis Who's Who. 2008, 2009, 2010, 2011. 2012; 2013; 2014
- Advisory Board and Full Member of the Centre for Climate and Global Change Research, McGill University 1990 – 1995;
- Visiting Fellow, National Center of Atmospheric Research, Boulder, CO 1988 1988;

Examples of Synergistic Activities

- **Advisory Panel**. Malaysian Oil Palm Board. Kuala Lumpur. Malaysia. 2014-2017.
- **Advisory Panel**. Peat Panel Review. Malaysian Oil Palm Board. Kuala Lumpur. Malaysia. 2014.
- Malaysian Palm Oil Board International Palm Oil Congress (PIPOC). October 2013. **Keynote Speaker 'Greenhouse Gas Emissions from Peat Lands'.**
- **International Society of Oil Palm Congress.** ISOP). Keynote Speaker. November 2013. Kuala Lumpur. Malaysia.
- **Journal of Oil Palm Research** (JOPR) Editorial Board 2014-
- **Associate Editor**. Journal of Ag. and Forest. Meteorology, Elsevier Publ., Dordrecht, The Netherlands. (No. 1 in Forestry and no. 3 in Agr. In terms of impact factor) 2005-Present.
- **Editorial Board**. Advances in Meteorology, Hindawi Publ. Mumbai. 2010-Present

- **Associate Editor**. American J. Climate Change. 2011- present.
- **Editor**. Earth Perspectives 2012- (new)
- **International Scientific Committee.** Atmospheric Chemistry in Vegetation Canopies. EGER. Castle Thurnau, Germany. 2009-2010**.**
- **Advisor** to the Ministry of Energy, Bangkok, Thailand on Impact Assessment of Climate Change.2009.
- **Advisor** to the Government of Bhutan, Prime Minister's Office. On Rapid Climate Change Adaptation and Preparedness. 2009.
- **Guest Lecturer**. Oxford Annual Round Table on Climate Change. 20th Anniversary. Univ. of Oxford, England –2008.
- **Past President.** International Society of Biometeorology. 2002-2005**.**
- **International Scientific Committee.** International Association for the promotion of c-operation with scientists from the New Independent States of the Soviet Union (INTAS). Member International Symposium on Footprints. . Bruxels, Belgium. 2001-2002/ 2002-2003**.**
- **Visiting Fellow**. National Center for Atmospheric Research (NCAR). 1988.

Selected Publications

Zhang G., M.Y. **Leclerc**, A. Karipot, H. Duarte, E. Mursch-Radlgruber, H.L. Gholz. 2011. The impact of logging on the surrounding flow in a managed plantation. Theoretical and Applied Climatology, Vol. 106, No. 3 pp. 511-521.

Pingintha N., **M. Y. Leclerc**, J. P. Beasley Jr., G. Zhang, C. Senthong. 2010. *Hysteresis Response of Daytime Net Ecosystem CO2 Exchange during a Drought.* Biogeosciences. Vol. 7, No.3 pp. 1159-1170.

van Gorsel E., N. Delpierre, R. Leuning, J. M. Munger, S. Wofsy, M. Aubinet, C. Heigenwinter, J. Beringer, D. Bonal, B. Chen, J. Chen, R. Clement, K. J. Davis, A. Desai, D. Dragoni, S. Etzold, T. Grunwald, L. Gu, B. Heinesch, L. R. Hutyra, W. W. P. Jans, W. Kutsch, B. E. Law, **M. Y. Leclerc,** I. Mammarrella, L. Montagnani, A. Noormets, C. Rebmann, S. Wharton. 2009. *Estimating nocturnal ecosystem respiration from the vertical turbulent flux and change in storage of CO_2.* Agricultural and Forest Meteorology, Vol. 149, No. 11. pp. 1919-1930.

Pingintha N., **M.Y. Leclerc**, J.P. Beasley Jr., G. Zhang, and C. Senthong. 2009. *Assessment of the soil CO_2 gradient method for soil CO_2 efflux measurements: comparison of six models in the calculation of the relative gas diffusion coefficient*. Tellus B, Vol. 62B, pp. 47-58.

Sogachev, A., **M. Y. Leclerc**, G. Zhang, U. Rannik, and T. Vesala. 2008. CO2 fluxes near a forest edge: a numerical study. Ecological Applications, 18(6), 1454-

1469.
Kim, J., Q. Guo, D.D. Baldocchi, **M.Y. Leclerc**, L. Xu and H.P. Schmid. 2006. *Upscaling Fluxes from Tower to Landscape: Overlaying Flux Footprints on High Resolution (IKONOS) Images of Vegetation Cover*, Agricultural and Forest Meteorology. 136 (3-4): 132-146.
Baldocchi, D., T. Krebs and **M.Y. Leclerc**. 2005. *'Wet/Dry Daisyworld': A Conceptual Tool for Quantifying the Spatial Scaling of Heterogeneous Landscapes and its Impact on the Subgrid Variability of Energy Fluxes.* Tellus, 57B: 1-14.
Hollinger, D.Y., J. Aber, B. Dail, E. A. Davidson, S. M. Goltz, H. Hughes, **M.Y. Leclerc**, J. T. Lee, A. D. Richardson, C. Rodrigues, N.A. Scott, D. Varier, and J. Walsh. 2004. *Spatial and Temporal Variability in Forest-Atmosphere CO2 Exchange.* Global Change Biology, 10: 1-18.

EXPERTISE RELEVANT TO THIS PROJECT:

Monique Y. Leclerc: Regents Professor, D.W. Brooks Distinguished Research Professor, and Head of the Laboratory for Environmental Physics at the University of Georgia. Dr. Leclerc has over 20 years of experience in field campaigns throughout the Americas, Europe, and Asia focusing on surface-atmosphere interactions. She has led field campaigns using a combination of eddy-covariance to measure greenhouse gas emissions.

Kristell HERGOUALC'H
Researcher in Ecosystem Functioning

Nationality French

Date of birth 30^{th} of March, 1974

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c/o Centro Internacional de la Papa (CIP)
Av. La Molina 1895, La Molina
Apartado postal 1558
Lima 12, Perú
Voice: +51 (1) 349 6017 ext 1015
Electronic: k.hergoualch@cgiar.org

Current position **Scientist in climate change mitigation**

With **CIFOR** (Center for International Forestry Research), Forests and Environment.

Research topics **Forestry, agroforestry, agriculture, land-use change, climate change, environmental services, peatlands, REDD+**

Soil fluxes of **greenhouse gases** (N_2O, CH_4, and CO_2). **Microbial processes** and **biophysical modeling** of soil fluxes of N_2O (NGAS, NOE, DNDC) and **C sequestration** (CO2Fix). **N** and **C cycles**. **Carbon dynamics** in soil and biomass.

Education

2008**: Ph D** in Ecosystem Functioning (SIBAGHE, SupAgro, Montpellier, France). Area: Soil sciences

2004: **MSc.** in **Agronomy** (Institut National Polytechnique de Lorraine, ENSAIA, Nancy, France)

1997: Engineer in **Energy and Environment** (Ecole Polytechnique Féminine, Paris, France). Areas: Renewable energies and environmental pollution (air, water, soil)

Employment history

Since November 2008: **CIFOR.** Bogor, Indonesia until July 2013; currently in Lima, Peru. Researcher in Ecosystem Functioning

Carbon stocks, stock changes and greenhouse gas fluxes (N_2O, CH_4, CO_2) associated with **land-use change** in the tropics, with a special focus on **peatlands**. Implications for climate change.

September 2004-January 2008: **CIRAD** (French center of cooperation specialized in development-oriented agricultural research for the tropics and subtropics)-**CATIE** (Latin American center of research and education in tropical agronomy)-**CEH** (English center of research in ecology and hydrology). Costa Rica, France & UK. Collaboration with **INRA** (French national institute of research in agronomy) and **IRD-SeqBio** (French institute of research for Development-Carbon Sequestration unity). Ph. D student in Ecosystems Functioning.

Soil **greenhouse gases (N_2O, CH_4 and CO_2)** emissions and **carbon** storage in a coffee monoculture and a coffee plantation shaded by the N_2 fixing legume species *Inga densiflora* on Andosols in Costa Rica. Characterization of the nitrification-denitrification processes and **modeling** of soil N_2O fluxes with the process-oriented models NOE and NGAS.

April 2007: **Rainforest Alliance** (NGO working on biodiversity conservation and sustainable livelihoods). Costa Rica. Freelance **consultant** on climate change mitigation.

Revision of a **method** for estimating carbon sequestration in coffee agroforestry systems.

September 2003-August 2004: **CIRAD-CATIE-CEH**. Costa Rica, France & UK. MSc. student in Agronomy

Nitrous oxide production by **nitrification** and **denitrification** in a volcanic soil under different coffee systems in Costa Rica.

January 2002-August 2003: **CIRAD-CATIE**. Costa Rica, Nicaragua, Guatemala.

Carbon sequestration **database** and **modeling** (**CO2Fix**) in coffee plantations.

Delegate of CATIE in the **Costarican agroforestry national committee** (CNAF). Design of the CNAF website. Contribution to the writing of the proposal of **payment for environmental services** to lands dedicated to **agroforestry**. Proposal approved by the Environment and Energy Ministry, come into effect in 2003.

June 1998-December 2001: **SupAgro** (International center of education in advanced agronomic sciences). France. Engineer.

Organization of computing software **trainings** applied to agronomy.

March-October 1997: **Lyonnaise des Eaux** (private French company specialized in energy and environment). Argentina. Engineer.

Environmental study on cyanide and chrome **contamination** in **rivers**, water network (water supply, sewage and wastewater treatment plant) and **soils** (sewage sludge application).

Students advisory committee

Aini F, Carbon stocks and soil greenhouse flux changes in a forest transition into oil palm and rubber plantations of Indonesia. Ph D, University of Aberdeen, UK.

Comeau L-P, Soil organic carbon dynamics after land-use change in tropical **peatlands**, Jambi, Indonesia. Ph D, University of Aberdeen, UK.

Farmer J (2014) Measuring and modeling soil carbon and carbon dioxide emissions from Indonesian **peatlands** under land-use change. Ph D, University of Aberdeen, UK.

Hartill J, Changes in soil nitrous oxide and methane fluxes following the conversion of tropical **peat** swamps in Jambi, Indonesia. Ph D, University of Aberdeen, UK.

Hendry Dede, Partitioning of soil respiration into auto- and heterotrophic components as affected by **peat** swamp forest conversion to **oil palm plantation**. MSc., IPB, Indonesia.

Novita N, Changes in greenhouse gases (CO_2, CH_4 and N_2O) fluxes and carbon stocks from tropical **peat** swamp forest conversion to **oil palm plantation**. Ph D, Oregon state university, US.

Oktarita S (2014) The effect of nitrogen fertilization on soil CO_2, CH_4, N_2O and NO emissions in an **oil palm plantation** cultivated on **peat** in Jambi, Sumatra, Indonesia. MSc., IPB, Indonesia.

Persch S, Fine root dynamics in different land-uses on tropical **peat** in Jambi, Sumatra. Ph D, University of Göttingen, Germany.

Persch S (2011) Carbon stock in aboveground and coarse root biomass in different land use treatments on tropical **peat**. MSc., University of Göttingen, Germany.

Swails E, Linking GRACE with optical satellite data and field measures to determine the effect of climate variability on greenhouse gas emissions from tropical **peatlands**. Ph D, University of Virginia, US.

Van Lent, The effect of **peat** forest degradation in the Peruvian Amazon basin on soil fluxes of greenhouse gases. Ph D, University of Wageningen, The Netherlands.

Geographical experience

Countries worked in: Argentina, Costa Rica, France, Guatemala, Indonesia, Nicaragua, Peru, UK.

Other visited countries: almost all countries of America, Africa (Morocco, Tunisia, Madagascar, Kenya), Middle East (Turkey) and Asia (the Philippines, India, Korea, Vietnam).

Languages

Mother tongue:	**French**
Working languages:	**English**, **Spanish**
Medium knowledge:	**Bahasa Indonesia**, Italian

Computer

Languages: Programming in C, Pascal, Fortran.
Software: Modeling with CO2Fix, DNDC. Database development with Access.

Articles

Implementing REDD+: Case study evidence on governance, evaluation and impacts

Matthews R, van Noordwijk M, Lambin E, Meyfroidt P, Gupta J, Veldkamp E, Verchot L, Hergoualc'h K (2014) Mitigation and adaptation strategies for global change. Submitted.

Mud, muddle and models in the knowledge value chain to action on tropical peatland issues

van Noordwijk M, Matthews R, Agus F, Farmer J, Verchot L, Hergoualc'h K, Persch S, Tata HL, Khasanah N, Widayati A, Dewi S (2014) Mitigation and adaptation strategies for global change. Submitted.

Soil N_2O and NO emissions from land use and land-use change in the tropics and subtropics: A meta-analysis

Van Lent J, Hergoualc'h K, Verchot LV (2014) Global change biology. Submitted.

Comparison of methods for quantifying soil carbon in tropical peats.

Farmer J, Matthews R, Hergoualc'h K, Verchot L, Langan C, Smith P, Smith JU (2014) Geoderma 214-215: 177-183

Greenhouse gas emission factors for land use and land-use change in Southeast Asian peatlands.

Hergoualc'h K, Verchot LV (2013) Mitigation and adaptation strategies for global change. DOI 10.1007/s11027-013-9511-x.

Generic allometric models including height best estimate forest biomass and carbon stocks in Indonesia.

Rutishauser E, Noor'an F, Laumonier Y, Halperin J, Rufi'ie, Hergoualc'h K, Verchot L (2013) Forest Ecology and Management 307: 219–225

Conversion of intact peat swamp forest to oil palm plantation: Effects on soil CO_2 fluxes in Jambi, Sumatra.

Comeau L-P, Hergoualc'h K, Smith JU, Verchot L (2013) Working paper 110. CIFOR, Bogor, Indonesia.

A cost-efficient method to assess carbon stocks in tropical peat soil.

Warren MW, Kauffman JB, Murdiyarso D, Anshari G, Hergoualc'h K, Kurnianto S, Purbopuspito J, Gusmayanti E, Afifudin M, Rahajoe J, Alhamd L, Limin S, Iswandi A (2012) Biogeosciences 9:7049-7071.

Changes in soil CH_4 fluxes from the conversion of tropical peat swamp forests: a meta-analysis.

Hergoualc'h K, Verchot LV (2012) Journal of Integrative Environmental Sciences 9:93-101

Changes in carbon stocks and greenhouse gas balance in a coffee (*Coffea arabica*) monoculture versus an agroforestry system with *Inga densiflora* in Costa Rica.

Hergoualc'h K, Harmand J-M, Blanchard E, Skiba U, Hénault C (2012) Agriculture, Ecosystems and Environment 148:102-110

Stocks and fluxes of carbon associated with land-use change in Southeast Asian tropical peatlands: a review

Hergoualc'h K, Verchot LV (2011) Global Biochemical Cycles, 25 doi:10.1029/2009GB003718

Opportunities for reducing greenhouse gas emissions tropical peatlands.

Murdiyarso D, Hergoualc'h K, Verchot LV (2010) PNAS 107:19655-19660

The utility of process-based model for simulating of N_2O emissions from soils: a case study based on Costa Rican coffee plantations.

Hergoualc'h K, Harmand J-M, Cannavo P, Skiba U, Hénault C (2009) Soil Biology and Biochemistry 41:2343-2355

Fluxes of greenhouse gases from Andosols under coffee in monoculture or shaded by *Inga densiflora* in Costa Rica.

Hergoualc'h K, Skiba U, Harmand J-M, Hénault C (2008) Biogeochemistry 89:329-345

Processes responsible for the nitrous oxide emission from a Costa Rican Andosol under a coffee agroforestry plantation.

Hergoualc'h K, Skiba U, Harmand J-M, Oliver R (2007) Biology and Fertility of Soils 43:787-795

Cuantificación del carbono almacenado en la biomasa aérea y el mantillo en sistemas agroforestales de café en el Sur Oeste de Costa Rica.

De Miguel S, Harmand J-M, Hergoualc'h K (2004) Agroforestería en las Américas 41-42:98-104

Book chapters

Chapter 2: Drained inland organic soils.
Drösler M, Verchot LV, Freibauer A, Pan G, Evans CD, Bourbonniere RA, Alm JP, Page S, Agus F, Hergoualc'h K, Couwenberg J, Jauhiainen J, Sabiham S, Wang C, Srivastava N, Borgeau-Chavez L, Hooijer A, Minkkinen K, French N, Strand T, Sirin A, Mickler R, Tansey K, Larkin N (2014) In: Hiraishi T, Krug T, Tanabe K, Srivastava N, Baasansuren J, Fukuda M, Troxler TG (eds) **2013 Supplement to the 2006 IPCC guidelines for national greenhouse gas inventories: Wetlands**. **IPCC**, Switzerland

Emissions factors, converting land use change to CO_2 estimates.
Verchot LV, Kamalakumari A, Romijn E, Herold M, Hergoualc'h K (2012) In: Angelsen A, Brockhaus M, Sunderlin WD, Verchot LV (eds) Analysing REDD+: Challenges and choices. CIFOR, Bogor, Indonesia, pp. 261-278

Ecosystem modeling of tropical wetlands.
Hergoualc'h K, Frolking S, Canadell P, Crooks S, Harrison M, Joosten H, Kurnianto S, Yeager C (2012) In: Murdiyarso D, Kauffman B, Warren M, Pramova E, Hergoualc'h K (eds) Tropical wetlands for climate change adaptation and mitigation: Science and policy imperatives with a special reference to Indonesia. CIFOR working paper 91, Bogor, Indonesia, pp. 15-17.

Principles and methods for assessing climate change mitigation as an ecosystem service in agroecosystems.
Hergoualc'h K (2011) In: Rapidel B, DeClerck F, Le Coq J-F, Beer J (eds) Ecosystem services from agriculture and agroforestry. Measurement and payment. Earthscan, London, UK, pp. 19-36

Books

Tropical wetlands for climate change adaptation and mitigation: Science and policy imperatives with a special reference to Indonesia.
Murdiyarso D, Kauffman B, Warren M, Pramova E, Hergoualc'h K (2012) CIFOR working paper 91, Bogor, Indonesia, 54 pp.

Communications

Soil GHG emissions from forest conversion and oil palm cultivation: An update on emission factors.
Hergoualc'h K, Aini F, Comeau L-P, Hartill J, Hendry D, Oktarita S, Novita N, Kauffman B, Verchot L (2014) 4th International Conference on Oil Palm and Environment (ICOPE), Bali, Indonesia, 12 - 14 February 2014

IPCC emission factors for greenhouse gas inventories in tropical peatlands.
Verchot LV, Hergoualc'h K (2014) International Indonesia Peatland Conversation, Jakarta, 11-12 February 2014

Tropical peat swamp forests: Current knowledge, gaps and science needs.
Murdiyarso D, Kauffman B, Verchot LV, Purbopuspito J, Warren M, Hergoualc'h K (2013) UNFCCC Workshop on technical and scientific aspects of ecosystems with high-carbon reservoirs not covered by other agenda items under the Convention, Bonn, Germany, 24-25 October 2013

Carbon dioxide fluxes and soil organic matter characteristics associated with land-use change in tropical peatlands of Jambi, Indonesia.
Comeau L-P, Hergoualc'h K, Smith J, Verchot LV, Hartill J (2013) 11th meeting of Southeast Asia soil science, Bogor, Indonesia, 24 September 2013

The effect of nitrogen fertilization on soil N2O emissions from oil palm cultivation on deep peat.

Oktarita S, Hergoualc'h K, Verchot LV (2013) 11th meeting of Southeast Asia soil science, Bogor, Indonesia, 24 September 2013

The effect of nitrogen fertilization on soil N2O emissions from oil palm cultivation on deep peat.

Oktarita S, Hergoualc'h K, Verchot LV (2013) Tropical Peat 2013 workshop, Sarawak, Malaysia, 7 September 2013

Modeling carbon accumulation dynamics in tropical peat swamp forests.

Kurnianto S, Frolking S, Warren M, Hergoualc'h K, Talbot J, Kauffman JB, Varner R, Murdiyarso D (2013) ATBC 2013 conference, San José, Costa Rica, 23-27 June 2013

CO_2 Flux Associated with Land Use Change in Tanjung Puting National Park, Central Borneo.

Novita N, Hergoualc'h K, Kauffman B (2013) IUSS Global Soil Carbon Conference, Madison WI, USA, 3-6, June 2013

Methane emissions following land-use change on tropical peat in Jambi, Sumatra.

Hartill J, Hergoualc'h K, Verchot LV, Smith J (2013) IUSS Global Soil Carbon Conference, Madison WI, USA, 3-6, June 2013

Soil CO_2 emission and soil organic matter characteristics associated with land-use change in tropical peatlands of Sumatra, Indonesia.

Comeau L-P, Hergoualc'h K, Verchot LV, Smith J, Hartill JA (2013) IUSS Global Soil Carbon Conference, Madison WI, USA, 3-6 June 2013

SEA tropical peatlands: GHG emissions in the LULUCF sector.

Hergoualc'h K, Verchot LV (2013) FAO workshop Towards sustainable land management practices for peatlands, Rome, Italy, 7-9 May 2013

Modeling long term carbon accumulation in tropical peat swamp forests: preliminary results.

Kurnianto S, Frolking S, Warren M, Hergoualc'h K, Talbot J, Kauffman JB, Varner R, Murdiyarso D (2013) Mer Bleue carbon meeting 2013, McGill university, Montreal, Quebec, Canada, 4-5 March 2013

CIFOR biophysical research on tropical peatlands.

Hergoualc'h K, Verchot LV, Warren M (2013) International Indonesia peatland conversations, Bandung, Indonesia, 25-27 February 2013

Carbon loss associated with land-use change and wildfires in tropical peat swamp forests.

Hergoualc'h K, Verchot LV (2012) 14th International Peat Congress, Stockholm, Sweden, 3-8 June 2012

Land-use change effects on soil emissions of N_2O in the tropics: a 3-continent comparative analysis.

Hergoualc'h K, Verchot LV, Aini FK, Brienza Júnior S, Cattânio JH, Costa de Oliveira V, Davidson E, Hairiah K, Neufeldt H, Thiongo M, van Noordwijk M (2012) Planet Under Pressure conference, London, UK, 25- 29 March 2012

Land-use change effects on soil respiration in the tropics: a 3-continent comparative analysis.

Verchot LV, Hergoualc'h K, Aini FK, Brienza Júnior S, Cattânio JH, Costa de Oliveira V, Davidson E, Hairiah K, Neufeldt H, Thiongo M, van Noordwijk M (2012) Planet Under Pressure conference, London, UK, 25- 29 March 2012

The forgotten D: challenges of addressing forest degradation in REDD+.

Rutishauser E, Bech Bruun T, de Neergaard A, Berry N, Hergoualc'h K, Verchot LV, Mertz O (2012) ATBC – Asia Pacific Chapter Annual Meeting, Xishuangbanna, China, 24-27 March 2012

Phytomass carbon stock changes following peat swamp forest conversion to oil palm plantation in Jambi, Sumatra.

Persch S, Hergoualc'h K, Verchot LV (2012) ATBC – Asia Pacific Chapter Annual Meeting, Xishuangbanna, China, 24-27 March 2012

Carbon stock in coarse root biomass in a primary forest, secondary logged forest and an oil palm plantation on tropical peat in Jambi, Sumatra.

Persch S, Hergoualc'h K, Verchot LV (2012) 3rd International Conference on Oil Palm and Environment (ICOPE), Bali, Indonesia, 22-24 February 2012

Soil CO_2, CH_4 and N_2O emissions from an oil palm plantation on deep peat as affected by nitrogen fertilization.

Hergoualc'h K, ,Handayani EP, Indrasuara K, van Noordwijk M, Bonneau X, Verchot LV (2012) 3rd International Conference on Oil Palm and Environment (ICOPE), Bali, Indonesia, 22-24 February 2012

Changes in soil CH_4 fluxes from the conversion of tropical peat swamp forests: a meta-analysis.

Hergoualc'h K, Verchot LV (2011) 6th International Symposium on non-CO_2 Greenhouse Gases (NCGG-6), Amsterdam, the Netherlands, 2-4 November 2011

CH_4 and N_2O flux changes from forest conversion to rubber and oil palm plantation in Jambi, Sumatra, Indonesia.

Aini FK, Hergoualc'h K, Verchot LV, Smith J (2011) 6th International Symposium on non-CO_2 Greenhouse Gases (NCGG-6), Amsterdam, the Netherlands, 2-4 November 2011

Carbon stock in coarse root biomass in different land-use systems on tropical peat.

Persch S, Hergoualc'h K, Laumonier Y, Verchot LV (2011) Workshop on tropical wetland ecosystems of Indonesia: Science needs to address climate change adaptation and mitigation, Bali, Indonesia, 11-14 April 2011

Assessing GHG emissions from peatlands: methodological challenges.

Murdiyarso D, Hergoualc'h K, Verchot L (2010) Workshop on options for carbon financing to support peatland management, Pekanbaru, Indonesia, 4-6 October 2010

Coffee production, nitrate leaching and N_2O emissions in *Coffea arabica* systems in Costa Rica according to fertilization and shade management.

Harmand JM, Chaves V, Cannavo P, Dionisio L, Zeller B, Hergoualc'h K, Siles P, Vaast P, Oliver R, Beer J, Dambrine E (2010) AGRO2010, The Scientific International Week around Agronomy, Montpellier, France, 29 August-3 September 2010

Carbon loss associated with land-use change in tropical peat forests: Methods and quantification.

Hergoualc'h K, Verchot L (2010) In: Parrotta, J.A., Carr, M.A. (Eds.), The international forestry review. Forests for the future: Sustaining society and the environment. XXIII IUFRO World Congress, 23-28 August 2010. Commonwealth forestry association, Seoul, Republic of Korea, p. 244

C loss associated with land-use change in tropical peatlands: Methods and knowledge gaps.

Hergoualc'h K (2010) USINDO (United States – Indonesia Society) conference, The Indonesia- United States comprehensive partnership, Jakarta, Indonesia, 2 March 2010

Carbon loss associated with the conversion of tropical peat forests to oil palm plantations.

Hergoualc'h K, Verchot L (2010) 2nd International Conference on Oil Palm and Environment, Bali, Indonesia, 23-25 February 2010

Balance between soil N_2O emissions and aboveground CO_2 uptakes in coffee monocultures and agroforestry plantations in Costa Rica.

Hergoualc'h K, Harmand J-M, Skiba U (2009) Second World Congress of Agroforestry, Nairobi, Kenya, 23-28 August 2009

Nitrate leaching and N_2O emissions in *Coffea arabica* systems in Costa Rica according to fertilization and shade management.

Harmand J-M, Chaves V, Cannavo P, Avila H, Dioniso L, Zeller B, Hergoualc'h K, Vaast P, Oliver R, Beer J, Dambrine E (2009) 2nd World Congress of Agroforestry, Nairobi, Kenya, 23-28 August 2009

Large variability in the partitioning of net primary productivity (NPP) between growth and litter production in major tropical plantations: Consequences for ecosystem carbon pools, respiration partitioning and stakes for carbon sequestration methodologies

Roupsard O, Nouvellon Y, Laclau J-P, Epron D, Harmand J-M, Vaast P, Hergoualc'h K, Jourdan C, Saint-André L, Thaler P, Lamade E, Gay F, Hamel O, Bouillet J-P (2008) IUFRO International conference on Processes Controlling Productivity in Tropical Plantations, IPEF, Porto Seguro, Bahia State, Brazil, 10-14 November 2008

Soil N_2O emissions and carbon balance in coffee monocultures and agroforestry plantations on Andosols in Costa Rica

Hergoualc'h K, Harmand J-M, Skiba U (2007) 2nd international symposium on Multi-Strata Agroforestry Systems with Perennial Crops, CATIE, Turrialba, Costa Rica, 17-21 September 2007

Carbon sequestration in aerial biomass and derived products from coffee agroforestry plantations in Central America

Harmand J-M, Hergoualc'h K, De Miguel S, Dzib B, Siles P, Vaast P, Locatelli B (2007) 2nd international symposium on Multi-Strata Agroforestry Systems with Perennial Crops, CATIE, Turrialba, Costa Rica, 17-21 September 2007

Nitrogen dynamics (coffee productivity, nitrate leaching and N_2O emissions) in *Coffea arabica* systems in Costa Rica according to edaphic conditions, fertilization and shade management

Harmand J-M, Chaves V, Cannavo P, Avila H, Dioniso L, Zeller B, Hergoualc'h K, Vaast P, Oliver R, Beer J, Dambrine E (2007) 2nd international symposium on Multi-Strata Agroforestry Systems with Perennial Crops, CATIE, Turrialba, Costa Rica, 17-21 September 2007

Carbon sequestration in coffee agroforestry plantations of Central America

Harmand JM, Hergoualc'h K, De Miguel, Dzib B, Siles P, Vaast P (2006) 21st international conference on coffee science (ASIC), CIRAD, Montpellier, France, 11-15 September 2006

Curriculum Vitae

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Department of Soil Science and Land Resource
Faculty of Agriculture
Bogor Agricultural University (IPB)

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I. Highlights of His Careers

Supiandi SABIHAM obtained a PhD Degree in Agricultural Sciences from Kyoto University, Japan in 1988 with the specialization in "Tropical Soil Sciences". He has been working as Professor of Land Resource Management at the Department of Soil Science and Land Resource, Faculty of Agriculture, Bogor Agricultural University, Indonesia. As a senior staff at his institution, he has more than 40 years of experience in teaching and researches focusing on the main topic of Ecology-Based Peatland Management. He has also conducted more than 10 titles of multiyear-researches supported by national and international research funds where each of the research was conducted in two to four years. He received the first international research-fund from Japanese Government (*Monbusho*) for his study in Kyoto University titled: Studies of Peats in the Coastal Plains of Sumatra and Borneo which are conducted in the period of 1983-1988. He received the second international research-fund from The Toyota Foundation for the three-year research (1991-1993) titled: Wetland Development in Sumatra, Indonesia in collaboration with the Japanese Scholars of Kyoto University. In the period of 1993-1994 he then conducted research in the Center for Southeast Asian Studies (CSEAS), Kyoto University as a Visiting Researcher to study peatland development in Japan compared with that in Indonesia. In the period of 1995-2005 he carried out research titled: Stability and Destabilization of the Indonesian Peats which is funded by Directorate General of Higher Education, Ministry of Education and Culture, the Republic of Indonesia (RI). Since 2006 he has then been working closely with Agricultural Research and Development Agency, Ministry of Agriculture, RI to evaluate peatland utilization for annual and perennial (plantation) crops. In the period of February-August in 2009, again he was invited by the CSEAS, Kyoto University as Visiting Scholar to carry out research titled: Indonesian Peatland Management Based on Ecosystem Unique. In November 2009, he received the two-year research grant from The Toyota Foundation in order to carry out research titled: An Adaptive Socio-entropy System: Balancing the Economic Endeavors and Socio Ecological Dynamics at a Palm Oil Plantation in Indonesia, which is conducted together with the Japanese Scholars of Kyoto University. Throughout all of his careers, more than 30 scientific papers have been written and published in the national and international journals, either written alone or with other scholars. In the period of 2011-2013 he worked as one of Lead Authors of 2013 Supplement to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for the National Greenhouse Gas Inventories: Wetlands. He was invited by the Department of Palynology and Climate Dynamics, Georg-August-University of Gottingen, Germany as Visiting Research Scholar during the period of January-February 2013 to study History of Peat Deposits in Indonesia. During the period of April 2013 to March 2014 he worked as Visiting Professor at Graduate School / Faculty of Agriculture, Kyoto University to conduct teaching and research titled: Carbon Management in the Tropical Peatlands.

II. His Careers / Experiences in Detail

Education Background

[1] **PhD**, Tropical Agriculture/ Soil Science (Kyoto Univ., Japan) 1988
[2] **Master**, Tropical Agriculture/Soil Science (Kyoto Univ., Japan) 1985
[3] ***Sarjana***[1]) in the field of Soil Science (IPB, Indonesia) 1974

Careers in Academic-Work

[1] **Visiting Professor** at Graduate School of Agriculture/Faculty of Agriculture, Kyoto University, Japan (one year) ………... 2013-2014
[2] **Visiting Research Scholar** at the Department of Palynology and Climate Dynamics, Georg-August-University of Gottingen, Germany …………………………………………………….. Jan-Feb 2013
[3] **Visiting Research Scholar** at the Center for Southeast Asian Studies, Kyoto University, Japan …………………………… Mar-Aug 2009
[4] **Dean** of the Faculty of Agriculture, IPB ……………………. 2003-2007
[5] **Professor** at the Dept. of Soil Science & Land Resource, IPB 2000-present
[6] **Vice Rector** of IPB ……………………………..…………… 1999-2003
[7] **Chairman** of the Dept. of Soil Science, IPB 1996-1999
[8] **Head** of the Laboratory of Soil Chemistry and Soil Fertility, Dept. of Soil Science, IPB …….. 1994-2002
[9] **Visiting Research Scholar** at the Center for Southeast Asian Studies, Kyoto University, Japan (one year) ……………… 1993-1994
[10] **Vice Dean** of the Faculty of Agriculture, IPB ………………. 1990-1993
[11] **Faculty Member** of the Dept. of Soil Science and Land Resource, IPB ………………………………………………... 1975-2000

Research Experiences

[1] Improving the productivity of lands on sustainable development of Telang's Integrated Autonomous-Region (KTM). Sponsored by Ministry of Man Power and Transmigration, RI in collaboration with IPB …………………………………………………... 2012
[2] Low carbon development strategies of Bengkalis District, Riau Province that reduces pressure on peatland ecosystems ………... 2011
[3] Management model for improving the productivity of lands on sustainable development of freshwater swamp areas based on local resources. Sponsored by Ministry of Agriculture, RI in

[1]) Education program for "***Sarjana*** degree" in IPB, in the period of 1968-1972, was six years.

collaboration with IPB (*KPP3T*) 2010-2011

[4] An adaptive socio-entropy system: Balancing economic endeavors and socio-ecological dynamics at a Palm Oil Plantation in Indonesian peatlands. Sponsored by the Toyota Foundation….. 2009-2010

[5] Increasing the synergetic role of *Brachiaria*'s root exudates, mycorrhiza, and compost of rice straw that was enriched by K for reducing Al content in soil and increasing cassava starch. Sponsored by Ministry of Agriculture, RI in collaboration with IPB (*KPP3T*) 2009-2010

[6] Study on the ecological and technological aspects of peat lands for sustainable agriculture. Sponsored by Agricultural Research & Development Agency, Ministry of Agriculture, the Republic of Indonesia (RI)... 2008-2012

[7] An Ecofarming model for sustainable farming on upland agricultural landuse areas. Sponsored by Ministry of Agriculture, RI in collaboration with IPB (*KPP3T*) 2008-2009

[8] Analysis of food-crop-based integrated farming system in the upland and lowland areas of South Cianjur. Sponsored by Ministry of Agriculture, R ....……………………….…… 2004-2007

[9] Improving peat productivity for paddy field by using mineral soil which has high content of Fe^{3+}. Sponsored by Ministry of Agriculture, RI... 2001-2004

[10] Stability condition and the processes of destabilization of the Indonesian tropical peat. Sponsored by URGE Project, DGHE Ministry of Education and Culture, RI…………………….…… 1999-2001

[11] Controlling toxic organic-acid reactivity for increasing the peat productivity. Sponsored by Ministry of Agriculture, RI............ 1995-1998

[12] Controlling methane emission from the Indonesian paddy soil. Sponsored by Osaka Gas Foundation, Japan. …………………. 1994-1997

[13] Ecological changes and landuse transformation in tidal swamplands of Sumatra. Sponsored by Toyota Foundation, Japan. …. 1989-1992

[14] Studies on peat in the coastal plains of Sumatra and Borneo (PhD Dissertation, Kyoto University). Sponsored by Ministry of Education and Culture, Japan……………………………….. 1985-1988

Work Experience in Extension

[1] Member of the Lead Authors of 2013 Supplement to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines For National Greenhouse Gas Inventories: Wetlands ..…………... 2011-2013

[2] Assessment of the Merauke Integrated Farming for Food and Energy (MIFFE) in Papua; sponsored by WWF …………………. 2010

[3] Assessment of tidal swamp lands in Sumatra for new settlements of transmigration; sponsored by Ministry of Public Works ……… 1975-1982

[4] Site Manager in order to assist the farmers in new settlements of transmigration of the Berbak Delta, Jambi in conducting soil cultivation for food and plantation crops; sponsored by Ministry of Public Works …………………………………………………. 1973-1974

Society/Organization Activities

[1] President of the Indonesian Peat Society…………………….. 2012-present

[2] President of the Kyoto Univ. Alumni (HAKU) in Indonesia… 2007-2009

[3] Secretary General of Agricultural Higher Education Forum in

Indonesia………………………………………………..…… 2005-2007

[4] Vice President of Int'l Society for Southeast-Asia Agricultural Sciences (ISSAAS)…………………………………………. 2004-2007

[5] President of the Indonesian Soil Science Society ……………… 2003-2007

[6] Vice President of the Indonesian Peat Society ………………… 2001-2005

[7] Secretary General of the Indonesian Soil Science Society……... 1999-2003

[8] Member of the Indonesian Peat Society………………………... 1988-present

[9] Member of the Indonesian Soil Science Society………………. 1975-present

Selected publication

[1] **Supiandi, S**., M. Setiari, T. Watanabe, S. Funakawa, U. Sudadi, and F. Agus. 2014. Estimating the relative contribution of root respiration and peat decomposition to the total CO_2 flux from peat soils at an oil palm plantation in Sumatra, Indonesia. J. Trop. Agri. (in press)

[2] **Supiandi, S**., S.D. Tarigan, Hariyadi, I. Las, F. Agus, Sukarman, P. Setyanto and Wahyunto. **2012**. Organic Carbon Storage and Management Strategies for reducing carbon emission from peatlands: Case study in oil palm plantation in West and Central Kalimantan, Indonesia. Pedologist 55(3):426-434.

[3] Hafif, B., S**. Supiandi**, I. Anas, A. Sutandi and Suyamto. **2012**. Impact of brachiaria, arbuscular mycorrhiza, and potassium enriched rice-straw-compost on aluminum, potassium and stability of acid soil aggregates. J. Agric. Sci. 13(1):27-34.

[4] Maswar, O. Haridjaja. **S. Supiandi**, and M. van Noordwijk. **2011**. Carbon loss from several landuse types on tropical peatland drainage (in Indonesia). J. Tanah dan Iklim 34:13-25.

[5**] Supiandi, S** and U. Sudadi. **2010**. Indonesian peatlands and their ecosystem unique: A science case for conservation and sound management. Proceedings the International Conference on Soil Fertility and Productivity – Differences of Efficiency of Soils for Land Uses, Expenditures and Returns held at Humboldt University, Berlin-Germany, March 17-20, 2010.

[6] Handayani, E.P., K. Idris., **S Supiandi**, S. Djuniwati, and M. van Noorwijk. **2010**.. Carbon dioxide (CO_2) emission of oil palm plantation on West Aceh Peat: The effects of various water table depths on CO_2 emission. *J. Tanah Trop*. Vol.15 No.3.

[7] Sudadi, U. **S. Supiandi**, A.Sutandi, and S. Saeni. **2008**. In situ inactivation of cadmium (Cd) pollution in arable soils using ameliorants snf fertilizers at rational dosage for crop cultivation (in Indonesian) ***J. Tanah Trop.*** 13(3):171-178..

[8] Nursyamsi, D., K. Idris, **S. Supiandi**, D.A. Rachim, and A. Sofyan. **2007**. Dominant soil characteristics that effect on available K at smectitic soils (in Indonesian) ***J. Tanah dan Iklim*** 26:13-28.

[9] Indriyati, L.T., **S. Supiandi**, L.K. Darusman, R. Situmorang, Sudarsono, and W.H. Sisworo. **2007**. Nitrogen transformation in flooded soil: Application of rice straw and rice straw composts and its effect on nitrogen uptake and acetylene reduction activity in rice plant rhizosphere (in Indonesian) ***J. Tanah dan Iklim*** 26:63-70.

[10] Subiksa, I.G.M., **S. Supiandi**, Sudarsono, and J.S. Adiningsih. **2006**. The relationship between the Q-I value of potassium with nutrient absorption and growth of maize (in Indonesian) ***J. Penel. Pert. Terapan*** 5(2):197-204.

[11] Muhammad, H. **S. Supiandi**, A. Rachim, and H. Adijuwana. **2005**. Transformation rate of sulfur to sulfate at three kinds of soil with the treatment of without and with organic matter (in Indonesian) ***J. Tanah dan Lingkungan*** 7(1):15-21.

[12] **Supiandi, S**. **2004**. Ecological issues of the Mega Rice Project: Case study of swampland development in Central Kalimantan. pp. 73-87. ***In*** Furukawa, H. *et al*. (eds.), *Destruction, Health, Development: Advancing Asian Paradigms*. Kyoto Univ. Press and Trans Pacific Press. 638p.

[13] Hartatik, W., K. Idris, **S. Supiandi**, S. Djuniwati, and J.S. Adiningsih. **2004**. Increasing the bounded-P in peat added by mineral materials and rock phosphate (in Indonesian) ***J. Tanah dan Lingkungan.*** 6(1):22-30.

[14] Pujiyanto, Sudarsono, A. Rachim, **S. Supiandi**, A. Sastiono, and J.B. Baon. **2003**. Influence of organic matter and kind of cover crops on the form of soil organic matter, the distribution of soil aggregate, and growth of cacao (in Indonesian). ***J. Tanah Trop.*** 17:75-87.

[15] Mario, M.D., and **S. Supiandi**. **2002**. The use of mineral soil enriched by materials containing higher of Fe^{3+} as ameliorant in order to increase the rice production and peat stability (in Indonesian). ***J. Agroteksos*** 2(1):35-45.

[16] **Supiandi, S**. **2001**. Increasing the productivity of the Indonesian tropical peat through controlling several toxic phenolic acids ***J. Agrivita***. 22:170-176.

[17] **Supiandi, S**. **2000**. Critical water content of the Center Kalimantan's peat in relation with irreversible drying (in Indonesian) ***J. Tanah Trop***. 11:21-30.

[18] **Supiandi, S**., and N.B.E. Sulistyono. **2000**. Studies on several inherent properties and behavior of peat: Losses of CO_2 and CH_4 through the processes of reduction-oxidation (in Indonesian). ***J. Tanah Trop***. 10:127-135.

[19] **Supiandi, S**., and Riwandi. 2000. The relationship between total iron with humification degree and derivative phenolic acids in peat of Jambi and Center Kalimantan (in Indonesian). ***J. Agrista***. 4(1):10-16.

[20] **Supiandi, S**. 1998. Several toxic phenolic acids in peat of Sumatra and Kalimantan (in Indonesian). *In*, ***Prosiding Seminar Nasional IV Kimia dalam Industri dan Lingkungan.***

[21] **Supiandi, S**. 1997. The use of selected cations for controlling toxic phenolic acids in peat (in Indonesian) ***J. Ilmu Pert***. 7(1):1-7.

[22] **Supiandi, S**., S. Dohong, and T. Prasetyo. 1997. Phenolic acids in Indonesian peat. pp. 289-292. ***In,*** Riley, J.O., and S.E. Page (eds.), *Biodiversity and Sustainability of Tropical Peatlands*. Smith Settle, UK.

[23] Husin, Y., D. Murdiyarso, M.A.K. Khalil, R.A. Rasmusen, M.J. Shearer **S. Supiandi**, A. Sunar, and H. Adijuwana. 1995. Methane flux from Indonesian wetland rice: The effect of water management and rice variety. ***Chemosphere*** 31(4):3153-3180.

[24] Kusmana, C., and **S. Supiandi**. 1992. An estimation of above ground tree biomass of mangrove forest in East Sumatra, Indonesia. ***Tropics*** 1(4):234-257.

[25] Kusmana, C., and **S. Supiandi**. 1991. Soil as a factor influencing mangrove forest community occurrence in Talidendang Besar, Riau. ***Media Komunikasi*** 3(3):49-56.

[26] **Supiandi, S**. 1990. Studies on the Holocene peat deposits in the coastal plains of Jambi, South Kalimantan, and Brunei: Research based on fossil pollen analysis (in Indonesian). ***Geol. Indon***. 13(1):37-61.

[27] Muhadiono, I., **S. Supiandi**, I. Mansjoer, and M.U. Garcia. 1990. Agroforestry technology: Rhizobium and endomycorrhizal infections in the root of *Albazia procera* (Roxb.) Benth., as biofertilizer for the future. ***Agroforestry and Tech***. 39:107-114 (Biotrop Spec. Publ.)

[28] **Supiandi, S**. 1990. Studies on peat in the coastal plains of Sumatra and Borneo: IV. A study of the floral composition of peat in the coastal plains of Brunei. ***Southeast Asian Studies*** 27(4): 461-484.

[29] **Supiandi, S**. 1989. Studies on peat in the coastal plains of Sumatra and Borneo: III. Micro-morphological study of peat in the coastal plains of Jambi, South Kalimantan, and Brunei. ***Southeast Asian Studies*** 27(3): 339-351.

[30] **Supiandi, S**., and B. Sumawinata. 1989. Studies on peat in the coastal plains of Sumatra and Borneo: II. The clay mineralogical composition of sediments in the coastal plains of Jambi and South Kalimantan. ***Southeast Asian Studies*** 27(1): 35-54.

[31] **Supiandi, S**. 1988. Studies on peat in the coastal plains of Sumatra and Borneo: I. Physiography and geomorphology of the coastal plains. ***Southeast Asian Studies*** 26(3): 308-335.

[32] **Supiandi, S**., and H. Furukawa. 1987. Stratigraphy and geomorphology of the coastal swampy lands in the lower Batang Hari river basin of Jambi, Sumatra, pp. 65-74. ***In***, Thiramongkol, N (ed.), *Proceedings of the Int'l Workshop on Economic Geology, Tectonic, Sedimentary Processes and Environment of the Quaternary in Southeast Asia*. Department of Geology, Chulalongkorn Univ.

[33] **Supiandi, S**., and H. Furukawa 1986. A study of floral composition of peat in the lower Batang Hari river basin of Jambi, Sumatra. ***Southeast Asian Studies*** 24(2):113-132.

[34] H. Furukawa, and **S. Supiandi**. 1985. Agricultural landscape in the lower Batang Hari: I. Stratigraphy and geomorphology of coastal swampy lands (written in Japanese). ***Tonan Ajia Kenkyu*** 23(1): 3-37.

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2005-2010 Ph.D., Wageningen University, Wageningen
Working on 1) spatial and temporal variability of greenhouse gas emissions in peatland ecosystems in the Netherlands, 2) the upscaling of fluxes based on regression models 3) improvement of measurement and upscaling techniques 4) estimates of total carbon balances in managed and unmanaged peat areas 5) Implementation of results in policy.

1997-2003 M.Sc. soil science, hydrology and meteorology, Wageningen University, Netherlands and Univ. of Saskatchewan, Canada
Thesis 1 and practical period: Carbon distribution and sediment redistribution in a Canadian pothole landscape
Thesis 2 : Management, Soil Structure and Organic Matter Dynamics in Dutch agricultural landscapes

1993-1997 Medical visual Techniques, Fontys Hogescholen, Eindhoven, Degree for X-ray technician

Relevant experiences in past 2 years
CEIC
2014-current: Exploring possibilities for peatland rewetting schemes under Goldstandard
2012-current: Associate expert Climate and Environment at Wetlands International, tasks include involvement as independent expert (reviewer) in the EU, UNFCCC, IPCC, EPA, RSB, RSPO and work related to REDD(+) activities and implementation.

2012-current. Expert reviewer of the IPCC Wetlands Supplement
2012-current. Various tasks related to life cycle analysis.
2013-current. Involvement in RSPO, including various tasks related to GHG emissions reporting, peatland conservation and rehabilitation, carbon sequestration options and carbon accounting, carbon and GHg emission monitoring, reviewer and (past) working group membership (peatland working group and emissions reduction working group).

Wetlands International Indonesia Programme, IND
2012-current. On behalf of Wetlands International part of a multi-disciplinary, scientific team of 12 people developing GHG emission and carbon sequestration methodologies (under VCS) for peatland conservation and restoration projects (for avoiding deforestation, forest degradation and peat soil degradation in tropical regions).

For RSPO/ Wetlands International Head Quarters, MAL/NL
2011-2013. Preparation of a scientific review on environmental and social impacts of oil palm cultivation on tropical peat. This report is commissioned by the Peatland Working Group (PLWG) of the RSPO and provides an independent review of available scientific information on impacts of the use of tropical peatlands for oil palm cultivation in Southeast Asia. The report provides recommendations for reducing negative impacts.

For RSPO/ Wetlands International Head Quarters, MAL/NL
2012-2013. Preparing a document on currently available methods for determining greenhouse gas emissions and carbon stocks from oil palm plantations and their surroundings in tropical peatlands. This report was commissioned by the peatland workgroup of the RSPO and provides insight in measuring, reporting and verifying carbon stocks and greenhouse gas emissions in tropical peatlands. The report presents gaps in knowledge, uncertainties and recommendations.

For Brinkmann Consultancy, NL
2011. Reviewing and helping to improve a (excel based) CIPO (Carbon Impact of Palm Oil)-tool that can be used to calculate the carbon footprint of palm oil production in a specific situation (e.g. on the level of an estate, a company, a region or a country), and can support the decision making processes. The tool focusses on the oil-palm-production-system. It includes the growing of palms, the processing of FFB's and potential land use change. It excludes transport, processing and use of CPO outside the the estate.

For Shelll , NL
2011. Assisting in preparing a document on wetlands and biofuels - impact of the global increase in biofuel use on the biodiversity, water and carbon resources of wetlands'. The purpose of this fact book is to support the development of criteria and standards for biofuels and their production, in order to produce fuels that are truly a sustainable alternative to fossil fuels. The focus of the document is on palm oil, rape seed and soya.

For Quantis/Epagma, FRA
2011-2012. Act as external reviewer of a Comparative life cycle assessment of peat and major growing media constituents.

Publications in scientific journals
Schrier-Uijl, A.P. et al (Biogeosciences Discussion, 2014, in preparation): Agricultural peatlands; towards a greenhouse gas sink.

Schrier-Uijl, A.P., Veraart, A.J., Leffelaar, P.A., Berendse, F., Veenendaal, E.M (2011). Release of CO2 and CH4 from lakes and drainage ditches in temperate wetlands. Biogeochemistry, doi:10.1007/s10533-010-9440-7.

Kroon, P.S., Schrier-Uijl, A.P., Hensen, A., Veenendaal., E.M., Jonker, H.J.J., (2010). Annual balances of CH4 and N2O from a managed fen meadow using eddy covariance flux measurements. Eur. J. Soil Sci.

Schrier-Uijl, A.P., Kroon, P.S., Hensen, A., Leffelaar, P.A., Berendse, F. & Veenendaal, E.M. (2009). Comparison of chamber and eddy covariance based CO2 and CH4 emission estimates in a heterogeneous grass ecosystem on peat, Agric. For. Meteorol., doi:10.1016/j.agrformet.2009.11.007.

Schrier-Uijl, A.P., Veenendaal, E.M., Leffelaar, P.A., van Huissteden, J.C., Berendse, F. (2010). Methane emissions in two drained peat agro-ecosystems with high and low agricultural intensity. Plant Soil, doi:10.1007/s11104-009-0180-1.

Jacobs, C.M.J., Jacobs, F.C., Bosveld, F.C., Hendriks, D.M.D., Hensen, A., Kroon, P.S., Moors, E.M., Nol, L., Schrier-Uijl, A.P. et al. (2007). Variability of annual CO2 exchange from Dutch grasslands. Biogeosciences, 4, pp. 803–816.

Veenendaal, E.M., Kolle, O., Leffelaar, P.S. Schrier-Uijl, A.P., Van Huissteden, J., Van Walsem, J., Möller, F. & Berends, F., (2007). CO2 exchange and carbon balance in two grassland sites on eutrophic drained peat soils. Biogeosciences, 4, pp. 1027-1040.

Bedard-Haughn, A., Jongbloed, F., Akkerman, J., Uijl, A., et al. (2006). The effects of erosional and management history on soil organic carbon stores in ephemeral wetlands of hummocky agricultural landscapes. Geoderma 135, pp. 296-306.

Pulleman, M.M., Six, J., Uijl, A, et al. (2005). Earthworms and management affect organic matter incorporation and microaggregate formation in agricultural soils. Applied Soil Ecology 29, 1, pp. 1-15.

Uijl, A., Didden, W., Marinissen, J. (2002). Earthworm activity and decomposition of C-14-labelled grass root systems. Biology and Fertility of Soil, 36, pp. 447-455.

Other publications

A.P. Schrier-Uijl et al, on behalf of the PLWG-RSPO and Wetlands International: Environmental and social impacts of oil palm cultivation on tropical peat in SE Asia – a scientific review (2013).

A.P. Schrier-Uijl et al, on behalf of the PLWG-RSPO and Wetlands International : Available methods for determining greenhouse gas emissions and carbon stocks from oil palm plantations and their surroundings in tropical peatlands (2013).

A.P. Schrier-Uijl, P.S. Kroon, D.M.D. Hendriks, P. A. Leffelaar, F. Berendse and E.M. Veenendaal (2009): How the methane balance changes if agricultural peatlands are transformed into wetland nature and how this transformation influences the total carbon balance – contribution to Cost Action ES0804. In: Water in a Changing Climate, 6th international Scientific Conference on the Global Energy and Water Cycle and 2nd Integrated Land Ecocystem – Atmosphere Processes Study (iLEAPS) Science Conference. Australia, Melbourne.

APPENDIX D
MATERIALS PROVIDED TO THE PEER-REVIEW PANEL

Technical Work Product for Peer Review:
Emission Factor for Tropical Peatlands Drained for Palm Oil Cultivation
May 15, 2014

Introduction:

In January 2012, the U.S. Environmental Protection Agency (EPA) released a Notice of Data Availability Concerning Renewable Fuels Produced from Palm Oil under the Renewable Fuel Standard (RFS) Program (the "January 2012 NODA").[1] As part of the January 2012 NODA, the EPA sought comment on its analysis of the lifecycle greenhouse gas (GHG) emissions associated with palm oil-based biodiesel and renewable diesel, which estimated that these biofuels reduce GHG emissions by 17% and 11%, respectively, compared to the petroleum diesel baseline. Based on the Agency's analysis, these biofuels would not meet the statutory 20% GHG emissions reduction threshold and thus would not qualify for the RFS program, with limited exceptions.[2] One of the major sources of GHG emissions in the EPA's analysis for the January 2012 NODA was emissions from development of palm oil plantations on tropical peat soils, which requires the peatlands to be drained in advance of plantation establishment. In this peer review EPA is requesting scientific input about the Agency's assessment of the average annual GHG emissions from tropical peatlands over the first thirty years resulting from the draining of the land for production of palm oil (the "peat soil emission factor") for use in EPA's lifecycle GHG analysis of palm oil-based biofuels.

Background:

EPA's analysis of palm oil-based biofuels for the January 2012 NODA estimated significant indirect emissions from land use changes, such as emissions resulting from drained organic peat soils preceding the development of new palm oil plantations. To estimate such emissions, the Agency projected the extent (area in hectares) by which peat soil drainage increased in a scenario with more palm oil biofuel production compared to a baseline scenario. This estimated area was multiplied by a peat soil emission factor, a coefficient quantifying the emissions in tonnes of carbon dioxide (CO_2) per hectare (ha) of drained peat soil, to obtain the total GHG emissions from the expansion of peat soil drainage.

For the January 2012 NODA, EPA used a peat soil emission factor of 95 tonnes of carbon dioxide-equivalent[3] per hectare per year (tCO_2e/ha/yr) over thirty years.[4] EPA chose this emission factor after a thorough survey of the literature. We are conducting further review of the scientific literature to determine whether new information warrants revisiting our choice of emission factor. Considering the

[1] U.S. EPA. 2012. Notice of Data Availability Concerning Renewable Fuels Produced from Palm Oil under the RFS Program. January 27, 2012. 77 FR 4300.
[2] A baseline volume of fuel produced from facilities that commenced construction prior to December 20, 2007 may qualify as renewable fuel even if it fails to achieve 20% greenhouse gas reduction (40 CFR 80.1403).
[3] EPA's emission factor for drained tropical peat soil only includes heterotrophic respiration of CO_2. Carbon stock changes from clearing standing vegetation such as trees, roots and stumps were considered separately.
[4] Based on extensive public comment and peer review, in the March 26, 2010, RFS final rule (75 FR 14669) EPA decided to annualize land use change GHG emissions over 30 years for purposes of biofuel lifecycle GHG assessment.

comments received on the NODA and new articles published or provided to EPA, our objective is to use a peat soil emission factor that meets the following criteria:

1. Estimates the impacts of tropical peat soil drainage on CO_2 emissions from heterotrophic respiration of drained peat soils, excluding such emissions from root respiration.
2. Includes all significant GHG emissions impacts resulting from drainage over a 30-year period following the drainage event, including any initial pulse of GHGs following drainage and loss of dissolved organic carbon (DOC) in drainage waters.
3. Represents average emissions from the development of palm oil plantations on tropical peat soil across Southeast Asia.

The first criterion is important because several studies that EPA has reviewed did not attempt to exclude CO_2 emissions from root respiration. Respiration from roots must be excluded from the peat soil emission factor because they are not the result of peat soil drainage, i.e., they likely would have occurred anyway. The second criterion is important because EPA's analysis seeks to estimate all significant emissions, including significant indirect emissions from land use changes. Many of the studies reviewed, particularly studies using a flux-chamber measurement technique, did not estimate the initial pulse of emissions immediately following drainage or the impacts of DOC. The literature suggests that such emissions sources are significant, and therefore they should be included in the emission factor used in EPA's assessment. The third criterion is based on the fact that EPA seeks to use one peat soil emission factor to estimate average emissions from peat soil drainage across Southeast Asia, particularly Indonesia and Malaysia. Based on our review of the literature, we believe that the present science and data available are not sufficient to justify, for the purposes of EPA's analysis, the use of different peat soil emission factors for different regions or peat soil types. Thus, we are working to develop an emission factor that represents average emissions impacts considering the average climatic, geophysical and other conditions found in tropical peatlands.

Technical Analysis:

Table 1, below, outlines the major studies EPA considered in choosing an emission factor for the January 2012 NODA, as well as studies that were referenced by commenters. The table indicates how well each study meets some of EPA's criteria and provides summary information about the spatial and temporal extent of measurements for the studies.

Based on EPA's review of the public comments[5] and relevant literature, the Agency believes that the peat soil emission factor of 95 tCO_2e/ha/yr, based on Hooijer et al. (2012), best meets our three criteria and is thus the most appropriate emission factor for EPA's purposes, for the following reasons.

Criterion #1: Estimates the impacts of tropical peat soil drainage on CO_2 emissions from heterotrophic respiration of drained peat soils, excluding such emissions from root respiration.

- The subsidence-based approach used in Hooijer et al. (2012) excludes respiration from roots, which is difficult to do in flux-based studies.

[5] Public comments on the January 2012 NODA are available at: http://www.regulations.gov/#!docketDetail;D=EPA-HQ-OAR-2011-0542

Criterion #2: Includes all significant GHG emissions impacts resulting from drainage over a 30-year period following the drainage event, including any initial pulse of GHGs following drainage and loss of dissolved organic carbon (DOC) in drainage waters.

- Hooijer et al. (2012) was the only study to integrate carbon losses from the period of time immediately following drainage. The authors did so by measuring the impacts from the first years following drainage, when emissions are known to be highest. In contrast, flux chamber-based measurements can only measure emissions at the moment of measurement. The flux-based studies that EPA reviewed took measurements over a relatively short period of time (generally weeks or months) many years after the initial drainage.

  The subsidence-based approach includes emissions from respiration of peat-derived DOC, which may be significant.[6] In contrast, the flux approach does not capture loss of DOC because it only measures gases respired into the flux chamber, whereas DOC losses lead to offsite CO_2 emissions.

Criterion #3: Represents average emissions from the development of palm oil plantations on drained tropical peat soil across Southeast Asia.

- Hooijer et al. (2012) evaluated the largest number of sampling locations of any study (>200 total, with 167 under palm oil or acacia), with the exception of one newer study that has other limitations.[7]
- The study provided good temporal coverage of emissions, and its measurement of subsidence under acacia (2 years for most locations, 8 years for some) was among the longest-term studies published. (Three other studies evaluated longer sets of data, but these studies are less appropriate based on the EPA's criteria.[8]) The measurements on palm oil were conducted over one year, similar to many other studies, but measurements were made more frequently (every two weeks).
- The study was conducted on deep, organic-rich peat with very low mineral content that is typical of peatlands in Southeast Asia that have been converted to palm oil.
- The study was carried out in a region of central Sumatra that receives intermediate amounts of rainfall compared to other places in Southeast Asia, suggesting that these locations should have

[6] See, for example, Moore, S., C.D. Evans, S.E. Page, M.H. Garnett, T.G. Jones, C. Freeman, A. Hooijer, A.J. Wiltshire, S.H. Limin, and V. Gauci (2013) Deep instability of deforested tropical peatlands revealed by fluvial organic carbon fluxes. Nature 493, 660-664.

[7] Couwenberg and Hooijer (2013) studied nine more locations than did Hooijer et al. (2012), but this study did not consider the original emissions pulse (see criterion #2 above) following drainage and thus is not as appropriate for EPA's purposes.

[8] Couwenberg and Hooijer (2013) extended the measurements included in Hooijer et al. (2012) out to three years for both palm oil and acacia and found similar emissions but did not constrain the initial emissions pulse. Wösten et al. (1997) measured subsidence over several decades; however, this study did not measure bulk density or carbon content and thus their emissions estimates are based on many assumptions. Othman et al. (2011) measured subsidence over 8 years; however, they used a relationship from Hooijer et al. (2010) to estimate emissions from subsidence.

intermediate levels of soil moisture and thus emissions representative of the average in the region.[9]

Other support for the use of the emission factor value from Hooijer et al. (2012):

- The emissions determined by the study agreed very well with flux chamber-based measurements made on one of the same locations published in Jauhiainen et al. (2012). As such, the emission factor was supported by two distinct measurement techniques. Additionally, a new paper by Couwenberg and Hooijer (2013) also confirms the long-term (>5 years after drainage) emissions estimates by extending measurement of subsidence in these locations out to three years. This last study avoided the use of estimates of the percent of subsidence due to oxidation (versus physical processes) and thus removed one source of uncertainty in the Hooijer et al. (2012) emission factor.
- The emission factor of 95 tCO_2e/ha/yr was recommended for a 30-year time period by Page et al. (2011) in their review of the literature on peat surface GHG emissions from palm oil plantations in Southeast Asia.
- The study was peer reviewed and published in a respected scientific journal.

EPA recognizes that the emission factor based on Hooijer et al. (2012) is among the highest published, but we believe this study is still the most appropriate for use in our lifecycle analysis of palm oil biofuels. There are legitimate reasons for this emission factor to be among the highest published because Hooijer et al. (2012) was the only study to consider two factors that we believe should be included as part of EPA's analysis. Specifically, as stated above, this study was the only one to include the pulse of emissions during the first years following drainage and was one of the only studies to include GHGs emitted via a DOC pathway.

Furthermore, we believe that although this emission factor is among the highest published, it is still likely a conservative representation of the net effect on GHG emissions from draining peat soils since it does not include emissions due to burning of drained peat during land clearing or via accidental fires. While such emissions are episodic and thus difficult to estimate, peat fires have been estimated to emit around 1000 tCO_2/ha per event, with very large variability (Couwenberg et al., 2010). The emission factor based on Hooijer et al. (2012) also does not consider emissions that may occur on inadvertently drained peatlands adjacent to drained palm oil plantations. Taken altogether, our qualitative assessment of areas of uncertainty suggests that, even though this estimate falls at the high end of published values, it is more likely an underestimate than an overestimate of the total GHG emissions impact associated with draining tropical peatlands for palm oil development.

Because this emission factor is an important piece of our lifecycle GHG emissions analysis, we are seeking additional input from the scientific community about whether the emission factor used by the EPA in the January 2012 NODA is the most appropriate for our final assessment.

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[9] Based on data from NASA's Tropical Rainfall Measuring Mission (TRMM) Satellite, http://pmm.nasa.gov/TRMM/TRMM-based-climatology

Literature consulted:

Agus, F., Handayani, E., van Noordwijk, M., Idris, K., & Sabiham, S. (2010). Root respiration interferes with peat CO_2 emission measurement. In Proceedings of the *19th World Congress of Soil Science, Soil Solutions for a Changing World*. Brisbane, Australia. http://www.iuss.org/19th%20WCSS/Symposium/pdf/0739.pdf

Agus, F., Wahyunto, Dariah, A., Runtunuwu, E., Susanti, E. & Supriatna, W. (2012) Emission reduction options for peatlands in the Kubu Raya and Pontianak Districts, West Kalimantan, Indonesia. *Journal of Palm oil Research*, 24, 1378-1387.

Agus, F., Henson, I.E., Sahardjo, B.H., Harris, N., van Noordwijk, M. & Killeen, T.J. (2013). Review of emission factors for assessment of CO2 emission from land use change to oil palm in Southeast Asia. *In* T.J. Killeen & J. Goon (eds.) *Reports from the Technical Panels of the Second RSPO GHG Working Group*, Roundtable on Sustainable Palm Oil – RSPO, Kuala Lumpur.

Ali, M., Taylor, D., & Inubushi, K. (2006) Effects of environmental variations on CO_2 efflux from a tropical peatland in eastern Sumatra. *Wetlands*, 26,612-618.

Couwenberg, J., Dommain, R. & Joosten, H. (2010). Greenhouse gas fluxes from tropical peatlands in south-east Asia. *Global Change Biology,* 16, 1715-1732.

Couwenberg, J. & Hooijer, A. (2013) Towards robust subsidence-based soil carbon emission factors for peat soils in south-east Asia, with special reference to palm oil plantations. *Mires and Peat*, 12, 1-13.

Dariah, A., Marwanto, S. & Agus, F. (2013) Root- and peat-based CO2 emissions from oil palm plantations, *Mitigation and Adaptation Strategies for Global Change*, doi: 10.1007/s11027-013-9515-6

Furukawa, Y., Inubushi, K., Ali, M., Itang, A.M. and Tsuruta, H. (2005) Effect of changing groundwater levels caused by land-use changes on greenhouse gas fluxes from tropical peat lands. *Nutrient Cycling in Agroecosystems*, 71, 81-91.

Hirano, T., Segah, H., Kusin, K., Limin, S., Takahashi, H., and Osaki, M. (2012) Effects of disturbances on the carbon balance of tropical peat swamp forests. *Global Change Biology*, doi: 10.1111/j.1365-2486.2012.02793.x

Hooijer, A., Page, S., Canadell, J.G., Silvius, M., Kwadijk, J., Wösten, H. & Jauhiainen, J. (2010) Current and future CO_2 emissions from drained peatlands in Southeast Asia. *Biogeosciences*, 7, 1505-1514.

Hooijer, A., Page, S. E., Jauhiainen, J., Lee, W. A., Idris, A., & Anshari, G. (2012) Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences, 9,* 1053-1071*.*

Husnain, Agus, F., Wigena, I.P., Dariah, A. & Marwanto, S. (in preparation) Peat CO_2 emissions from several land use types in Indonesia. Manuscript provided to EPA by the Government of Indonesia.

Inubushi, K., Furukawa, Y., Hadi, A., Purnomo, E. & Tsuruta, H. (2003) Seasonal changes of CO_2, CH_4, and N_2O fluxes in relation to land-use change in tropical peatlands located in coastal areas of South Kalimantan. *Chemosphere*, 52, 603-608.

IPCC (2014) 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. and Troxler, T.G. (eds). Published: IPCC, Switzerland

Jauhiainen, J., Heikkinen, J., Martikainen, P., & Vasander, H. (2001) CO_2 and CH_4 fluxes in pristine peat swamp forest and peatland converted to agriculture in Central Kalimantan, Indonesia. *International Peat Journal*, 11, 43-49.

Jauhiainen, J., Hooijer, A., & Page, S. E. (2012). Carbon dioxide emissions from an *Acacia* plantation on peatland in Sumatra, Indonesia. *Biogeosciences*, 9, 617-630.

Kool, D.M., Buurman, P. & Hoekman, D.H. (2006) Oxidation and compaction of a collapsed peat dome in Central Kalimantan. *Geoderma*, 137, 217-225.

Marwanto, S. & Agus, F. (2013) Is CO_2 flux from palm oil plantations on peatland controlled by water table, soil moisture, day/night rhythm and/or temperature. *Mitigation and Adaptation Strategies for Global Change*, doi: 10.1007/s11027-013-9518-3

Melling, L., Hatano, R. & Goh, K.J. (2005). Soil CO_2 flux from three ecosystems in tropical peatland of Sarawak, Malaysia. *Tellus*, 57B, 1-11.

Melling, L., Goh, K.J., Beauvais, C. & Hatano, R. (2007). Carbon flow and budget in a young mature palm oil agroecosystem on deep tropical peat. *Proceedings of the International Symposium and Workshop on Tropical Peatland*, Yogyakarta, 27-29 August 2007.

Murayama, S. & Bakar, Z.A. (1996). Decomposition of Tropical Peat Soils. *Japan Agricultural Research Quarterly*, 30, 153-158.

Othman, H., Mohammed, A.T., Darus, F.M., Harun, M.H. & Zambri, M.P. (2011) Best management practices for palm oil cultivation on peat: Ground water-table maintenance in relation to peat subsidence and estimateion of CO_2 emissions at Sessang, Sarawak. *Journal of Palm oil Research*, 23, 1078-1086.

Page, S.E., Morrison, R., Malins, C., Hooijer, A., Rieley, J.O., & Jauhiainen, J. (2011) Review of peat surface greenhouse gas emissions from palm oil plantations in Southeast Asia. International Council on Clean Transportation (ICCT) White Paper Number 15, Indirect Effects of Biofuel Production Series.

Setiawan, B.I. (unpublished) Study by Bogor Agricultural University. Study is preliminary so a manuscript was unavailable, but the study was cited in comments by Bogor Agricultural University.

Setyanto, P., Susilawati, H.L., Rahutomo, S. & Erningpraja, D.L. (2010) CO_2 emission from peat under palm oil plantation. *International Palm oil Conference*, 1-3 June 2010, Yogyakarta, Indonesia.

U.S. EPA. 2012. Notice of Data Availability Concerning Renewable Fuels Produced from Palm Oil under the RFS Program. Federal Register, Vol. 77, No. 18, p. 4300, January 27, 2012.

Wösten, J.M.H., Ismail, A.B. & van Wijk, A.L.M. (1997). Peat subsidence and its practical implications: A case study in Malaysia. *Geoderma*, 78, 25-36.

Table 1. Outline of studies consulted. The study used by EPA is in bold, and the studies most frequently recommended by commenters are italicized.[10]

Study	Method	Peer Reviewed?	Land Use?	Info on Drainage Depth?	Info on Drainage Time?	Heterotrophic Respiration?	Loss to DOC?	Initial Pulse?	# of Locations	Years Measured	Measurement Frequency
Murayama & Bakar (1996)	Flux	Yes	OP+						<10	<1	Once
Jauhiainen et al. (2001)	Flux	Yes	Ag	Yes	Yes				20-49		Periodic[a] (>Monthly)
Inubushi et al. (2003)	Flux	Yes	Ag/F	Yes					<10	1	~Monthly
Furukawa et al. (2005)	Flux	Yes	Ag/F	Yes	Yes				<10	1	Monthly
Melling et al. (2005)	*Flux*	*Yes*	*OP/F+*	*Yes*	*Yes*[b]				*<10*	*1*	*Monthly*
Ali et al. (2006)	Flux	Yes	Ag/F	Yes					10-19	<1	>Monthly
Melling et al. (2007)	Flux		OP		Yes[b]	Yes			<10	1	Monthly
Agus et al. (2010)	Flux	?	OP		Yes[b]				<10	<1	<Monthly
Setyanto et al. (2010)	Flux	?	OP/F	Yes	Yes[b]	Yes			10-19	1	<Monthly
Jauhiainen et al. (2012)	Flux	Yes	Ac	Yes	Yes	Yes			~100[c]	2	Monthly
Marwanto & Agus (2013)	Flux	Yes	OP	Yes	Yes[b]	Yes			20-49	1	Periodic[a] (>Monthly)
Dariah et al. (2013)	Flux	Yes	OP	Yes	Yes[b]	Yes			~50[c]	1	Periodic[a] (>Monthly)
Husnain et al.	Flux		OP	Yes	Yes[b]	Yes			20-49[c,d]	1	Periodic[a]

[10] The studies listed in Table 1 include new and previously considered studies mentioned in comments to EPA, discussed in review papers on this topic or provided to EPA by stakeholders. The table only includes studies that focused on estimating an emission factor based on experimental data via primary research or meta-analysis of primary studies. The table excludes a preliminary study mentioned in a comment by Bogar Agricultural University (Setiawan et al., unpublished) because a manuscript describing the study was not yet available, and several papers provided to EPA that did not derive a new peat soil emission factor (e.g., Agus et al., 2012; Hirano et al., 2012). EPA also considered Kool et al. (2006), but because this study focused on the rapid collapse of a peat dome (i.e., over several months), rather than the long-term subsidence of peats (i.e., over many decades), we do not consider these results relevant to EPA's purposes.

Study	Method	Peer Reviewed?	Land Use?	Info on Drainage Depth?	Info on Drainage Time?	Heterotrophic Respiration?	Loss to DOC?	Initial Pulse?	# of Locations	Years Measured	Measurement Frequency
(in prep)											(>Monthly)
Wösten et al. (1997)	Subsid.	Yes	?		Yes	Yes	Yes		10-19[e]	21	<Monthly
Othman et al. (2011)	Subsid.	Yes	OP	Yes	Yes	Yes	Yes		20-49	8	<Monthly
Hooijer et al. (2012)	**Subsid.**	**Yes**	**OP/Ac**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**>100**	**2-8 (Ac), 1 (OP)**	**? Monthly (Ac) > Monthly (OP)**
Couwenberg & Hooijer (2013)	Subsid.	Yes	OP/Ac	Yes	Yes	Yes	Yes		>100	3	Monthly (Ac), >Monthly (OP)
Hooijer et al. (2010)	Meta	Yes	Many	Yes	Yes?				20-49	Variable	
Couwenberg et al. (2010)	Meta	Yes	Many	Yes	Yes	Yes	Yes		20-49	Variable	
Agus et al. (2013)	*Meta*	Yes	*Many*	*Yes?*	*Yes?*	*Yes*			*20-49*	*Variable*	
IPCC (2014)	Meta	Yes	OP	Yes	Yes	Yes	Yes	No	>100[f]	Variable	

Notes:

Method. Flux = flux chamber method used, Subsid. = subsidence method used, Meta = meta-analysis of other studies.
Peer Reviewed. Yes = published in peer reviewed journal, Blank = not published in peer reviewed journal, ? = uncertainty regarding peer review status.
Land Use. Land use at site during study period. OP = palm oil, Ag = agricultural, Ac = acacia, F = forest, + = additional land uses.
Info on Drainage Depth. Indicates whether the study discussed drainage depth at the site.
Info on Drainage Time. Indicates whether the study discussed when drainage occurred relative to the study period.
Heterotrophic Respiration. Indicates whether the study attempted to isolate heterotrophic respiration from peat soil, e.g., by excluding root respiration.
Loss to DOC. Indicates whether the study captured emissions related to losses via DOC.
Initial Pulse. Indicates whether the study captured the initial pulse of respiration following drainage.
# of Locations. Number of sites sampled, including replicates at the same location. Grouped into bins for comparison.
Years Measured. Length of study period. Grouped into bins for comparison.
Measurement Frequency. Indicates how often measurements were taken. Grouped into bins for comparison.
[a] Emissions were measured intensively for several periods of time per year, e.g. weekly for one month, every third month. Overall, the number of sampling times per year is greater than 12.
[b] The paper provided information on plantation age but not explicitly on time since drainage.
[c] Only includes chambers used to estimate heterotrophic respiration.
[d] Only includes that part of the study that was not published in other papers. Number of locations was not clear from manuscript; number is an estimate.

[e] This study appears to have measured more locations, but only 17 were mentioned in the publication.
[f] Number of locations is an estimate based on references cited by this study.

Charge Questions for Peer Review:
Emission Factor for Tropical Peatlands Drained for Oil Palm Cultivation
May 15, 2014

Instructions:
Please review the attached Technical Work Product (TWP) and respond to the charge questions provided below. We ask that you organize your responses based on the structure of the charge questions provided. Please provide detailed explanations for all responses and provide citations as appropriate.

Charge Questions:

1. **Overarching charge question**: Given the three criteria outlined in the TWP and the estimates available in the literature, did the U.S. Environmental Protection Agency (EPA) choose the most appropriate value for the peat soil emission factor? If not, please provide a recommendation on the most appropriate peat soil emission factor to use in EPA's analysis, with a detailed explanation.

2. **Potential adjustment of emission factor from Hooijer et al. (2012):** Some commenters have raised questions about particular values used in the Hooijer et al. (2012) study (e.g., organic carbon content and peat bulk density). Would you recommend that EPA use the overall approach and data published in Hooijer et al. (2012) but use a different value for: (a) organic carbon content, (b) peat bulk density, (c) the percent of subsidence due to oxidation, or (d) another parameter (please specify)? Please explain your recommendation and provide supporting documentation.

3. **Directionality of estimate:** EPA recognizes that the Hooijer et al. (2012) study that forms the foundation of our estimate of peat soil emissions was conducted under specific circumstances. For example, it was conducted in a limited number of plantations on the island of Sumatra. For the reasons listed in the TWP, we believe this is the best available estimate of peat soil emissions, but we recognize that numerous factors could cause this estimate to be higher or lower than the average emission factor for peat soils drained for oil palm across Southeast Asia. Please discuss whether the emission factor value used by EPA (95 tCO_2e/ha/yr) is likely to overestimate, underestimate (and if so by how much) or provide a plausible estimate of average greenhouse gas (GHG) emissions from peat soil drainage for oil palm across Southeast Asia. In particular, please discuss whether the following factors are likely to make EPA's emission factor an overestimate or an underestimate:

    a. Variation in the type of peat soil (mineral content, carbon content, depth, extent of degradation, etc).

    b. Precipitation regime (annual rainfall, timing of rainfall, etc).

    c. Differing water management practices at plantations.

    d. Different types of plantations (e.g., oil palm versus acacia).

e. The approach used by Hooijer et al. (2012) to estimate emissions during the first five years after drainage.

f. Omission of methane and nitrous oxide emissions.

g. Omission of emissions due to fire. (As discussed in the TWP, omission of this factor will cause EPA's emission factor to underestimate emissions, but we welcome comments about how large this underestimation may be.)

h. Omission of incidentally drained peat swamps adjoining the plantations.

4. **Intergovernmental Panel on Climate Change (IPCC) report:** IPCC (2014) lists a Tier 1 emission factor of 40 tCO_2/ha/year for tropical drained oil palm plantations. This value does not include emissions for the first 6 years after drainage. However, studies have shown that a pulse of higher emissions occurs right after drainage. The IPCC report also gives a default DOC emission factor of 3 tCO_2/ha/yr. In addition, the IPCC gives guidance on quantifying emissions from fires. The report gives a default emission factor of 1701 gCO_2/(kg dry matter burned) for tropical organic soil and a default dry matter consumption value of 155 t/ha for prescribed fires in the tropics.[1]

   a. Would it be appropriate for EPA to use the IPCC Tier 1 default emission factor of 40 tCO_2/ha/year, or is it scientifically justified to use a different number based on more detailed information?

   b. Should the emission factor that EPA uses include the emissions pulse that occurs in the first several years immediately following drainage?

   c. Should EPA include DOC and fire emission factors in the overall emission factor? If so, are the IPCC emission factors appropriate to use, or are there better estimates for EPA's purpose?

   d. There are also erosion losses of particulate organic carbon (POC) and waterborne transport of dissolved inorganic carbon (primarily dissolved CO_2) derived from autotrophic and heterotrophic respiration within the organic soil. The IPCC concluded that at present the science and available data are not sufficient to provide guidance on CO_2 emissions or removals associated with these waterborne carbon fluxes. Do you agree that the science on these factors is not sufficient for EPA to consider losses of POC and dissolved inorganic carbon in its peat soil emission factor?

5. Additional input: Please provide any additional scientific information that you believe the EPA should consider regarding the Agency's assessment of the average annual GHG emissions from draining tropical peatlands for palm oil cultivation for use in EPA's lifecycle GHG analysis of palm oil-based biofuels.

[1] Putting these factors together yields 264 tCO2 per ha of prescribed burning.

APPENDIX E
PEER-REVIEW RESPONSES

Peer Review Response from Dr. Scott Bridgham, University of Oregon

Emission Factor for Tropical Peatlands Drained for Oil Palm Cultivation

1. Overarching charge question

The EPA used the soil emission factor for conversion of tropical peatlands to oil palm (OP) cultivation from Hooijer et al. (2012). I thoroughly reviewed this paper, as well as a number of other estimates of soil CO_2 emissions from drainage of peatlands in SE Asia. I am also quite familiar with the methods described in these papers for estimating soil CO_2 emissions. Based upon my best professional judgment, the Hooijer et al. (2012) paper is the best estimate of soil CO_2 emissions from tropical peatlands converted to OP cultivation, so I concur with the EPA's decision on this matter.

My assessment is based upon the following reasons. Hooijer et al. (2012) included 218 locations monitored over multiple time points from one to three years, which more than doubled the extant dataset in Southeast Asia. The analysis was done very carefully, separating out the biological oxidation component of subsidence from the physical components, with the latter not producing CO_2 emissions. They also captured the initial rapid flush of soil respiration after conversion to OP, which is rare in these types of studies. Bulk density was measured very carefully in this study using excavated soil pits (although a literature value for soil carbon content was used). The subsidence methodology is based upon minimal assumptions and only requires estimation of subsidence, consolidation and compaction, and soil carbon content within a peatland. A carefully done soil respiration study that separated the autotrophic and heterotrophic components of soil respiration at the same sites (Jauhiainen et al. 2012) gave essentially the same values as the subsidence method over the time period of measurement.

A number of studies have been published using chamber-based methods that estimate substantially lower soil CO_2 emissions from OP plantations (reviewed in Page et al. 2011a). Chamber-based estimates of soil respiration are inherently difficult to scale up to multi-year estimates of a soil emission factor at a landscape scale. Maybe most importantly, most estimates include respiration of live roots, and this is an unknown or poorly constrained portion of total soil respiration. Methods of isolating heterotrophic soil respiration such as trenching likely lead to large artifacts in the data that are difficult-to-impossible to quantify. Additionally, most soil respiration estimates in tropical OP plantations occurred only during a limited period of the day, were infrequent over the year, and were done for no more than one year (and often less). Also, typically only a few locations were measured. So essentially a few dozens of heterogeneous (and potentially biased) hourly flux measurements were upscaled to years and large landscapes, with all of the inherent limitations in such an exercise. Consequently, I have little faith in such estimates.

Other studies give similar rates of subsidence after the rapid consolidation phase early after drainage, supporting the results in this study (see review in Page et al. 2013). Couwenberg and Hooijer (2013) supplemented the sampling locations in Hooijer et al. (2012), added additional years of observation, and used a different subsidence-based technique to estimate the soil emission factor. The CO_2 emission estimates more than five years after drainage are very similar (68 vs. 66 CO_{2eq} ha^{-1} yr^{-1}) between the two studies, adding further confidence in the results of Hooijer et al. (2012).

2. Potential adjustment of emission factor from Hooijer et al. (2012)

The largest limitation to the Hooijer et al. (2012) study was that it was geographically limited, if intensively sampled within that area. As noted above, their long-term subsidence values appear to be very reasonable compared to other studies. Having taken many bulk density measurements in peat myself, I am impressed by the care they took in sampling bulk density with their deep soil pits. Hooijer et al. (2012) do a reasonable job of estimating the effect of bulk density and soil C estimates from the literature, and show that the effect on their estimates is small. If anything, their bulk density estimates are lower than many published values (e.g., Page et al. 2011b), and using higher initial bulk density measurements would only increase their soil CO_2 emission factor.

Given the straight-forwardness of the approach used in Hooijer et al. (2012) and the high quality of their data, there is no reason to believe that their calculated percent of subsidence due to oxidation is not correct.

3. Directionality of estimate

Overall, it is my impression from reading the appropriate scientific literature that the sites used by Hooijer et al. (2012) are relatively representative of SE Asian peatlands, and also of those areas that are converted into OP. Sumatra originally had 45% of all peatland swamp forest area in SE Asia (Schrier-Uijl et al. 2013), and it is an area of intensive conversion of those peatlands to OP (Page et al. 2011a).

a. *Variation in the type of peat soil (mineral content, carbon content, depth, extent of degradation, etc.).*

It is likely that mineral content of peatlands will affect soil oxidation rates upon drainage, although I am uncertain of the directionality of that effect. The carbon content is a direct part of the estimate of soil CO_2 emissions using the subsidence technique, so the effect of variation in that parameter is straight forward to estimate (they do so in Hooijer et al. 2012). The major effect of peat depth (unless very shallow) will likely be in the absolute amount of peat that is available for oxidation before water-table control is no longer effective (conceptually illustrated in Fig. 6 of Page et al. 2011a). The extent of peat degradation will affect both bulk density and the amount of labile carbon available for oxidation, as illustrated by the decrease in oxidation over time after drainage. Increases in soil pH will also increase decomposition rates of soil organic matter (Ye et al. 2012). However, most SE Asian peatlands have deep, acidic, woody peats and are ombrotrophic (Page et al. 2011a; Schrier-Uijl et al. 2013), and thus they will likely resemble reasonably closely those studied by Hooijer et al. (2012).

b. *Precipitation regime (annual rainfall, timing of rainfall, etc.).*

Increasing precipitation and the evenness of that precipitation will be important controls over the regional water table level, and thus the effectiveness of drainage. This should affect soil CO_2 emissions rate from OP plantations. However to my knowledge, the climate of Sumatra is not substantially different than other areas of high density of OP plantations on peat.

c. *Differing water management practices at plantations.*

A number of studies (e.g., Wösten et al. 1997; Couwenberg et al. 2010; Hooijer et al. 2010) demonstrate a substantial effect of drainage level on soil subsidence and soil CO_2 emissions. Interestingly, this water table effect was not observed in Hooijer et al. (2013) in OP plantations, which they ascribed to a nitrogen fertilization effect. To my knowledge, the average water table depth in the sites studied by Hooijer et al. (2012) is quite representative of OP plantations.

d. *Different types of plantations (e.g., oil palm versus acacia).*

Soil CO_2 emissions do not appear to be very different between these two land-use types if drainage is similar.

e. The approach used by Hooijer et al. (2012) to estimate emissions during the first five years after drainage.

I have confidence in the approach used by Hooijer et al. (2012) to estimate emissions during the first five years after drainage. In fact, it is based upon a very minimal set of assumptions that seem quite reasonable.

f. Omission of methane and nitrous oxide emissions.

The published data strongly indicate that tropical peatlands have relatively low emissions of both methane and nitrous oxide. Conversion of natural peatlands into OP plantations will reduce the methane emissions and likely increase nitrous oxide emissions. However, the limited data on these emissions in OP plantations suggest that the effect is small relative to soil CO_2 emissions (Page et al. 2011a).

g. Omission of emissions due to fire. (As discussed in the TWP, omission of this factor will cause EPA's emission factor to underestimate emissions, but we welcome comments about how large this underestimation may be.)

While highly episodic in nature, emissions due to fire are massive in SE Asian peatlands (range 86 to 387 Tg C yr^{-1} in Couwenberg et al. 2010, Hooijer et al. 2006, van der Werf et al. 2008). Since drainage of peatlands directly leads to increased incidence of fires, it is my opinion that the EPA should consider them in the soil emission factor.

h. Omission of incidentally drained peat swamps adjoining the plantations.

Hooijer et al. (2012) suggest that incidental drainage of adjacent forests can cause large emissions of CO_2, and thus they should be included in the soil emission factor in my opinion.

4. Intergovernmental Panel on Climate Change (IPCC) report:

a. Would it be appropriate for EPA to use the IPCC Tier 1 default emission factor of 40 tCO2/ha/year, or is it scientifically justified to use a different number based on more detailed information?

The recent IPCC Wetlands Supplement (2014) used a Tier 1 emission factor that was based on the average of chamber-based and subsidence-based estimates. Furthermore, they used a carbon gain-loss mass budget approach that subtracted autotrophic soil respiration and above- and belowground litter inputs into the soil. While this is a conceptually correct mass balance approach, it has the same uncertainties as described above in my discussion of chamber-based measurements, and includes further uncertainties associated with estimating litter inputs (which, in my opinion, is an almost insurmountable difficulty for belowground inputs). It is clear from the text of the IPCC document (Annex 2A.1) that the authors were challenged by the difficulty of deriving the corrections necessary to calculate soil oxidation from flux measurements and were divided about the best approach to take. It is my professional opinion that the emission factor from Hooijer et al. (2012) is more accurate than that derived from the IPCC (2014). The approach of Hooijer et al. (2012) is imminently clearer and more defensible that an averaging of studies without regard to the quality of their data. Also, including the initial flush of carbon emissions after drainage would increase the IPCC estimate, although it would still be substantially lower than the one given in Hooijer et al. (2012).

b. Should the emission factor that EPA uses include the emissions pulse that occurs in the first several years immediately following drainage?

The answer to this questions seems to be obviously yes. The only reason to not do this would be if the data were not available, but that is not the case with the publication of the Hooijer et al. (2012) study. It would be better if more of this type of data were available for comparison, but to not include it would clearly underestimate soil CO_2 emissions.

c. Should EPA include DOC and fire emission factors in the overall emission factor? If so, are the IPCC emission factors appropriate to use, or are there better estimates for EPA's purpose?

If the subsidence method is used, then it is not necessary to include DOC fluxes because they are already accounted for in the loss of soil carbon and mass. However if the soil respiration method is used, then it is necessary to include DOC fluxes. This somewhat nuanced distinction is described more clearly in 2006 IPCC Guidelines (IPCC 2006, p. 2.9) than in the 2013 Wetlands Supplement (IPCC 2014).

As stated above, it is my opinion that a fire emission factor should be included. While the highly episodic nature of these fires makes including them in emission estimates to be controversial, numerous studies have shown that ignoring their massive emissions is even more problematic. I am unsure of the correct emission factor to use for this without substantial more reading of the underlying literature.

d. There are also erosion losses of particulate organic carbon (POC) and waterborne transport of dissolved inorganic carbon (primarily dissolved CO2) derived from autotrophic and heterotrophic respiration within the organic soil. The IPCC concluded that at present the science and available data are not sufficient to provide guidance on CO2 emissions or removals associated with these waterborne carbon fluxes. Do you agree that the science on these factors is not sufficient for EPA to consider losses of POC and dissolved inorganic carbon in its peat soil emission factor?

As in item 4c for DOC, it is not necessary to account for POC and DIC losses if a stock-based approach is used (i.e., the subsidence method). To the extent that these losses are important (DIC losses may be particularly large, see Aufdemkampe et al. 2011), this is another reason that emission estimates based upon soil respiration would be lower than those based upon the subsidence method. I have not done an extensive literature search on the availability of POC and DIC losses from peatlands, or even more specifically in SE Asian peatlands converted to OP, but I doubt that much, if any, of such data exists. This is yet another reason that the gain-loss approach of the IPCC (of which soil respiration is but one component) is inappropriate for estimating emission factors in this particular case.

5. Additional Input

I have no further information to add beyond what I state above.

References Cited

Aufdenkampe, A. K., E. Mayorga, P. A. Raymond, J. M. Melack, S. C. Doney, S. R. Alin, R. E. Aalto, and K. Yoo. 2011. Riverine coupling of biogeochemical cycles between land, oceans, and atmosphere. Frontiers in Ecology and the Environment **9**:53-60.

Couwenberg, J., R. Dommain, and H. Joosten. 2010. Greenhouse gas fluxes from tropical peatlands in south-east Asia. Glob Chang Biol **16**:1715-1732.

Couwenberg, J. and A. Hooijer. 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.

Hooijer, A., M. Silvius, H. Wösten, and S. Page. 2006. PEAT-CO2, Assessment of CO2 emissions from drained peatlands in SE Asia. Delft Hydraulics report Q3943.

Hooijer, A., S. Page, J. G. Canadell, M. Silvius, J. Kwadijk, H. Wosten, and J. Jauhiainen. 2010. Current and future CO2 emissions from drained peatlands in Southeast Asia. Biogeosciences **7**:1505-1514.

Hooijer, A., S. Page, J. Jauhiainen, W. A. Lee, X. X. Lu, A. Idris, and G. Anshari. 2012. Subsidence and carbon loss in drained tropical peatlands. Biogeosciences **9**:1053-1071.

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4 Agriculture, Forestry and Other Land. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston ,H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (eds). IGES, Japan.

IPCC. 2014. 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. and Troxler, T.G. (eds.). IPCC, Switzerland

Jauhiainen, J., A. Hooijer, and S. E. Page. 2012. Carbon dioxide emissions from an Acacia plantation on peatland in Sumatra, Indonesia. Biogeosciences **9**:617-630.

Page, S. E., R. Morrison, C. Malins, A. Hooijer, J. O. Rieley, and J. Jauhiainen. 2011a. Review of Peat Surface Greenhouse Gas Emissions from Oil Palm Plantations in Southeast Asia. White Paper 15, The International Council on Clean Transportation, Washington, DC.

Page, S. E., J. O. Rieley, and C. J. Banks. 2011b. Global and regional importance of the tropical peatland carbon pool. Global Change Biology **17**:798-818.

Schrier-Uijl, A. P., M. Silvius, F. Parish, K. H. Lim, S. Rosediana, and G. Anshari. 2013. Environmental and Societal Impacts of Oil Palm Cultivation on Tropical Peat: A Scientific Review. Reports from the Technical Panels of the 2nd Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil (RSPO), Kuala Lumpur, Malaysia.

van der Werf, G. R., J. T. Randerson, G. J. Collatz, L. Giglio, P. S. Kasibhatla, A. F. Arellano, S. C. Olsen, and E. S. Kasischke. 2004. Continental-scale partitioning of fire emissions during the 1997 to 2001 El Nino/La Nina period. Science **303**:73-76.

Wösten, J. H. M., A. B. Ismail, and A. L. M. van Wijk. 1997. Peat subsidence and its practical implications: a case study in Malaysia. Geoderma **78**:25-36.

Ye, R., Q. Jin, B. Bohannan, J. K. Keller, S. A. McAllister, and S. D. Bridgham. 2012. pH controls over anaerobic carbon mineralization, the efficiency of methane production, and methanogenic pathways in peatlands across an ombrotrophic-minerotrophic gradient. Soil Biology and Biochemistry **54**:36-47.

Peer Review Response from Dr. Kristell Hergoualc'h, Center for International Forestry Research (CIFOR)

Emission Factor for Tropical Peatlands Drained for Oil Palm Cultivation

1. Overarching charge question

The 3 criteria outlined by the EPA are that the emission factor:

1. Estimates the impacts of tropical peat soil drainage on CO_2 emissions from heterotrophic respiration of drained peat soils, excluding such emissions from root respiration

2. Includes all significant GHG emissions impacts resulting from drainage over a 30-year period following the drainage event, including any initial pulse of GHGs following drainage and loss of dissolved organic carbon (DOC) in drainage waters

3. Represents average emissions from the development of palm oil plantations on tropical peat soil across Southeast Asia.

First of all, it is not clear which reference is used by the EPA for its emission factor. Page 2 of the technical work product mentions a "peat soil emission factor of **95** tCO_{2e} ha^{-1} yr^{-1}, based on Hooijer et al. (2012)". But the results for the oil palm plantation on peat studied by Hooijer et al. (2012) are: **109** tonnes CO_2 ha^{-1} yr^{-1} for a **25-year** time period or **94** tonnes CO_2 ha^{-1} yr^{-1} for a **50-year** time period. Page 4 of the technical work product says that the emission factor of 95 tCO_{2e} ha^{1} yr^{-1} was recommended for a 30-year time period by Page et al. (2011) in their review. But the review by Page et al. (2011) was published before the Hooijer et al. (2012) study and refers to both oil palm and pulp wood plantations.

Whatever the reference used (Page et al. (2011) or Hooijer et al. (2012)), the emission factor that the EPA proposes to adopt is based on a single study and thus definitely **does not meet the 'representativeness across Southeast Asia' criterion**. If the reference used is Page et al. (2011), it does not meet the '**representativeness from the development of palm oil plantations'** criterion as pulp wood plantations are merged with oil palm plantations.

I recommend the EPA to use the emission factors recently published by the IPCC. Chapter 2 (Drösler et al., 2014) of the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2014) reviewed extensively the existing literature, scrutinized the quality of the data and proposes emission factors that represent carbon losses in oil palm plantations on peat across Southeast Asia. The emission factors are:

- On-site CO_2 emissions: 11 tonnes CO_2-C ha^{-1} yr^{-1} or 40 tonnes CO_2 ha^{-1} yr^{-1}
- Off-site CO_2 emissions via waterborne carbon losses: 0.82 CO_2-C ha^{-1} yr^{-1} or 3 tonnes CO_2 ha^{-1} yr^{-1}
- CO_2 from prescribed fires: 71.9 tonnes CO_2-C ha^{-1} or 264 tonnes CO_2 ha^{-1} CO_2 from wildfires: 163.8 tonnes CO_2-C ha^{-1} or 601 tonnes CO_2 ha^{-1}

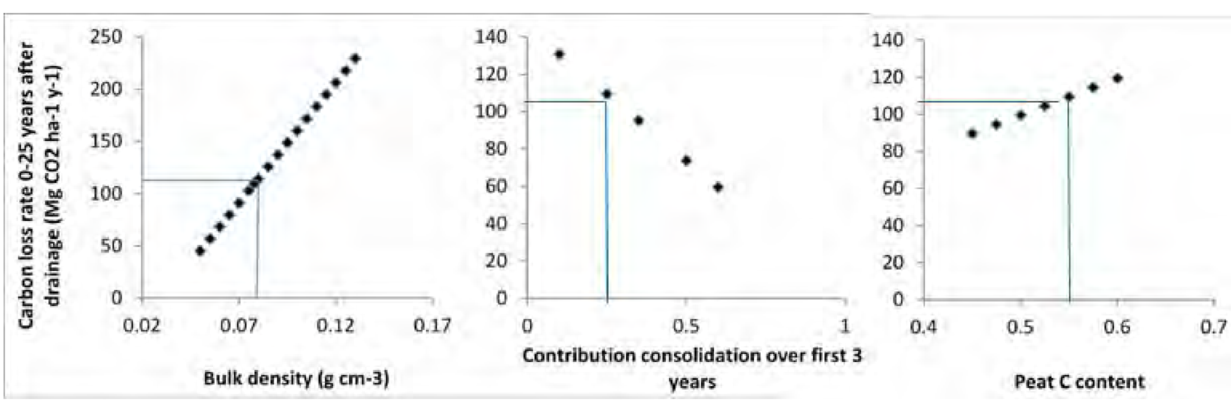
The on-site emission factor integrates data from 10 sites, 9 different ages after drainage, 2 countries, and includes both industrial and small holder plantations. The 10 sites include the oil palm plantation studied by Hooijer et al. (2012). Hence if the EPA judges that the study of Hooijer et al. (2012) meets the 'initial pulse of GHGs following drainage' criterion; implicitly the on-site emission factor of the IPCC also does. This initial pulse of emissions was in fact not measured by Hooijer et al. (2012) but artificially introduced in the C loss calculation.

2. Potential adjustment of emission factor from Hooijer et al. (2012)

The subsidence method is an alternative to the conventional C stock change and C flux change approaches for estimating peat C losses following drainage and conversion. It assumes that most induced chemical and physical changes (compaction, shrinkage, organic matter/carbon loss) occur above the water table and that solely consolidation-induced subsidence takes place below the water table. The method hypothesizes that the relative contribution of the different factors leading to peat subsidence above the water table (compaction, shrinkage, organic matter/carbon loss) is detectable by observing changes or absence of changes in peat bulk density. It assumes that in a given volume of subsiding peat if no change in bulk density happens then all the volume is lost in the form of organic matter/carbon. This hypothesis is erroneous as all processes leading to organic matter/carbon loss also induce bulk density changes. The method requires peat **bulk density** data **at the start** and **end** of the subsidence monitoring period of **several years**; **at the same site or using a nearby reference site** that would represent the initial conditions (Hooijer et al., 2012).

The study of Hooijer et al. (2012) was implemented in a mature oil palm plantation in Jambi that was drained on average 18 years prior to the start of the experiment. The authors specify that fire was used for land clearing before establishing the plantation. Subsidence measurements took place **over a year** at 42 monitoring points and bulk density measurements were undertaken at 10 locations. All measurements were done on average 18 years after drainage. There was **no reference site representing the initial site condition**. The authors assumed that the **bulk density below the water table depth** was representative of **the initial bulk density** before drainage. This assumption is not correct as bulk density varies with depth in undrained peat swamp forests (Matthew Warren, personal communication). This variation is apparent on the bulk density profile of the primary forest in Figure D-1 of Hooijer et al. (2012) and is recognized by the authors themselves in section 4.5 of their publication. The authors **hypothesized** that **subsidence during the first 5 years after drainage was more intense** than afterwards and **assigned** to the oil palm plantation an initial (0-5 years) subsidence rate which was measured in an Acacia (N_2 fixing tree which N inputs may promote peat mineralization) plantation with different history (e.g. no fire) and practices (e.g. no fertilization and high soil disturbance due to short rotation periods) than the oil palm plantation and located several hundred kilometers to the north in Sumatra. The assigned subsidence rate during the first 5 years was 28.4 cm y^{-1}. Peat **consolidation** was **assumed** to take place **over the first 3 years after drainage** and was calculated as **25% of the subsidence (75 cm)** during the first year in the Acacia plantation. These **25%** and **3 years** factors are **arbitrary** and **not based on measurements**. After removing the peat volume lost due to consolidation, the organic matter volume lost was calculated using the equations provided in section 2.5 of the article. These calculations used, as already mentioned, **hypothetical initial bulk density values** from below the water table. Organic matter losses were converted using a **default peat C content value** of **55%** which seems high when compared to values measured in Indonesian peat swamp forests (Warren et al., 2012). The final results indicated C losses of 119, 109 and 94 tonnes CO2 ha^{-1} y^{-1} for 18-, 25- and 50-year time periods, respectively.

Figure D-1. Variation of Hooijer et al. (2012)'s results of carbon loss rate 0-25 years after drainage as affected by the chosen value of bulk density before drainage (left), contribution of consolidation to subsidence 3 years after drainage (middle) and peat C content (right). Blue lines indicate the values assigned in the study, leading to C losses of 109 tonnes CO_2 ha^{-1} y^{-1} 0 -25 years after drainage.



Those results, which are **based on a series of hypotheses and assumptions**, evaluate peat total C losses including losses from prescribed fire(s) and particulate losses. **The results**

hinge on **the accuracy of the values chosen for key parameters such as bulk density before drainage, contribution of consolidation to subsidence or peat C content**. A **sensitivity analysis** shows that **an increase of 0.01 in the bulk density value before drainage** induces an **increase in the 0-25 year C loss rate of 23 tonnes CO_2 ha^{-1} y^{-1}** (Fig. 1 left); **an increase of 0.1** (10%) in the **contribution of consolidation to subsidence** over the first 3 years after drainage induces a **decrease in the 0-25 year C loss rate of 14 tonnes CO_2 ha^{-1} y^{-1}** (Fig. 1 middle); and **an increase of 0.05** (5%) in the **peat C content** induces an **increase in the 0-25 year C loss rate of 10 tonnes CO_2 ha^{-1} y^{-1}** (Fig. 1 right).None of these three parameters was measured by the authors therefore it's not surprising that commenters have raised questions about the values adopted. Using an initial bulk density value of 0.9 g cm^{-3} (average value cited by the authors in their discussion section 4.5), a consolidation contribution to subsidence of 75% instead of 25%, and a peat C content of 50% instead of 55% leads to C losses over 0-25 years of **50 tonnes CO_2 ha^{-1} y^{-1} rather than 109 tonnes CO_2 $ha^{-1}y^{-1}$**.

I would not recommend the EPA to use the overall approach proposed by Hooijer et al. (2012) and change the values of some parameters. This approach is too sensitive to the chosen parameter values. I also would not recommend the EPA to base its emission factor exclusively on the Hooijer et al. (2012)'s study for the same reasons.

3. Directionality of estimate

The emission factor of 95 tonnes CO_2 ha^{-1} y^{-1} (which should actually be 109 tonnes CO_2 ha^{-1} y^{-1} if truly based on the reference mentioned) based on the single study of Hooijer et al. (2012) which calculated the highest C loss rate in oil palm plantation on peat in the scientific literature will likely overestimate the actual loss rate. All other studies carried out in oil palm plantations on peat show lower C loss rates.

a. *Variation in the type of peat soil (mineral content, carbon content, depth, extent of degradation, etc.).*

Peat properties likely affect the C loss rate after conversion. The study of Othman et al. (2011), for instance, measured lower peat subsidence rates in shallow peats cultivated with oil palm than in deeper peats. The differences between the studied shallow and deep peat soils such as nitrogen content, C/N ratio, phosphorous, exchangeable bases, etc. are probably at the origin of the differences in subsidence rate. It could also be that the importance of consolidation is greater than previously thought and deep profiles experience ongoing consolidation for long periods of time.

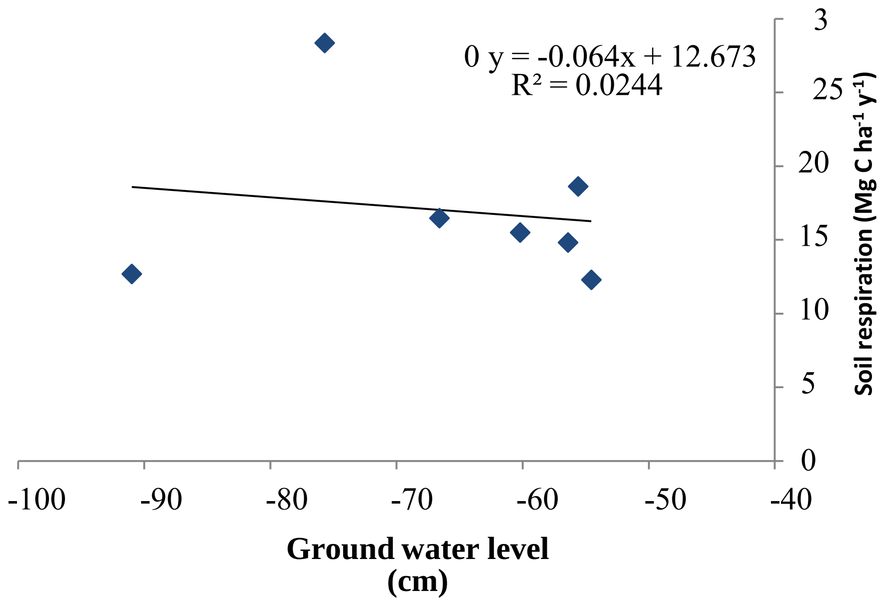
b. *Precipitation regime (annual rainfall, timing of rainfall, etc.).*

To date there is no scientific evidence that rainfall patterns can influence peat C losses in converted tropical peatlands.

c. *Differing water management practices at plantations.*

The studies of Othman et al. (2011) and Wösten et al. (1997) (based on DID and LAWOO (1996)) found relationships between subsidence rate and ground water level in oil plantation on peat. These studies indicate increasing subsidence when the ground water level decreases. Field measurements of soil respiration in oil palm plantation on peat, on the other hand, do not correlate well with ground water level (Figure D-2). Laboratory incubations of peat from an oil palm plantation indicate that peat decomposition rate is related to water content via an optimum curve (Husnain et al., 2012). Peat respiration increases sharply from wet (100 % water-filled pore space (WFPS)) to moist soil (80 to 40 % WFPS), and decreases when soil dries (20 % WFPS).The peat WFPS in oil plantations is usually between 60 and 80%.

Figure D-2. Annual soil respiration rate in oil palm plantations on peat as a function of the annual average ground water level. Soil respiration rates are from the studies of Melling et al. (2005); Comeau et al. (2013); Dariah et al. (2013); Marwanto and Agus (2013); Melling et al. (2013). The slope of the regression is not significant (P = 0.34).



d. *Different types of plantations (e.g., oil palm versus acacia).*

Acacia plantations on peat are confined in 2 regions of Sumatra (Riau and Jambi) whereas oil palm plantations on peat are spread over Peninsular Malaysia, Sumatra, Borneo and Papua. Acacia on peat is grown by industrial groups only while oil palm is cultivated half in an industrial way and half by small holders. Small holders usually drain their plantations less than industrial groups. For all these reasons much more variability in C loss rate can be expected in oil palm than in Acacia plantations on peat.

The recommended drainage depth for growing Acacia is higher than the one recommended for growing oil palm; which may lead to higher C losses in Acacia than in oil palm plantations on peat. In addition Acacia is an N_2 fixing tree which N inputs to the soil may stimulate peat decomposition. Finally and very importantly the short rotation time (5-6 years) in Acacia plantations induce frequent extreme soil disturbance that may also enhance the decomposition of the peat. Soil respiration rate in Acacia plantations (29 tonnes C ha^{-1} y^{-1}) is significantly higher than that in oil palm plantations on peat (17 tonnes C ha^{-1} y^{-1}) with, at the same time, a higher contribution of heterotrophic respiration to total respiration (Hergoualc'h and Verchot, 2013).

Therefore the use of an emission factor developed for both plantation types will likely overestimate the C loss rate in oil palm plantations on peat.

e. *The approach used by Hooijer et al. (2012) to estimate emissions during the first five years after drainage.*

As already noted, this approach is highly hypothetical:

- Subsidence rate over the 1st 5 years is from an Acacia plantation with different management and history and located elsewhere in Sumatra,
- Consolidation is estimated to take place over 3 years and assumed to amount to 25% of the subsidence rate during the 1st year in the Acacia plantation.
- Bulk density deep in the soil profile is assumed to represent pre-drainage bulk density over the whole profile.
- No shrink swell effects of peat fibers affecting the short term measurements of peat elevation.

f. *Omission of methane and nitrous oxide emissions.*

Methane emissions in oil palm plantations on peat seem negligible (Hergoualc'h and Verchot, 2013) and could indeed be omitted. Nitrous oxide emissions were barely measured. The only study available (Melling et al., 2007) assessed an emission rate of 1.2 kg N ha^{-1} y^{-1} but did not measure the high emissions expected following nitrogen fertilization. Given the high global warming potential of nitrous oxide I would recommend to take these emissions into account and use the IPCC emission factors:

1.2 kg N ha^{-1} y^{-1} (Drösler et al., 2014) + 1% N applied kg N ha^{-1} y^{-1} (IPCC, 2006)

g. *Omission of emissions due to fire. (As discussed in the TWP, omission of this factor will cause EPA's emission factor to underestimate emissions, but we welcome comments about how large this underestimation may be.)*

Fire-induced emissions are extremely high and should be accounted for whenever a fire either prescribed or wild happens. The 2013 IPCC guidelines provide emission factors for both types of fires.

h. *Omission of incidentally drained peat swamps adjoining the plantations.*

The spatial extent of the impact of the drainage in the oil palm plantation on adjacent lands is difficult to estimate and will depend on the ground cover (forest, shrubland, cropland, etc.) of the adjacent land. I don't think the current scientific knowledge on tropical peatlands allows integrating this impact in the emission factor.

4. Intergovernmental Panel on Climate Change (IPCC) report:

a. *Would it be appropriate for EPA to use the IPCC Tier 1 default emission factor of 40 tCO2/ha/year, or is it scientifically justified to use a different number based on more detailed information?*

The IPCC on-site CO_2 emission factor for oil palm cultivation on peat of 40 tonnes CO_2 ha^{-1} y^{-1} integrates 10 sites (DID and LAWOO, 1996; Melling et al., 2005; Hooijer et al., 2012; Comeau et al., 2013; Dariah et al., 2013; Marwanto and Agus, 2013; Melling et al., 2013), 7 for which a soil flux balance approach (excluding root respiration) was applied and 3 for which the subsidence method was implemented. The ages of the plantations are 1 year (n =1), 4 years (n = 1), 5 years (n = 1), 6 years (n = 1), 7 years (n = 2), 15 years (n = 1), 18 years (n = 1). For 2 of the subsidence sites the age of the palms is unknown but the study specifies that drainage started 12 and 24 years, respectively, previous to the monitoring period. The sites are located both in Indonesia (n = 4) and Malaysia (n = 6), in industrial (n = 6) and small holder (n = 4) plantations and thus span the climate, peat properties and management variability existing in the region. The review done by the author team of the IPCC is, up to date, the most complete one and all available results in the literature were thoroughly scrutinized. There is no sound scientific justification for the EPA to exclude 9 of the 10 sites considered by the IPCC. Such an emission factor would certainly not meet criterion 3 set by the EPA.

The high emissions during the first years following drainage are in some sense intuitive; it is also important to note that there is a significant physical restructuring of the peat profile as peat “matures” following drainage. Intact wood breaks down, peat compacts as buoyancy is lost, etc. There are no good data on CO_2 fluxes to the atmosphere during this phase.

b. *Should the emission factor that EPA uses include the emissions pulse that occurs in the first several years immediately following drainage?*

The only study carried out in tropical peatlands measuring subsidence a few years after drainage is the one of Hooijer et al. (2012). The subsidence rate was observed to decrease from year 1 to year 6 after drainage **in an Acacia plantation**; **not in an oil palm plantation**. The corresponding C loss rate calculated by the authors heavily depends on a number of assumptions notably on the contribution of consolidation to subsidence in the first years after drainage (http://www.biogeosciences-discuss.net/8/C4429/2011/bgd-8-C4429-2011.pdf , see p. C4434; and see sensitivity analysis above). The study demonstrates indeed the pulse in subsidence after drainage but not the pulse in emissions. The study of Jauhiainen et al. (2012) which took place at the same Acacia plantation measured heterotrophic soil respiration rates in the first rotation transects (i.e. less than 5 years after drainage) of about 83 tonnes CO_2 ha^{-1} y^{-1}, which is about half the value of 178 tonnes CO_2 ha^{-1} y^{-1} calculated by Hooijer et al. (2012) for years 0-5 after drainage. Hence the consolidation in the first years may have been more important than estimated by the authors. The “emission pulse in the first several years immediately following drainage” still remains hypothetical and not based on sound scientific evidence.

c. *Should EPA include DOC and fire emission factors in the overall emission factor? If so, are the IPCC emission factors appropriate to use, or are there better estimates for EPA’s purpose?*

The EPA could eventually merge the On- and Off- site emission factors of the IPCC but the emission factors for prescribed fires and wildfires should be kept apart to acknowledge site specific land use history.

d. *There are also erosion losses of particulate organic carbon (POC) and waterborne transport of dissolved inorganic carbon (primarily dissolved CO_2) derived from autotrophic and heterotrophic respiration within the organic soil. The IPCC concluded that at present the science and available data are not sufficient to provide guidance on CO_2 emissions or removals associated with these waterborne carbon fluxes. Do you agree that the science on these factors is not sufficient for EPA to consider losses of POC and dissolved inorganic carbon in its peat soil emission factor?*

Yes, I agree.

5. Additional input:

The literature review carried out by the EPA seems incomplete. A number of soil respiration studies were ignored. Hergoualc'h and Verchot (2013) made the list of publications that meet the IPCC quality criteria available at: http://thedata.harvard.edu/dvn/dv/CIFOR/faces/study/StudyPage.xhtml?globalId=hdl:1902.1/22351

Some sentences in the technical work product (e.g. "In contrast, the flux approach does not capture loss of DOC because it only measures gases respired into the flux chamber") suggest that the approach for calculating an emission factor using peat C fluxes is not fully understood by the EPA. The C flux approach calculates at different points in time the balance between the rate of C deposition and the rate of C decomposition and other losses. Carbon enters the peat through above and belowground litter inputs; it exits via decomposition of the peat and litter, fire if any and dissolved and particulate C. In pristine peat swamp forests the rate of C deposition exceeds the rate of decomposition and other losses so the peat accumulates C. In drained converted lands, it is the opposite. It has been demonstrated that peat and litter decomposition rates exceed by far C deposition as well as particulate C losses in oil palm plantations on peat (Hergoualc'h and Verchot, 2013). However, assuming that C losses equal soil heterotrophic respiration - as the EPA seems to - is erroneous and ignoring C inputs to and other C outputs from the peat is incorrect. The impact on the atmosphere is the net effect of inputs and outputs and this concept is anchored in the gain-loss approach of the IPCC. Failing to account for inputs is the equivalent of calculating a bank balance by looking only at withdrawals and not taking deposits into account. Using the soil C flux approach Hergoualc'h and Verchot (2013) calculated emission factors of CO_2, CH_4 and N_2O for different land-use types however the study is not even mentioned in the technical work product.

References

Comeau, L.-P., Hergoualc'h, K., Smith, J.U., Verchot, L.V., 2013. Conversion of intact peat swamp forest to oil palm plantation: Effects on soil CO_2 fluxes in Jambi, Sumatra. Working Paper 110. CIFOR, Bogor, Indonesia.

Dariah, A., Marwanto, S., Agus, F., 2013. Root- and peat-based CO_2 emissions from oil palm plantations. Mitig Adapt Strateg Glob Change DOI 10.1007/s11027-013-9515-6.

DID, LAWOO, 1996. Department of Irrigation and Drainage and Land and Water Research Group. Western Jahore integrated Agricultural Development Project. Peat Soil Management Study. Final report, Wageningen, The Netherlands. In.

Drösler, M., Verchot, L.V., Freibauer, A., Pan, G., Evans, C.D., Bourbonniere, R.A., Alm, J.P., Page, S., Agus, F., Hergoualc'h, K., Couwenberg, J., Jauhiainen, J., Sabiham, S., Wang, C., Srivastava, N., Borgeau-Chavez, L., Hooijer, A., Minkkinen, K., French, N., Strand, T., Sirin, A., Mickler, R., Tansey, K., Larkin, N., 2014. Chapter 2 Drained inland organic soils. In: Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Jamsranjav, B., Fukuda, M., Troxler, T. (Eds.), 2013 Supplement to the 2006 guidelines for national greenhouse gas inventories: Wetlands. IPCC, Switzerland.

Hergoualc'h, K., Verchot, L.V., 2013. Greenhouse gas emission factors for land use and land-use change in Southeast Asian peatlands. Mitig Adapt Strateg Glob Change DOI 10.1007/s11027-013-9511-x.

Hooijer, A., Page, S., Jauhiainen, J., Lee, W.A., Lu, X.X., Idris, A., Anshari, G., 2012. Subsidence and carbon loss in drained tropical peatlands. Biogeosciences 9, 1053-1071.

Husnain, Agus, F., Wigena, P., Maswar, Dariah, A., Marwanto, S., 2012. Peat CO_2 emissions from several land-use types in Indonesia. To be submitted to Mitigation and adaptation strategies for global change.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies (IGES), Hayama, Japan.

Jauhiainen, J., Hooijer, A., Page, S.E., 2012. Carbon dioxide emissions from an Acacia plantation on peatland in Sumatra, Indonesia. Biogeosciences 9, 617-630.

Marwanto, S., Agus, F., 2013. Is CO_2 flux from oil palm plantations on peatland controlled by soil moisture and/or soil and air temperatures? Mitig Adapt Strateg Glob Change DOI 10.1007/s11027-013-9518-3.

Melling, L., Chaddy, A., Goh, K.J., Hatano, R., 2013. Soil CO_2 fluxes from different ages of oil palm in tropical peatland of Sarawak, Malaysia as influenced by environmental and soil properties. Acta Hort. (ISHS) 982, 25-35.

Melling, L., Hatano, R., Goh, K.J., 2005. Soil CO_2 flux from three ecosystems in tropical peatland of Sarawak, Malaysia. Tellus 57B, 1–11.

Melling, L., Hatano, R., Goh, K.J., 2007. Nitrous oxide emissions from three ecosystems in tropical peatland of Sarawak, Malaysia. Soil Science and Plant Nutrition 53, 792–805.

Othman, H., Mohammed, A.T., Darus, F.M., Harun, M.H., Zambri, M.P., 2011. Best management practices for oil palm cultivation on peat: ground water-table maintenance in relation to peat subsidence and estimation of CO_2 emissions at Sessang, Sarawak. Journal of Oil Palm Research 23, 1078-1086.

Page, S.E., Morrison, R., Malins, C., Hooijer, A., Rieley, J.O., Jauhiainen, J., 2011. Review of peat surface greenhouse gas emissions from oil palm plantations in Southeast Asia. International Council on Clean Transportation. White Paper Number 15, Indirect Effects of Biofuel Production Series.

Warren, M.W., Kauffman, J.B., Murdiyarso, D., Anshari, G., Hergoualc'h, K., Kurnianto, S., Purbopuspito, J., Gusmayanti, E., Afifudin, M., Rahajoe, J., Alhamd, L., Limin, S., Iswandi, A., 2012. A cost-efficient method to assess carbon stocks in tropical peat soil. Biogeosciences Discuss. 9, 7049-7071.

Wösten, J.M.H., Ismail, A.B., van Wijk, A.L.M., 1997. Peat subsidence and its practical implications: a case study in Malaysia. Geoderma 78, 25-36.

Peer Review Response from Dr. Monique Leclerc, University of Georgia

Emission Factor for Tropical Peatlands Drained for Oil Palm Cultivation

1. Overarching charge question

This reviewer/commenter praises the EPA team for recognizing the importance of the work by Hooijer et al. (2012) to be used as an average value of peat emission factor (95t C/ha/hr). The Hooijer et al. (2012) study has the advantage of including drainage data from the first year onward and this is a welcome contrast with many other studies. Its second significant advantage is to also include the emissions from waterways, something few, if any, studies consider at the present time in the published literature (although as we speak, there are ongoing efforts to remedy this lack of data). Given the above, this emission factor value, on a first examination, appears to be a reasonable and sensible choice. However, there is insufficient information to determine and constrain the range of information to derive an estimate. There is also insufficient information on whether the proposed emission factor is biased primarily at the low or high end of the spectrum and the degree to which this can translate into a lower and higher revised emission factor. There are reservations regarding the estimated current value:

1. This reviewer agrees with the suggestion that data on root respiration is important and should be excluded from all GHG estimates related to peat emissions; this information is likely to play a significant modulating influence in reducing the uncertainties associated with the current estimate. That is one of the three main criteria and that one is not currently met to derive the emission factor. At this point in time, this reviewer believes there are no such studies yet that identifies the component of heterotrophic respiration from the assessment leading to the characterization of the proposed emission factor. As this time, it is thus not possible to come up with a modification related to root respiration to the proposed emission factor that would take that variable into account. Assuming more published literature becomes available at the time the emission factor comes into effect, the role of root respiration should be examined to quantify the differences between peat swamp forests, oil palm and acacia.

   Thus, the aspect of quantifying and removing autotrophic respiration needs to be assessed to refine the current proposed factor. Depending on which method of calculation is used to arrive at this estimate, the results can vary significantly. If the stock-difference approach is used, the root-to-shoot ratio for mature dense peat forests hovers between 0.01-0.06 (**Brady, VA (1997). Organic matter dynamics of coastal peat deposits in Sumatra, Indonesia. *PhD thesis.* University, University of British Columbia, Vancouver**). The difference between these forests and tree cropping systems is still unknown. Assuming it were the same for both the managed oil palm/acacia plantation and the mature dense forest, the results are less likely to be sensitive to the fact that root respiration is unknown at this time. This hypothesis however is unlikely because of the intensive management practices associated with oil palm.

The alternate approach, the accounting approach, requires the information that the study by Hooijer et al. (2012) suggests as needed. It is highly likely to yield a more robust, scientifically credible estimate than the stock-difference approach as it uses measurements of the various carbon pools. At present, there is an urgent need to characterize all the carbon sources and sinks within oil palm grown on peat plantations and to do so in contrasting peat characteristics of peat characteristics and management practices.

2. The Hooijer et al. (2012) is based on an approach that has large uncertainties and is fraught with numerous assumptions which we do not understand the implications. The change away from the proposed average emission factor should be predicated on accessing or creating a larger database on the interrelashionship between GHG emissions and spatially and temporally varying peat characteristics and peat management practices and, to a lesser degree, climate characteristics of precipitation and temperature. So, on that basis alone, no the current emission factor needs revision which should be higher. The magnitude of this factor is in direct relation to other factors such as peat characteristics, root respiration, peat depth, land-use history and management practices. The second criterion used by EPA which is important and not currently met in the present TWP document is that the peat soil emission factor should include ALL the significant GHG emissions impacts resulting from drainage over a 30-yr period following the drainage event and loss of carbon to the drainage canals. This criterion is critical and should be met. Non-CO_2 GHG emissions in oil-palm grown on peat is extremely important to be investigated as this likely will sway the emission factor out of the average zone into the higher CO_2-equivalent emissions zone. Given the global warming potential of nitrous oxide (238 times that of CO_2) and given the intensive fertilization and water table practices used by the OP industry, quantitative information on the latter is necessary before a robust, scientifically credible value for CO_2-equivalent emission factor.

3. The emission factor does not represent the average emission from the development of OP plantations on tropical peat land. The Hooijer et al. (2012) study has an extremely narrow range of sample locations in a region which, unlike in temperate latitudes, is characterized with extremely heterogeneous peat depth, composition and decomposition rates. It is also subjected to rapid transformation through LUCLCC which leads to a variety of 'signatures' on the peat. The role of management practices and how these values vary is also absent. That is likely a reflection of the fact that there are few if any quantitative studies that pertain to their importance.

Another addition which might be considered as a potential fourth criterion lies in the emissions caused by logging at the time of land conversion, opening canals, and land clearing with resulting large forest fires. The TWP has limited its task to post-clearing CO_2 emissions and focuses its attention to the period from the first pulse of CO_2 following the initial drainage onward over a thirty-year period. Furthermore, the occurrence of peat fires following the establishment of oil-palm plantations on peat land is also ignored. Fires emissions of carbon monoxide and carbon dioxide are significant with smoldering fires that can linger for months after their onset.

In summary, there is such a paucity of information on important questions (nitrous oxide and methane emissions from peat) and simplifications regarding peat types and other variables detract from the otherwise very careful work of Hooijer et al. (2012). The emissions factor could be used TEMPORARILY as this will have already an effect on emissions, but should be made conditional to the urgent need of further studies as we may still underestimate the emissions.

2. Potential adjustment of emission factor from Hooijer et al. (2012)

The approach used to arrive at a suitable average emission factor should be refined. At present, we do not know the importance of several key variables. It is thus possible that the current proposed emission factor overestimates or underestimates the current emissions by an order of magnitude. Having sufficient baseline information on many of these variables can harm the economy of emerging countries or, conversely, can have an even more deleterious impact on the climate than suspected. Organic carbon content and peat bulk density are good variables but the broad variability in the number of estimates of the Hooijer et al. study for different (and limited) sample locations suggest that the authors have left out other variables. A key factor lies in the recognition that characteristics of peat lands are highly heterogeneous geographically and over short distances from the coast (Paramanthan 2014 article published in Geoderma). The peat varies both in composition and in depth, both of which are likely to impact the results of the study by Hooijer et al. (2012). While it is recognized that EPA seeks an 'average' value for an emission factor, there are still important facts that have been left out of the Hooijer et al. (2012) study which should be taken into account before an emission factor value is formally arrived at. The degree to which peat characteristics modulates the emissions of GHGs is unknown and temporal changes in peat characteristics and carbon loss over decades, should be assessed and incorporated into the emission factor. That, together with the fact that proposed emission factor is based on CO_2 gas alone, is perhaps the single, most significant variation to the current emission factor. It is not possible at this time to provide a solid, credible revised emission factor. Another significant factor that limits the robustness of the emission factor used is the relationship of subsidence rate versus CO_2 emissions which remains to be verified for different peat classifications (hemic sapric, fibric). Since most current classifications were developed for the most part for temperate latitude peat, a more meaningful classification should include peat depth and peat composition and management other than the water table level. At present, only the peat classification of Paramanthan published in Geoderma focuses on the mapping of the characteristics of Southeast Asian lands. The Hooijer et al. (2012) study does not appear to recognize the important regional differences in peat composition and the variables of bulk density and organic carbon content leave out related variables.

Always discussing why the third criterion does not represent the emissions as well as hoped, is the issue of management practices and land-use history. Another limitation of the Hooijer et al. (2012) study is management practices information is not considered outside water table management. Management in this context should thus include more than water table management: it should also include ground cover which acts both to reduce CO_2 emissions and acts to partially offset the emissions. We cannot make an informed recommendation on the level of importance of the ground cover in reducing the carbon dioxide emissions since there is no data at present. This addition of ground cover is increasingly being used as part of Best Management Practices in Southeast Asian oil palm plantations.

More such factors pertaining to management practices include fertilizer application on peat. The timing of the applications, the fact that in oil palm the applications are continuous throughout the year and the currently standard fertilizer application rate have to be examined for contrasting peat types. This is also left out and should be added to the two main variables. As the amount of fertilizer in the peat changes, the amount of CO_2 emissions will also changes in ways that have not been quantified. That is interrelated to the second criterion which encompasses the non-CO_2 GHGs. We cannot make a revision to the proposed factor even though this is very important as there is a lack of relevant data.

In the study by Hooijer et al. (2012), the importance of emission factor for global warming potential should be examined and not just limited to CO_2. The nitrogen and the carbon cycles are intertwined and modulate one another through the activity of the methanogenesis and other bacterial action mechanisms. It is highly possible that methane and nitrous oxides can exceed the true GWP of CO_2 in terms of GHG emissions. This is because of the extremely important nitrous oxide has the global warming potential of 238 that of carbon dioxide and 25 times that of CO_2 in the case of methane. With fertilization as a standard management practice, this aspect of emissions remains unknown and urgently needs quantification. (The two existing related studies were discussed in a different section).

3. Directionality of estimate

There is such an unprecedented paucity of data available in quality peer-review literature that it is challenging to adequately address this question directly. The Achilles' heel of the study is as follow: the main limitation of the study is the fact that only CO_2 emissions are considered when in peat, methane emissions and nitrous oxides resulting from fertilization practices are certain. It is thus likely that the neglect of these radiatively important greenhouse gases underestimate the proposed emission factor. It is highly recommended to include all three GHGs and to not oversimplify this variable in the determination of a reasonable emission factor.

a. *Variation in the type of peat soil (mineral content, carbon content, depth, extent of degradation, etc.).*

A key factor beside the non-inclusion of two powerful GHGs lies in the fact that the widely varying peat characteristics (as discussed earlier). The rate of peat decomposition is intricately intertwined with the release of carbon dioxide and we can expect the proposed factor to underestimate the emissions more for sapric peat than for fibric and hemic. There is no literature either that documents this. Different peat types (hemic, sapric or fibric) will have different emission rates, a fact that is ignored from the average emission factor. We do not know at time the significance of leaving this variable out (high and low ends of the range of values and what fraction of the total OP grown on peat is on one type of peat rather than on the other).

In addition, the Hooijer et al. study does not consider that peat changes composition over time, that fibric material, over a 30-yr period for instance, may turn hemic and sapric. The variation between emissions from these different peat needs to be quantified before sensible average emission factors can be derived with more certainty.

b. *Precipitation regime (annual rainfall, timing of rainfall, etc.).*

The precipitation regime is the main climatic driver in the tropics, unlike in temperate latitudes where temperature is an important limiting variable. The local microclimate with its concommittant spatial and temporal characteristics of heavy precipitation near the coast, rain clouds at high altitudes, interseasonal monsoonal variation in total precipitation and timing of the precipitation in relation to the years following LUCLCC, are expected to impact the emissions as it modifies the water content in the peat and its importance has yet to be examined.

c. *Differing water management practices at plantations.*

Current water table management practice with the suggestion of keeping it as high as possible results in the emission of methane, due to the action of anaerobic microbial activity (methanogenesis). That means that CO_2 emissions rise when CH_4 emissions fall and vice versa due to the preponderance of one microbial population over the other. Thus, customary water table management, as is currently practiced to keep the water level high, should be revised to decrease the total GHGs (calculated in terms of CO_2-equivalent) emissions and not just CO_2. It can thus been concluded that organic content and peat density as the main variables are insufficient predictors of carbon dioxide emissions. The resulting emissions, framed in terms of CO_2-equivalent, is thus likely to be higher than estimated by the emission factor.

Given that the emission factor is so closely intertwined with the cycles of nitrous oxide and methane and carbon dioxide, studies related to nitrous oxide emissions from fertilized peat are scant and contradictory: One such study suggests that N20 emissions from highly fertilized crop fields and peat forests to be extremely elevated (with emissions as high as 52Mg of CO_2 (**Takakai, F. et al. 2006. Effects of agricultural and-use change and forest fire on N_2O emission from tropical peatlands., Central Kalimantan, Indonesia. *Soil Sci. Plant Nutri*. (Tokyo) 52: 662-674).** In that study, the authors conclude that nitrous oxide emissions are comparable and even larger than total C loss resulting from conversion of peat swap forests into oil palm. Since these emissions are peat-depth dependent, there are likely to be a wide variability in these estimates. However, another study finds contrasting results and concluded that nitrous oxide emissions are likely to play a minor role in the generation of nitrous oxide emissions from oil palm grown on peat. The process of nitrification and denitrification are the main processes that produce nitrous oxide emissions and these effluxes peak when the water content is around field capacity (often 60% of pore-filled space filled with water). Thus, drainage is likely to increase emissions, particularly in fertilized systems or in systems with nitrogen-fixing trees (**Murdiyarso, D., K. Hergoualc' and L. V. Verchot. Opportunities for reducing greenhouse gas emissions in tropical peatlands. *Proceedings of the National Academy of Science* DOI 10.1073/pnas.091: 1966-107**). The study by Hooijer et al. was conducted in an acacia plantation (**Melling, L., Hatano, Fl., Goh K) 2005. Methane fluxes from three ecosystems in tropical peatland of Sarawak, Malaysia. *Soil Biol. Biochem* 37:1445-145). T**he cycles of methane, CO_2 and nitrous oxide are closely interrelated and there needs to be a greater body of studies in this regard as well as intercomparison/validation experiments.

The frequency of the measurements used to arrive at this average value is too low. The use of monthly data can be hazardous given the temporal variability and intermittency of precipitation. There is a large diurnal and a seasonal variability in these estimates. The timing of the precipitation in relation to CO_2 emission measurements needs to be addressed. The data should be collected continuously and makes a spatial integration (with the eddy flux method) using different instrumentation.

The impact that different plantations types have on CO_2 emissions when grown in peat: As alluded earlier, the lack of information on the role of root respiration is a limitation of the study by Hooijer et al. (2012). This information (see earlier discussion) may help revise slightly downward the emission factor and it is unlikely to modify the two other greenhouse gases. However, given that any difference between the root respiration of a natural peat swamp forest and oil palm is unknown, no information can be used at the present time.

d. Different types of plantations (e.g., oil palm versus acacia).

The impact of different types of plantations on emissions is likely to be concentrated across plantations differences between root respiration and whether the crop is one that fixes nitrogen or not (i.e. reduced fertilizer application). Plantation age is also a factor that the TWP does not address as this is relevant in terms of GHG emissions across different plantations (not just plantation types but also plantation age since the degree of variability across plantation types may be of the same order of variability seen across plantation ages for the same species of trees). Murdiyarso et al. (2010) suggest that the differences in emissions of nitrous oxides could be larger following the conversion of swamp forests in Acacia sp. plantations than on oil-palm. No supporting data is provided however for this statement.

e. The approach used by Hooijer et al. (2012) to estimate emissions during the first five years after drainage.

Given that the method itself is seen as a good first try, that may be ok but this is not an approach that is likely to represent the mean or median of the emissions for the Malaysian/Indonesian peninsula.

f. Omission of methane and nitrous oxide emissions.

Always related to the second criterion outlined in the TWP document, the contribution of methane production is also not considered and converted into CO_2-equivalent in the current calculations of the present emission factor. Methane production is a function of moisture, compaction and temperature; it is also linked to $NH4^+$ $NO3^-$ contents in the case of fertilized systems. Oil palm plantations on peat are subjected to frequent fertilizer applications and how the combined result of altered soil organic content, soil porosity and water table impact these GHG emissions should be quantified.

g. Omission of emissions due to fire. (As discussed in the TWP, omission of this factor will cause EPA's emission factor to underestimate emissions, but we welcome comments about how large this underestimation may be.)

Emissions from fires arising from land-use conversion are by far the most considerable source of emissions. In most cases, vegetation and forest fires are lit intentionally to remove vegetation residues or debris before introducing new plantations. With the detectable drying signature of changes to the climate, droughts-induced fires are also increasingly significant. Although peat fires are intermittent, the CO_2 flux from smoldering peat fires can be at least as large as the decomposition flux from peatlands (**Rein, G., Cohen S., Simeon A. 2009. Carbon emissions from smoldering peat in shallow and strong fronts. Proc. Combustion Ins. 32:2489-2496)**. Quoting Murdiyarso et al. (2010), recent data using a Moderate Resolution Imaging Spectroradiometer and Measurements of Pollution in the Troposphere sensors suggest an average CO_2 emissions from fires from 2000-2006 of 6.5 Pg/yr **(van der Werf G. R. et al. 2008. Climate regulation of fire emissions and deforestation in equatorial Asia. Agr. Ecosyst. Environ. 104: 47-56).**

h. *Omission of incidentally drained peat swamps adjoining the plantations.*

Horizontal carbon content advected from the neighboring swamps is unknown and should be quantified. A migration of DOC from regions of highly concentrated DOC to the lower DOC regions within the water table is expected.

Charge Question # 4:

a. *Would it be appropriate for EPA to use the IPCC Tier 1 default emission factor of 40 tCO_2/ha/year, or is it scientifically justified to use a different number based on more detailed information?*

With regards to EPA using the IPCC Tier 1 default of 40t CO_2/ha/yr, this estimate is likely to be too low. It is based on earlier, older literature data and also does not recognize the many factors outlined in the present review. In this regard, the EPA value appears closer to a genuine average emission factor.

b. *Should the emission factor that EPA uses include the emissions pulse that occurs in the first several years immediately following drainage?*

The emission factor that EPA uses should definitely include as much as possible all the sources and sinks modifications that result from land-use change and the first five years following drainage are very important.

c. *Should EPA include DOC and fire emission factors in the overall emission factor? If so, are the IPCC emission factors appropriate to use, or are there better estimates for EPA's purpose?*

EPA should include DOC and fire emission factors. DOCs are a 'hot spot' of GHGs and are now being documented. Advection from neighboring regions is caused by land-use conversion and this is also should be taken into account for robust emission factors to be determined.

d. There are also erosion losses of particulate organic carbon (POC) and waterborne transport of dissolved inorganic carbon (primarily dissolved CO_2) derived from autotrophic and heterotrophic respiration within the organic soil. The IPCC concluded that at present the science and available data are not sufficient to provide guidance on CO_2 emissions or removals associated with these waterborne carbon fluxes. Do you agree that the science on these factors is not sufficient for EPA to consider losses of POC and dissolved inorganic carbon in its peat soil emission factor?

The level of POC arising from erosion should be quantified and I agree with the assertion that the current level of science is insufficient to decide whether these factors should be included in the determination of the emission factor or neglected.

5. Additional input

I have no further information to add beyond what I state above.

Peer Review Response from Dr. Supiandi Sabiham, Department of Soil Science and Land Resource, Bogor Agricultural University Indonesia

Emission Factor for Tropical Peatlands Drained for Oil Palm Cultivation

I. Introduction

As an independent reviewer, I have read the Technical Work Product (TWP): Emission factor for Tropical Peatlands Drained for Oil Palm Cultivation reported by US Environmental Protection Agency (EPA) and the Charge Questions provided by RTI International. I also have read several literatures in relation to the topic in order to make comments on the EPA's report concerning the lifecycle greenhouse gas (GHG) emissions associated with palm oil-based biodiesel, which is estimated by EPA that this biofuel should reduce the GHG emissions by 17% compared to the petroleum diesel baseline. In January 2012, EPA released a Notice of Data Availability (NODA) concerning the renewable fuels produced from palm oil under Renewable Fuel Standard (RFS) Program. For this January 2012 NODA, the Agency assumed that average emission factor from drained tropical-peatlands, referring to the subsidence studies of Hooijer *et al*. [2012] and review paper of Page *et al*. [2011], was of 95 t CO_2 (eq) ha^{-1} yr^{-1} over a 30-year time period. Based on this emission factor, EPA then analyzed that the biofuel was not meeting the statutory 20% GHG emissions reduction. Agus *et al*. [2013] has calculated the CO_2 emission from peat oxidation under oil palm plantation, where the result was of 43 t CO_2(eq) ha^{-1} yr^{-1}; this emission factor was then used by them as a default value based on their evaluation of various published studies with an assumption that groundwater level of peat soil under such plantation is at approximately 60 cm below the soil surface.

II. Review of TWP

The paper of Hooijer *et al*. [2012] is the developed paper of Hooijer *et al*. [2011], from which the Agency has adopted the emission factor of peats under oil palm plantation, i.e.: 95 t CO_2 ha^{-1} yr^{-1} over a 30-year time period as mean high-emission rate from peats covered by oil palm plantation for 25 and 50 years of the plantation cycles (Table D-1). I observed that the paper of Hooijer *et al*. [2012] has two strength and several weaknesses in relation to the methodology they used. The strength includes: (i) the use of subsidence method that seems to be free from root respiration confusion, which could influence the emission measurement using closed chamber technique, (ii) large number of subsidence observation points with a total of 218, namely: 42 points in oil palm plantations, 125 points in *Acacia* plantation, and 51 points in peat swamp forest adjacent to the plantations of *Acacia*, and (iii) a high measurement intervals that vary from 1 to 3 months.

Table D-1. Annualized values for peat carbon losses from plantations over various time scales, according for higher rates of emissions in the years immediately following drainage [Page *et al*., 2011]

Number of years	Carbon loss (t CO_2(eq) ha^{-1} yr^{-1})
5	178
10	121
20	106
25	100
30	**95**
40	90
50	86

The weaknesses, which can disqualify a validity of the emission factor, are described as follow. The accuracy of carbon stock measurement using the subsidence technique depends on the complete measurements of peat soil bulk density (BD) and carbon content throughout the profile of peat soil. I observe that no review was conducted on the change of peat BD profile. Hooijer *et al*. [2011] only used peat BD data from the soil surface to the depth of 1.2 m in *Acacia* plantation and 2 to 2.5 m in oil palm plantation; they assumed that peat BD data below these depths were the same value with that at above. They also estimated the change of peat BD only from the different locations and the different land uses, i.e.: under: *Acacia* plantations of 2 years, *Acacia* plantations of 5-7 years, and oil palm plantations of 18 years after drainage was started. It was not done to review peat BD at the same site, at least at the beginning and the end of their three- year-data collection. I understand that their research approach is the best for their research purposes since they had difficulties to meet data of peat BD at the same site for a period of many years of observations. However, to use such data as database for calculation of carbon stock and hence carbon emission from peat under oil palm plantation, however, it would give information which is not scientifically justifiable. In a reality, peat thickness of even at 1000 ha (for example at the MPOB Research Station at Sessang, Sarawak) varied from 100 to 400 cm consisting of the nature of peat BD that varied from 0.09 to 0.14 [Othman *et al*., 2011]; after the use of peat for oil palm cultivation in several years, peat BD sharply changed (Table D-2).

Table D-2. Mean peat BD (g cm^{-3}) from several planting block (before and after peat development for palm oil cultivation) [Othman *et al.*, 2011]

Peat devel.	Nature of peat	After peat development for palm oil cultivation								
Thick peat		2001	2002	2003	2004	2005	2006	2007	2008	Mean
2-9 yr	0.09	0.08 (2)	0.10 (3)	0.11 (4)	0.12 (5)	0.14 (6)	0.15 (7)	0.16 (8)	0.17 (9)	0.13
6-13 yr		0.11 (6)	0.12 (7)	0.14 (8)	0.15 (9)	0.16 (10)	0.17 (11)	0.18 (12)	0.19 (13)	0.15
Shallow peat										
9-16 yr	0.14	0.17 (9)	0.18 (10)	0.19 (11)	0.20 (12)	0.21 (13)	0.22 (14)	0.23 (15)	0.24 (16)	0.21

Notes: Numbers in blanket show year after development. Thick peat: >150 cm; Shallow peat: 100-150 cm.

The other weaknesses are in peat subsidence and organic carbon (org-C) content measurements. Peat subsidence monitoring carried out under oil palm plantation was only conducted for one year (July 2009 to June 2010), which is too short a time period for a subsidence research. The result of the cumulative subsidence from 14 subsidence poles including in Acacia plantation was then recalculated to annual mean values that allowed comparison between all locations.

In relation to org-C content analysis, Hooijer *et al*. [2011] and Hooijer *et al.* [2012] adopted the analysis result of org-C content of 55% in peat based on Suhardjo and Widjaja-Adhi [1977]. Kanapathy [1976] in his research on peat in Malaysia reported the values ranged from 58% at the peat surface to 25% in the subsoil, and studies by Tie [1982] in Sarawak showed a range of 20% to 38%; these indicates that peat soil has large variations of org-C values both horizontally and vertically. Sedimentation during flooding gave a possibility to decrease the content of peat org- C. From our experiences, org-C contents in peat samples from Sumatra and Kalimantan mostly lay around 30% to 55%. It should also be noted that Hooijer *et al*. [2011] and Hooijer *et al*. [2012] determined that contribution of peat oxidation to subsidence was 92% for plantations on the drained tropical peat, which is not based on the direct measurement of the change of carbon stock according to the change of BD and org-C content. They then applied such constant as a basis of the rates of carbon loss which is equivalent CO_2 emissions from peat.

Regarding these problems, EPA has been conducted further review to the scientific literatures in order to revisiting the Agency's choice of emission factor. To revisit such emission factor, EPA consideration has been focused on three criteria mentioned in TWP. However, for the second criterion, to me it seems to have a difficulty to include indirect emissions from land use changes since the primary peat swamp-forest was mostly not converted directly to oil palm plantation, but it has followed the long-term processes as Pagiola [2000] stated (Table 3).

Table D-3. Long-term Processes of Forest Conversion in Indonesia [modified from Pagiola, 2000]

Transmigration Project	Logging	Estate Crops
Transmigration project that started in 1969 became the primary engine for new settlements of the Outer Islands, reaching its peak in the mid-1980s. In addition to its direct impact on the forests, the project had substantial secondary impact through mechanical land-clearing. During the period of 1969 to 2000, number of population who resettled at several locations in the main Outer Islands (Sumatra, Kalimantan, and Papua) was of 3.05 M [Tjondronegoro, 2004]; for which the lands of 8.94 M ha, provided by government, are mostly derived from primary forests. As an indirect impact of the project, there has been substantial amount of spontaneous settlement into the forest areas both by local population and by migrants from the more heavily populated islands.	In line with the transmigration project, systematic logging in the Outer Islands was developed, which is started from 1970s. Logging also provided the access that facilitated spontaneous settlement into the forest areas. From a review of the available evidence indicates that estimated deforestation rate was of 0.6 M ha year-1, much of it due to the programs sponsored by the Indonesian government, including the transmigration program and forest concessions (HPH). The loss of natural forest that reaching its peak during the period of 1985 to 1997 was of about 6.7 M ha in Sumatra and about 8.5 M ha in Kalimantan; this amounts to an average annual rate in such two islands of about 1.26 M ha year-1 [Holmes, 2000].	The mid-1980s saw the government commence its policy of promoting the diversification of product with a strong focus on the development of degraded forests for tree crop and oil palm plantations. From around 0.5 M ha in 1984, the gross area of degraded forest under oil palm had increased to over 1.3 M ha by 1990, and nearly 2.4 M ha in 1997. Expansion of oil palm into degraded peat swamp forest, reaching its peak in the mid-1990s, was due to lack of available mineral-soil lands, particularly in the regions that having areas dominated by peat swamp forest. From around 8.02 M ha of oil palm plantation in 2010, the area of most degraded peat swamp forest under oil palm was about 1.71 M ha [Agus et al, 2011].

A recalculation from data availability [Gunarso *et al*, 2013], it can be summarized that oil palm expansion into peatland between 1990 and 2010 used only around 6% primary forest, 28% degraded forest, 26% shrubland, and 40% other land uses including rubber plantation, timber plantation and other low carbon biomass agriculture and grasslands. For 2000 to 2010, based on the same database mentioned above, the expansion of oil palm into peat swamp forest in Sumatra and Kalimantan was only 28%, which mostly replaced the degraded forest [Table D-4].

Table D-4. Expansion of Oil Palm Plantation Into Land Use Types During the Period of 1990 to 2010 Based on Agus *et al*. [2011] estimate (in %)

Land Use Type	Historical 1990 – 2010 for the Three Main Islands in Indonesia	Historical 2000 – 2010 for Sumatra and Kalimantan
Peat swamp forest:		
• Primary forest	6	
• Degraded forest	28	28
Mixed (agroforestry)*	34	26
Shrubland	26	23
Grassland and cropland	6	23

*) Rubber and timber plantation – agroforestry.

III. Charge Questions

1. Overarching charge question

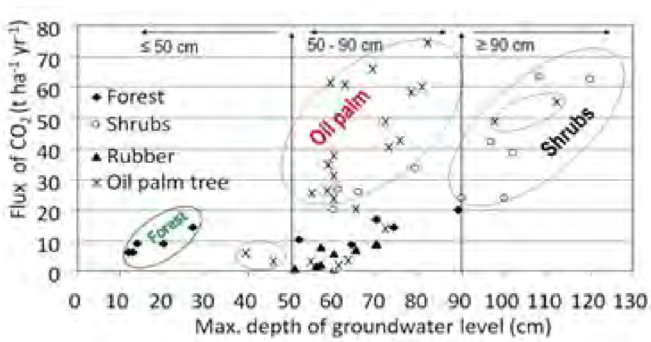
As I have mentioned above, the Agency chose the value of peat soil emission factor based on Hooijer *et al*. [2012] and Hooijer *et al*. [2011] that having several weaknesses, particularly in relation to database of peat BD and peat org-C content, needs to reconsider again for revisiting new choice of emission factor. I convinced that average emissions from peat soil drainage of 95 t CO_2(eq) ha^{-1} yr^{-1} over a 30-year time period under oil palm plantation is categorized as a high emission rate. Table D-5 shows peat emission factor groupings under oil palm plantation based on closed chamber measurement.

It should be noted that groundwater table of peat soil under oil palm plantations as deep as 60 cm is considered most representative and recommended as the best management practice for maintaining the low emission, where the production of oil palm (FFB, fresh fruit bunch) is also still in high level (Figure D-3). Based on data availability of the emission that measured by using closed chamber method (Table D-5) and groundwater level of 50 to 60 cm below soil surface, I have then calculated the average of emission rate under oil palm plantation as high as 43.6 t CO_2(eq) ha^{-1} yr^{-1}. Therefore, I recommend that this value is the most appropriate peat soil emission factor; such value has comparable with that of Melling's report [Melling *et al*. 2007] of 41 t CO_2(eq) ha^{-1} yr^{-1} with root respiration included.

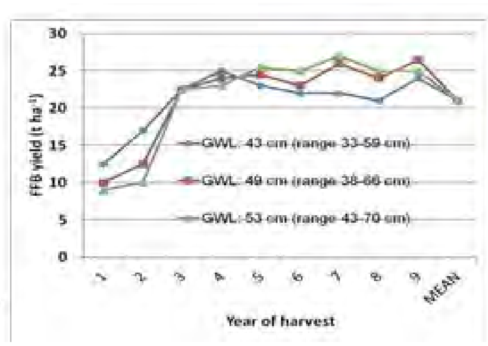
Table D-5. Peat Emission-Factor Groupings Under Oil Palm Plantation Based on Different Sources, Which Are Measured by Using Closed Chamber and Peat Subsidence Methods

Carbon emission from peat ($t\ CO_2\ ha^{-1}\ yr^{-1}$)	Remarks	References
	Based on closed chamber	
20 – 56.5	Depend on age of oil palm; and having the limitations of short-term measurements and mixture of root respiration	Agus *et al*. [2010] Fargione *et al*. [2008] Jauhiainen *et al*. [2011] Melling *et al*. [2005] Melling *et al*. [2007] Murayama & Bakar [1996] Murdiyarso *et al*. [2010] Reijnders & Huijibregts [2008] Wicke *et al.* [2008]
33.3 8 38.5 2 43.0 0 45.4 5	Immature oil palm 9 years old mature oil palm 15 years old mature oil palm 21 years old mature oil palm All these values have the limitations of short-term measurements and mixture of root respiration	Indonesian Oil Palm Research Institute (IOPRI) [2009]
63.0 4	Mean emission calculated from the emissions that measured at the 8-position between nearest (1.0 m) and further (4.5 m) from the 15-year old oil palm trees, where groundwater levels were ≥100 cm below soil surface; having the limitations and mixture of root respiration.	Sabiham *et al*. [2014]
	Based on peat subsidence	
8 5 (Std Dev: 21)	None involves directs measurement of the change in carbon stock; groundwater level was assumed at 85 cm below soil surface	Couwenberg *et al*. [2010] Delft Hydraulics [2006] Hooijer *et al*. [2011] Hooijer *et al*. [2010] Wösten *et al*. [1997]

Figure D-3. Groundwater level in peat in relation to carbon flux (a) and oil palm production (b)



(a) Data from Maswar [2011]



(b) Source: Othman [2010]

The emissions from peat soil under oil palm plantations shown in Table 5 exclude the important of oil palm roots on the total CO_2 emission. Jauhiainen *et al*. [2012] have been reported that the *Acacia* roots have important contribution to CO_2 flux in peat soils of Kampar, Riau. However, there are few reports concerning the contribution of root respiration to the total CO_2 emission from peat soil under oil palm plantation due to several difficulties in measuring respiration from oil palm roots directly in flux-based studies. Relative contribution of root respiration in mineral soil to the total CO_2 flux was obtained successfully by Werth and Kuzyakov [2008], where the contributing proportion was found using isotopes ^{13}C and ^{14}C; the result showed that the relative contribution of root respiration to the total flux ranged from 69 to 94%. In humid temperate region, the contribution of root respiration in peat soil range from 55% to 65% of the total soil respiration.

The relative contribution of root respiration to the total CO_2 fluxes of root respiration and peat oxidation from peat soil of Muaro Jambi, Sumatra (1^o 43' 0.7" S; 103^o 52' 56.7" E) under the 15- year-old oil palm plantation was reported by Sabiham et al. [2014]; this relative contribution of root respiration was of 74%. The average CO_2 flux based on its measurement per oil palm tree at the 8-position observation points between the nearest (1.0 m) and the further (4.5 m) from oil palm tree was of 63.04 t CO_2 ha^{-1} yr^{-1}. Dariah *et al*. [2013] have been reported that contribution of oil palm root to the total CO_2 flux from peat soil at distances of 1.0, 1.5, 2.0, and 2.5 m from the 6-year-old oil palm trees was of 49%, 42%, 31%, and 17%, respectively. These indicate that the age of oil palm has clearly influenced the root-related contribution to the total CO_2 fluxes.

2. Potential adjustment of emission factor from Hooijer *et al.* [2012]

It should be noted that the process of peat subsidence is not simple to be calculated because it depends on several factors such as peat compaction, peat consolidation, peat decomposition (peat oxidation), and the loss of peat materials due to erosion. Peat consolidation can be estimated by using the method based on the decrease of groundwater level of peat, and peat oxidation can be predicted by flux-based studies. However, there is lack of information about how much the rate of peat subsidence due to respective compaction and erosion processes. Therefore, estimating the most appropriate value for the peat soil emission factor based on subsidence research has to be reconsidered again. I agree that subsidence based technique seems to have better long-term effect of drainage on carbon stock depletion of peat as opposed to the technique of closed chamber measurement which reflects instantaneous CO_2 efflux and based on the majority of research design. However, subsidence technique is still questionable whether the accuracy of carbon-stock depletion measurement is valid or not, since the complete measurement of peat BD and org-C content throughout peat profiles was not conducted.

As I have already mentioned before that org-C content in the upper layer of peat soil depends on specific locations that varies from 20% to 58%, and vertically (at peat profile) it varies from 60% at the peat surface and 25% in the subsoil [Kanaphaty, 1979; Tie, 1982]. Our experiences, based on peat soil survey in Sumatra and Kalimantan, org-C content mostly ranged from 30% to 55%.

Therefore, I recommend that the value of the most appropriate peat org-C content that can be used by US-EPA is not more than 45%, and it has comparable with that of our finding in the Indonesian peats which had the majority of less than 48%.

In relation to peat BD, Agus and Wahdini [2008] showed that peat BD in oil palm plantation varies from more than 0.25 g cm^{-3} at the depth of 0-50 cm to 0.20-0.25 g cm^{-3} at the depth of 150-200 cm. They also reported that under secondary forest, peat BD varies from about 0.05 g cm^{-3} at the depth of 0 to 100 cm up to about 0.1 g cm^{-3} at the depth of 450 to 500 cm. Marwanto [2012] reported that peat BD in oil palm plantation of Muaro Jambi, Sumatra varies from 0.09 to 0.22 g cm^{-3} at the depth of 0-50 cm; the high peat BD was mostly at the depth of 0-30 cm that varies from 0.14 to 0.22 g cm^{-3}. In the case of peat BD in oil palm plantation, I believe that the high BD at the upper layer of peat is caused by peat consolidation due to drainage and by peat compaction due to intensive cultivation. These data clearly show: (i) a high range of BD for peat before and after drained peat developed, and (ii) higher BD at the upper layer of the drained peat compared with those reported by Hooijer *et al.* [2011] and Hooijer *et al.* [2012]. This explains that generalized assumption of peat BD is not applicable. Therefore, I recommend that the value of peat BD that can be used by US-EPA should be in the range between 0.07 to 0.1 g cm^{-3} for peat soil at the start of drainage, and between 0.18 to 0.22 g cm^{-3} for peat soil after drained peat developed, i.e. for cultivated peat for oil palm plantation, which means after subsidence started.

Regarding the percent of subsidence due to oxidation, it should be noted that papers reviewed by Page *et al*. [2011] which is shown contrastingly different estimation of peat oxidation/subsidence ratio. Couwenberg *et al*. [2010] reviewed the papers to estimate oxidation/subsidence ratio, where they came to conclude it at 40%, Wösten *et al*. [1997] estimated it at 60%, and Hooijer *et al*. [2011] gave with a figure of 92%. However, Kool *et al*. [2006], based on their measurement of the changes of peat ash-content and peat subsidence in Central Kalimantan which was not reviewed by Page *et al*. [2011], concluded that oxidation was only a small portion of the subsidence while consolidation and compaction is the major one. As I have mentioned before that contribution of oil palm root respiration, which depends on age of cultivated crops, and specific location, ranged from 17% to 74% [Dariah *et al*. 2013; Sabiham *et al*. 2014]. These values could be used as another parameter for correcting the high ratio of oxidation/subsidence proposed by Hooijer *et al*. [2011]. Based on this information, I recommend that the most appropriate oxidation/subsidence ratio of peat soil under oil palm plantation is 44% which comparable with review result of Couwenberg *et al*. [2010].

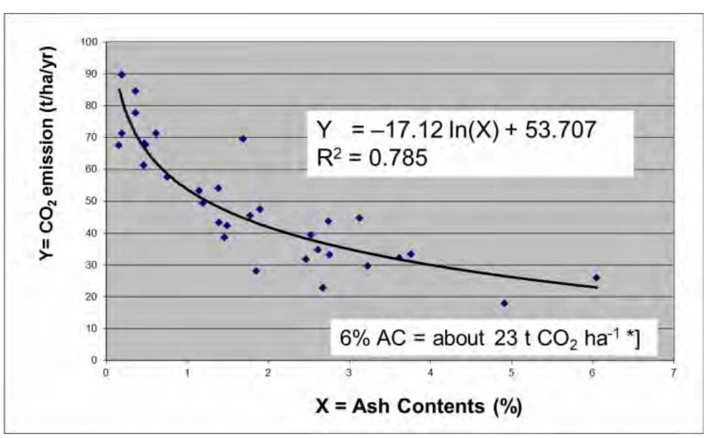
3. Directionally of estimate

Regarding the peat emission factor of 95 t CO_2(eq) ha^{-1} yr^{-1} used by US-EPA which has referred to Hooijer *et al*. [2012], Hooijer *et al*. [2011], and Page *et al*. [2011], it is likely to overestimate of the average greenhouse gas (GHG) emission from peat soil drainage under oil palm plantation in Southeast Asia, particularly in Indonesia. Several reasons are discussed here. The discussion is based on Research Triangle Institute (RTI) instruction.

a. Variation in the type of peat soil

One of the important parameter that causes variation in the type of peat soil is mineral content or ash content. In the upper layer of thick peat (>3 m thick), ash content is mostly low to very low (<5% of oven dried peat) compared to that in the bottom layer due to the influence of mineral soil underlying the peat. However, in some locations, ash content in the upper layer at the depth of 0-50 cm is often found in high level (5-6% of oven dried peat). Sedimentation during flooding is the cause of the increasing ash content in peat. Based on our experience, such condition could decrease the emission [Sabiham *et al*., 2012] (Figure D-4).

Figure D-4. The Relationship Between Ash Content of Peat Soil Under Oil Palm Plantation at Several Locations in West and Kalimantan Provinces



Regarding org-C content, it clearly influences the total carbon stock of peat soil, meaning that org-C stock is one of the main parameters that should intensively be measured in order to meet an accurate estimation of the carbon loss through subsidence research technique. Org-C content of peat soil also depends on the type of peat soil. Peat soil with high content of mineral material (ash content) showed org-C content in low level [Kanaphaty, 1979; Tie, 1982]. Therefore, the assumption of peat org-C of 55% is to be overestimate.

Not much information I found that thickness of peat soil under oil palm plantation is categorized as one of the main parameters which could influence the emission measured by using the closed chamber technique. Sabiham *et al*. [2012] reported that peat thickness had no correlation with CO_2 emission measured by using such technique; they conclude that although peat soil has the thickness of >3 m, gas CO_2 was emitted only from oxidized layers at a certain groundwater level. This means that water content at surface layer which has relationship with groundwater level and precipitation is also the important factor in relation to CO_2 production. Hooijer *et al*. [2012] also reported that no statistically significant relation between subsidence rate and peat thickness (R^2 =

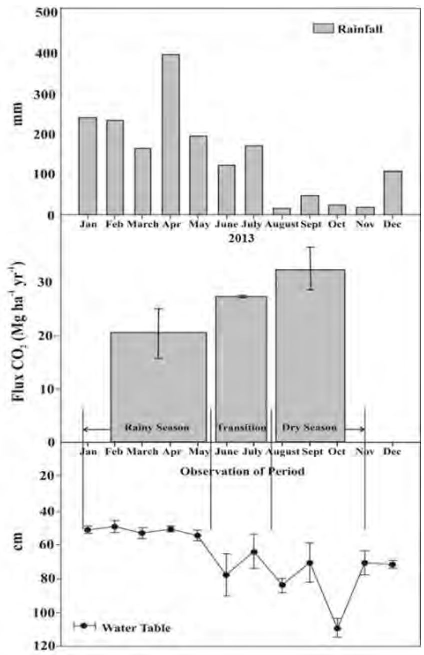
0.002), with being around 5 cm yr^{-1}. Instead, Hooijer *et al*. [2010] used the change of the groundwater level depth, rather than the thickness of peat, for estimating the change of CO_2 emission. They then drew a linear relationship whereby the rate of the emission increases as much as 0.91 t CO_2 ha^{-1} yr^{-1} with every 1.0 cm decrease in groundwater level depth.

Regarding extent of peat swamp forest degradation, it has close relationship with above-ground biomass. In a peat area, significant amount of carbon stock is depending on available above- ground biomass. Default values of the carbon stock used as emission factor for oil palm plantation ranged from 23 to 60 t C ha^{-1}, lower than that for undisturbed and disturbed swamp forest which has the range from 90 to 200 t C ha^{-1} and 42 to 82 t C ha^{-1}, respectively [Agus *et al*., 2013]. However, for determining the peat-oxidation-based emission in oil palm plantation, the extent of degradation is not the main factor. The extent of degradation is mostly not caused by expansion of plantations [see Pagiola, 2000], and it can only be used for determining the emission factor due to land use changes.

b. Precipitation regime

Regarding annual rainfall pattern, it clearly influences groundwater level in the drained peat soil. Nurzakiah [2014], based on her research during 2013 at peat soil under rubber garden in Central Kalimantan (2° 30'30" S; 114° 09'30" E), has been reported that during dry season groundwater level rapidly depleted in peat profile (Figure D-5). This groundwater level pattern was derived from piezometric time series data collected at the same year. Because the depletion of groundwater levels, the emission measured using the closed chamber technique was higher compared to that in rainy season (Figure D-5), but it was still much lower than the emission factor which has been used by US-EPA.

Figure D-5. CO_2 Flux (middle), Groundwater Level Fluctuation (below), and Annual Rainfall (above) Based on Observation Results During 2013



Based on Figure D-5, therefore, water management in drained peat soil is important to be done for maintaining groundwater level and conserving as much water as possible for the incoming dry season through water control structures such as water gates/stop logs in order to reach a level of groundwater as same high as the level during rainy season. Because the plantation management could manage in maintaining groundwater at certain level following the RSPO Guideline, which could be able to decrease the emission, so the emission factor used by EPA, i.e. 95 t CO_2(eq) ha^{-1} yr^{-1}, seems to be overestimate.

c. Differing water management practices at plantations

Peat development approach for plantations is always based on high production of the planted crop(s). In order to meet the production in a high level, the management of plantations then developed the peat soil to change its ecosystem from anaerobic condition (swampy condition) into aerobic condition (an oxidized peat condition at the upper layers of <50 cm and

>50 cm during rainy and dry seasons, respectively) as drained peat soil through the construction of canals. According to RSPO Guideline, however, the drained peat soil under oil palm plantation is a condition of peat soil in which groundwater level should be maintained as deep as 60 cm below soil surface. This groundwater level has been considered by the management of oil palm plantation as the most representatives and recommended as the best management practice not only for maintaining the high production, but also for keeping the emission in low level.

d. Different type of plantations

Different type of plantations, such as *Acacia* and oil palm plantations, has a different system in water management and crop cultivation. Hooijer *et al*. [2012], based on their calculation of total cumulative carbon loss from *Acacia* and oil palm plantations, found that because both the very high loss in the first of 5 years, they then accounted the lower loss in the subsequent period. From their calculation, over 25 years period they found the high average carbon loss of 90 t CO_2(eq) ha^{-1} yr^{-1} for the *Acacia* plantation and 109 CO_2(eq) ha^{-1} yr^{-1} for the oil palm plantation, and for over 50 years period the values become 79 and 94 CO_2(eq) ha^{-1} yr^{-1}, respectively.

However, to calculate the average carbon loss over 25 and 50 years period for *Acacia* and oil palm plantation which are respectively becomes 100 and 86 CO_2(eq) ha^{-1} yr^{-1}, is not scientifically justifiable.

e. The approach used by Hooijer et al. [2012] to estimate emission during the first five years after drainage

Estimating emission during the first 5-years after drainage for oil palm plantation that based on an assumption of the same subsidence in *Acacia* plantation proposed by Hooijer et al. [2012] has several weaknesses particularly in using the data of peat BD and org-C as the main factors for calculation. As I have mentioned before, peat soil has high variation in terms of peat properties from one location to the others; therefore, using assumption on the subsidence of peat under oil palm plantation based on that under *Acacia* plantation is not correct. The other weakness is in determining a total of 0.86 m of the total subsidence of 1.42 m at the *Acacia* plantation over the first 5-years that was caused by a combination of compaction and oxidation; the question is how to differ exactly the subsidence due to compaction and oxidation in order to meet average peat oxidative CO_2 emission? These are the main problems in estimating the emission from peat soil under oil palm plantation at the first five years cultivation after drainage that proposed by Hooijer et al. [2012], because some data for calculation were taken by them from different type of plantation.

f. Omission of methane and nitrous oxide emissions

Although, recent evidence shows that some methane (CH_4) emissions occurred from the surface of drained peat soil and from the ditch networks constructed during drainage [Minkkinen and Laine, 2006; Schrier-Uijl *et al*., 2011; Hyvönen *et al*., 2013], but Melling *et al*. [2005] shows that CH_4 emission from drained peat soil under oil palm plantation was zero. Therefore, I agree with Hooijer *et al*. [2012] assumption that no carbon is lost as CH_4 from drained peat soil under oil palm plantation.

Regarding the nitrous oxide (N_2O) emission from peat soil under oil plantation, Hooijer *et al*. [2012] also assumed that no CO_2(eq) in their calculation is lost as N_2O. Melling *et al*. [2007] reported that N_2O emission from drained peat soil under oil palm plantation was of only 0.0012 t N_2O-N ha^{-1} yr^{-1} which could be categorized as very low even after converted to CO_2 emission. Therefore, I convinced that the assumption of Hooijer *et al*. [2012] was valid.

g. Omission of emission due to fire

It is true that omission of this factor caused EPA's emission to underestimate emission, if the management of oil palm plantation cultivated the peat by burning method. Instead, the emission due to fire (wildfire) was previously reported, but it mostly existed outside the plantations and it had very high uncertainty. So far, no burning method has been used by the management of oil palm plantation. On the ***Permentan*** (the Minister of Agriculture Regulation) No. 14, 2009 clearly instructed that cultivating peat soil for oil palm should be conducted by zero burning. Therefore, the emission due to fire should be neglected in the calculation to estimate the emission factor from peat soil under oil palm plantation.

h. Omission of incidentally drained peat swamps adjoining the plantations

EPA's report stated that the previous decade over 50% of oil palm expansion grown on areas classified as the forest. Table 4 showed the result of Agus *et al*. [2011] analysis which is substantiated by the report of Pagiola [2000] that the expansion of oil palm plantation between 1990 and 2010 used only around 34%, in which about 28% was degraded forest. Recently, on the ***Inpres*** (the Presidential Instruction) No. 10, 2011 clearly stated the moratorium of new permit for using primary forest and peat soil for any kinds of alternative uses including oil palm plantation should be implemented. Therefore, EPA's analysis in estimating significant indirect emissions from land uses changes is suggested to be exclusion.

4. Intergovernmental Panel on Climate Change (IPCC) report

It should be noted, why does the value of emission factor of 40 t CO(eq) ha^{-1} yr^{-1} for the Tier 1 not include the emission for the first 6 years after drainage? Firstly, it was not captured by Tier 1 methodology due to lack of data for deriving default emission factor measured by using closed chamber technique. Secondly, although there are studies based on the subsidence rate measurement that have been reported a pulse of higher emissions which occurs right after drainage, but the calculation in order to meet the average peat oxidative CO_2 emission was only based on peat consolidation and peat compaction. In fact, before drainage, the upper layer of peat under the forest vegetation was mostly fibric (immature) which having high porosity. So, the subsidence at the first 5-6 years after drainage would be very rapid due to the decrease of groundwater level. This means that carbon loss due to peat oxidation would not be easy to calculate using subsidence research, particularly at several years immediately after drainage.

a. *Would the emission factor of 40 t CO_2 ha^{-1} yr^{-1} proposed by IPCC [2014] be appropriate for EPA?*

It would be appropriate for EPA to use the IPCC Tier 1 default emission factor of 40 t CO_2 ha^{-1} yr^{-1} from peat soil under oil palm plantation, for which groundwater level of peat soil should be maintained at the depth of ≤60 cm below soil surface. The value as high as 44 t CO_2 ha^{-1} yr^{-1}, as I have already mentioned with detailed information, are proposed as the most appropriate for the Agency's consideration to decide the appropriate emission factor, which is comparable with IPCC [2014].

b. *Should the emission factor that EPA uses include the emission pulse that occurs in the first several years immediately following drainage?*

Hooijer *et al*. [2012] applied the method for determining carbon stocks through subsidence studies at both peat soils under oil palm and *Acacia* plantations using the assumption that total subsidence of peat under oil palm plantation is the same subsidence with that under *Acacia* plantation, i.e. 1.42 m over the first 5 years after drainage. By this method, they then result a subsidence rate of 5 cm yr^{-1} in the subsequent 13 years, an equivalent average peat oxidative CO_2 emission of 119 t ha^{-1} yr^{-1}. However, this analyses may have confused different location based plantation, oil palm and *Acacia* plantations. Because of this weakness, which has consequence to the quality of the result of carbon loss, I suggest that EPA should be considered to exclude the emission pulse that occurs in the first several years after drainage (see also my argumentation in the points 4 and 5).

c. Should EPA include DOC and fire emission factors in the overall emission factor?

Regarding DOC (dissolved organic carbon), it is commonly the largest component of waterborne carbon loss or carbon export from the area of peat soil, which is categorized as one of off-site C emissions [Dawson *et al*., 2004; Jonsson *et al*., 2007; Dinsmore *et al*., 2010]. From the tropical Peat swamp forests (Indonesia and Malaysia), carbon exports with measured fluxes were of the range 0.47 to 0.63 t C ha^{-1} yr^{-1} [IPCC, 2014]; while from drained peat soil (from same countries), they were of the range 0.63 to 0.97 t C ha^{-1} yr^{-1} [Inubushi *et al*., 1998; Moore *et al*., 2013]. This means that DOC fluxes from both natural forest and drained peat soils is not much different. Because DOC fluxes belongs to the off-site C emission, where the fluxes from both different peat areas is very low, therefore, I suggest that EPA is no need to include DOC fluxes in the overall emission factor for peat soil under oil palm plantation.

Regarding fire emission factor, as I have already stated before, it had very high uncertainty. If the fire exists it is mostly outside the plantations; no management of the plantations recommends to using fire during peat soil cultivation for oil palm. The Minister of Agriculture Regulation has been instructed to all managements of oil palm plantation through the ***Permentan*** No. 14, 2009 that cultivating peat soil should be carried out by zero burning. Therefore, I also suggest excluding fire emission factor in the overall emission factor for peat soil under oil palm plantation.

d. Do you agree that the science on particulate organic carbon (POC) and the dissolved inorganic carbon (primarily dissolved CO_2) is not sufficient for EPA to include in the peat soil emission factor?

POC is generally a negligible component of the carbon balance of the natural peat soil; however, disturbance of peat soil through land use changes, including drainage, burning (managed burning and wildfire, conversion to arable land and peat extraction, yields a high rate of POC-loss via the waterborne and wind erosions [IPCC, 2014]. However, for drained peat soil under oil palm plantation that has been cultivated carefully by the management, which should follow regulations through the best management practices, such as zero burning method during land preparation and maintaining groundwater at certain level in order to avoid over dry of peat materials during dry season, POC should be at low level. Therefore, EPA is no need to include POC loss in the overall emission factor for peat soil under oil palm plantation.

Regarding the dissolved inorganic carbon (primarily dissolved CO_2) derived from autotrophic and heterotrophic respirations, I agree that it still not sufficient for EPA to include in the peat soil emission factor. Research on these topics for tropical drained peat-soil under oil palm plantation is still rare, although from several research results [Dariah *et al*., 2013; Sabiham *et al*., 2014] indicate that the contribution of root respiration could be considered as the value for correction factor of the carbon emission, particularly for such emission measured by closed chamber technique.

5. Additional Input

Peat soil in the tropical regions, such as in Indonesia, is rather similar in peat composition, being very rich in wood, i.e. more or less decomposed trunks and branches derived from the former vegetation covers [Sabiham, 1988]. In relation to this peat composition, the Indonesian peat soils under the forest vegetation contain mostly fibric peat with have high total porosity that showed in the range of 88 to 93% based on the total volume [Sabiham, 2010] with the average total porosity of about 90%. This parameter is very important for calculation of the carbon loss using subsidence measurement technique, particularly for the first 5-years after drainage. Because fibric peat has very high total porosity, it causes that subsidence of peat in the first several years immediately after drainage is very rapid, so it would give confusion in the calculating subsidence rate due to peat oxidation.

The other important factor that influenced the subsidence rate of peat is a critical water content (CWC). The value of the CWC could be resulted by calculation method based on the relationship between water content at certain levels and the proportion of irreversible drying of organic matter [Bisdom *et al*., 1993]. The irreversible drying is a condition of organic matter in which the organic materials could not be able to adsorbing water again. Based on our observation on the upper layer of peat soil in the first year immediately after drainage, fibric peat has higher average value of the CWC (364.9% w/w based on dried oven) compared to hemic and sapric peats which have the average values of 263.9% and 253.6% w/w, respectively. Fibric peat needed a shorter period to reach an irreversible drying condition compared with hemic and sapric peats. Peats at the condition of irreversible drying are called as pseudo-sand, at which carbon loss (emission) due to peat oxidation could not exist, but it very easy to be fire.

IV. Closing Remarks

a. *Emission factor of 95 t CO_2 ha^{-1} yr^{-1} derived from the results of subsidence measurement technique, not from CO_2 flux measurement (carbon stock changes), had several weaknesses, although subsidence measurement at a long term period after drainage is the best method; some difficulties in getting data from the same sites under the same plantation crops were the main problem for subsidence measurement technique.*

b. *I suggest that US-EPA choose the emission factor as high as 44 t CO_2 ha^{-1} yr^{-1} that represents direct measurements of CO_2 flux using closed chamber technique from the location of Southeast Asia countries and thus at present it most appropriate peat soil emission.*

c. *Although there are still lacks of information regarding dissolved inorganic carbon (CO_2), I propose that US-EPA should consider to use root respiration value from peat soil under oil palm plantation as a correction factor for carbon emission.*

d. *Omission of CH_4 and N_2O emission and omission of the emission due to fire (wildfire) from peat soil under oil palm plantation are valid. Because DOC and POC losses are very few, so US-EPA is no need to include them in the overall emission factor for peat soil under oil palm plantation.*

e. *Subsidence research for the future should address the uncertainty emission factor; therefore, the measurement of subsidence rate in order to determine the change of carbon stock should include the direct measurement of BD, org-C content, and the total porosity and critical water content of peat at the same site for the long-term multi-location subsidence research.*

References

Agus, F., I.E. Henson, B.H. Suhardjo, N. Harris, M. van Noordwijk, and T.J. Killen. 2013. Review of emission factors for assessment of CO_2 emission from land used change to oil palm in Southeast Asia. Technical Panels of the 2nd Greenhouse Gas working Group of the Roundtable on Sustainable Palm Oil (RSPO).

Agus, F., P. Gunarso, B.H. Sahardjo, K.T. Joseph, A. Rashid, K. Hamzah, N. Harris, and M. van Noordwijk. 2011. Strategies for CO_2 emission reduction from land use changes to oil palm plantations in Indonesia, Malaysia and Papua New Guinea. RSPO, Kuala Lumpur. Presented at the Roundtable 9 of the Roundtable on Sustainable Palm Oil, Kota Kinabalu, Malaysia. (http://www. rt9.rspo.org/ckfinder/userfiles/files/P6_3_Dr_Fahmuddin_Agus(2).pdf

Agus, F., E. Handayani, M. van Noordwijk, K. Idris, and S. Sabiham. 2010. Root respiration interferes with peat CO_2 emission measurement. pp. 50-53 In Proceedings 2010 19th World Congress of Soil Science, 1–6 August 2010, Brisbane, Australia. Published on DVD.

Agus, F. and W. Wahdini. 2008. Assessment of carbon stock of peatland at Tripa, Nagan Raya District, Nanggroe Aceh Darussalam Province of Indonesia. Indonesian Centre for Agricultural Land Resources Research and Development and World Agroforestry Centre (ICRAF). Bogor, Indonesia.

Bisdom, E.B.A., L.W. Dekker, and J.F. Th. Schoute. 1993. Water repellency of sieve fraction from sandy soils and relationship with organic material and soil structure. *Geoderma* 56:59-70.

Couwenberg, J., R. Dommain, and H. Joosten. 2010. Greenhouse gas fluxes from tropical peatlands in south-east Asia. *Global Change Biology* 16: 1715-1732.

Dariah, A., S. Marwanto, F. Agus. 2013. Root- and peat-based CO_2 emission from oil palm plantation.

Mitig. Adapt. Strateg. Glob. Change. Published online. Springer. DOI 10.1007/s11027-013-9515-6.

Dawson, J.J.C., M.F. Billett, D. Hope, S.M. Palmer, and C.M. Deacon. 2004. Source and sinks of aquatic carbon in a peatland stream continuum. *Biogeochemistry*. 70:71-92.

Delft Hydraulics. 2006. Peat-CO_2, Assessment of CO_2 emissions from drained peatlands in Southeast Asia (Report Q3943). Delft, The Netherlands: A. Hooijer, M. Silvius, H. Wösten, and S. Page.

Dinsmore, K.J., M.F. Billett, U.M. Skiba, R.M. Rees, J. Drewer, and C. Helfter. 2010. Role of the aquatic pathway in the carbon and greenhouse gas budget of a peatland catchment. *Global Change Biology* 16:2750-2762.

Hyvönen, N.P., J.T. Huttunen, N.J. Shurpali, S.E. Lind, M.E. Marushchak, L. Heitto, and P.J. Martikainen. 2013. The role of drainage ditches in greenhouse gas emission and surface leaching losses from a cutaway peatlands cultivated with a perennial bioenergy crop. *Boreal Environment Research* 18:109-126.

Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. 2008. Land clearing and the biofuel carbon debt. *Science* 319: 1235-1238.

Gunarso, P., M.E. Hartoyo, and Y. Nugroho. 2013. Analysis of land-cover changes to oil palm in

Indonesia (in Indonesian, *Analisis penutupan lahan dan perubahannya menjadi kelapa sawit di Indonesia*). Universitas Negeri Jakarta. Indonesia

Holmes, D. 2000. Deforestation in Indonesia: A review of the situation in Sumatra, Kalimantan, and Sulawesi. Jakarta. World Bank.

Hooijer, A., S. E. Page, J. Jauhiainen, W..A. Lee, X.X. Lu, A. Idris, and G. Anshari. 2012. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences* 9:1053-1071.

Hooijer, A., S.E. Page, J. Jauhiainen, W.A. Lee, X.X. Lu, A. Idris, and G. Anshari. 2011. Subsidence and carbon loss in drained tropical peatland: reducing uncertainty and implications for emission reduction options. *Biogeosciences Discuss.* 8:9311-9356.

Hooijer, A., S.E. Page, J.G. Canadell, M. Silvius, J. Kwadijk, H. Wösten, and J. Jauhiainen. 2010. Current and future CO_2 emissions from drained peatlands in Southeast Asia. *Biogeosciences* 7:1505-1514.

IOPRI, Indonesian Oil Palm Research Institute. 2009. CO_2 emission on oil palm plantation: field observation. Paper presented on Indonesian Palm Oil Conference and price Outlook 2010. Bali, December 1-4 2009.

Inubushi, K., A. Hadi, M. Okazaki, and K. Yonebayashi. 1998. Effect of converting wetland forest to sago palm plantation on methane gas flux and organic carbon dynamics in tropical peat soil. *Hydrological Processes* 12:2073-2080.

IPCC, Intergovernmental Panel on Climate Changes. 2014. 2013 Supplement to the 2006 IPCC guidelines for national greenhouse gas inventories: Wetlands. Task Force on National Greenhouse Gas Inventories. WHO-UNEP.

Jauhiainen, J., A. Hooijer, and S.E. Page. 2012. Carbon dioxide emission from an *Acacia* plantation on peatland in Sumatra, Indonesia. *Biogeosciences* 9:617-630.

Jauhiainen, J., A. Hooijer, and S.E. Page. 2011. Carbon dioxide fluxes in an *Acacia* plantation on tropical peatland. *Biogeosciences Discuss.* 8:8269-8302.

Jonsson, A., G. Algesten, A.K. Bergström, K. Bishop, S. Sebek, I.J. Tranvik, and M. Jansson. 2007.

Integrating aquatic carbon fluxes in a boreal catchment carbon budget. *Journal of Hydrologi* 334:141-150

Kanapathy, K. 1976. Fertilizer requirement on peat soils. Malaysian Agric. J. 50:292-307

Kool, D.M., P. Buurman, and D.H. Hoekman. 2006. Oxidation and compaction of a collapsed peat dome in Central Kalimantan. *Geoderma* 137:217–225.

Marwanto, S. 2012. Contribution of oil palm roots on CO_2 flux at peatland of Sungai Gelam Subdistrict, Muaro Bungo, Jambi (in Indonesian: *Kontribusi perakaran kelapa sawit terhadap fluks CO_2 di lahan gambut Kecamatan Sungai Gelam, Muaro Bungo, Jambi*). Magister Thesis. Graduate School of Agriculture, Bogor Agricultural University.

Maswar. 2011. Studies on carbon stock on tropical peatland drained for perennial crops (in Indonesian: *Kajian cadangan karbon pada lahan gambut tropika yang didrainase untuk tanaman tahunan*. Dissertation Doctor Program. Graduate School of Agriculture, Bogor Agricultural University.

Minkkinen, K. and J. Laine. 2006. Vegetation heterogeneity and ditches create spatial variability in methane fluxes from peatlands drained for forestry. *Plant and Soil* 285:289-304.

Melling, L., K.J. Goh, C. Beauvais, and R. Hatano. 2007. Carbon flow and budget in a young mature oil palm agroecosystem on deep tropical peat. *In*: Rieley J.O., C.J. Banks, and B. Radjagukguk (Eds.), *Proceedings of the International Symposium and Workshop on Tropical Peatland*, Yogyakarta, Indonesia. http://www.geog.le.ac.uk/carbopeat/media/pdf/yogyapapers/yogyaproceedings.pdf

Melling, L., R. Hatano, and K.J. Goh. 2005. Soil CO_2 flux from three ecosystems in tropical peatland of

Sarawak, Malaysia. *Tellus* 57B:1-11.

Moore, S., C.D. Evans, S.E. Page, M.G. Garnett, T.G. Jones, C. Freeman, A. Hooijer, A. Wiltshire, S. Limin, and V. Gauci. 2013. Deep instability of deforested tropical peatlands revealed by fluvial organic carbon fluxes. *Nature* 493:660-664.

Murayama, S., and Z.A. Bakar. 1996. Decomposition of Tropical Peat Soils. *Japan Agricultural Research Quarterly,* 30, 153-158.

Murdiyarso, D., K. Hergoualc'h, and L.V. Verchot. 2010. Opportunities for reducing greenhouse gas emissions in tropical peatlands, *PNAS* 107:19655-19660.

Nurzakiah, S. 2014. Estimation of the potential carbon emission from acrotemic and catotelmis peats. *J.Trop. Soil.* (in press)

Othman, H., A.T. Mohammed, F.M. Darus, M.H. Harun, and M.P. Zambri. 2011. Best management practices for oil palm cultivation on peat: Groundwater table maintenance in relation to peat subsidence and estimation of CO_2 emissions at Sessang, Sarawak. Journal of Palm Oil Research 23:1078-1086.

Othman, H. 2010. Best management practices (BMP) for oil palm planted in the field. Malaysian Palm Oil Board.

Page, S., E.R. Morrison, C. Malins, A. Hooijer, J.O. Rieley, and J. Jauhiainen. 2011. Review of peat surface greenhouse gas emissions from oil palm plantations in Southeast Asia. The International Council on Clean Transportation, Washington, DC.

Pagiola, S. 2000. Land use change in Indonesia. A background paper for Indonesia: Environment and natural resource management in a time of transition. World Bank.

Reijnders L. and M.A.J. Huijbregts. 2008. Palm oil and the emission of carbon-based greenhouse gases. *J. Cleaner Prod* 16 477-482.

Sabiham, S., S. Marwanto, T. Watanabe, S. Furukawa, U. Sudadi, and F. Agus. 2014. Estimating the Relative Contributions of Root Respiration and Peat Decomposition to the Total CO_2 Flux from Peat Soil at an Oil Palm Plantation in Sumatra, Indonesia. *J. Trop. Agric. Dev.* (in press)/

Sabiham, S., S.D. Tarigan, Hariyadi, I. Las, F. Agus, Sukarman, P. Setyanto, and Wahyunto. 2012.

Organic carbon storage and management strategies for reducing carbon emission from peatlands: A case study in oil palm plantations in West and Central Kalimantan, Indonesia. Pedologist 55(3):426-434

Sabiham, S. 2010. Properties of Indonesia peats in relation to chemistry of carbon emission.

Proceedings of the International Workshop on Soil Carbon organized by Food and Fertilizer Technology Center (FFTC) and the Indonesian Soil Research Institute, Bogor-Indonesia, September 2010.

Sabiham, S. 1988. Studies on peat in the coastal plains of Sumatra and Borneo. PhD Dissertation. Kyoto University, Kyoto, Japan.

Schrier-Uijl, A.P., A.J. Veraart, P.J. Leffelaar, F. Berendse, and F.M. Veenendaal. 2011. Release of CO_2 and CH_4 from lakes and drainage ditches in temperate wetlands. Biogeochemistry 102:265-279

Suhardjo, H., and I.P.G. Widjaja-Adhi. 1977. Chemical characteristics of the upper 30 cm of peat soils from Riau, Sumatra, Indonesia. *In*, Final Report, Agricultural Technical Assistance Programme (Indonesia-The Nederlands 1974-1977. pp.: 74-92. *Lembaga Penelitian Tanah, Bogor, Indonesia*. Tie, Y.L. 1982. Soil classification in Sarawak. Technical Paper No. 6. Department of Agriculture, Sarawak. 86p.

Tjondronegoro, S. M. P. 2004. From colonization to transmigration: Changing policies in population resettlement. *In*, Furukawa, H. et al. (eds.), Destruction, Health, and Development: Advancing Asian Paradigms. Kyoto University Press and Trans Pacific Press. 638p.

Werth, M., and Y. Kuzyakov. 2008. Root-derived carbon in soil respiration and microbial biomass determined by ^{14}C and ^{13}C. Soil Biol. Biochem. 40: 625–637

Wicke, B., V. Dornburg, M. Junginger, and A. Faaij. 2008. Different palm oil production systems for energy purposes and their greenhouse gas implications. *Biomass and Bioenergy*, 32, 1322-1337.

Wösten, J.M.H., A.B. Ismail, and A.L.M. van Wijk. 1997. Peat subsidence and its practical implications: A case study in Malaysia. *Geoderma* 78:25-36

Peer Review Response from Dr. Arina Schrier, CEIC (Climate & Environment International Consultancy)

Emission Factor for Tropical Peatlands Drained for Oil Palm Cultivation

1. Overarching charge question

For now, EPA chose the most appropriate value for the peat emission factor for oil palm on peat. Given the literature that is currently available (annex 1) for drained peat soils in tropical regions, the CO_2 EF for oil palm on peat given by Hooijer et al. 2012 (calculated for the first 30 years) is within the uncertainty range at the high end of published EF's. Hooijer et al. 2012 included the emissions in the first years of development. Emissions directly after and during plantation development are higher compared to the emissions of later years (Page et al., 2011; Hooijer et al., 2012). These elevated emissions are potentially driven by rapid consumption of a limited labile (readily decomposable) carbon pool, leaving behind a greater fraction of recalcitrant carbon in later years (Hooijer et al. 2012). By using the soil subsidence method for carbon loss estimates, Hooijer (2012) automatically included the losses of carbon transported by rivers, ditches and streams.

However, it is recommended to evaluate this value each year since more research becomes available and EF's for CH_4 and DOC emissions as well as initial pulse emissions are currently very uncertain although EF's are provided by IPCC. In fact, Hooijer et al. 2012 did not discuss in detail the separation between CO_2-C and CH_4-C emissions related to drainage of peat (ditch emissions) and given the assumptions made for the oxidation, compaction and consolidation components of soil subsidence (including the uncertainties and discussions around bulk density and carbon fraction of the peat) the following is recommended for the near future:

1. Consider a separation between 'base emissions' (the continues, long term emissions following land use change, and resulting from the continues drainage of peat soil for agriculture) from 'initial pulse emissions'. The reason is that the 'base EF' can be established with a small uncertainty range, while initial emissions, including CO_2 and CH_4 are much more uncertain and make the EF less strong in terms of uncertainty. It is recommended to add the initial pulse emissions as a 'multiplication factor' for the first five years based on the literature available. Hooijer et al. (2012) found that for the first 1-4 years after draining, average rate of carbon loss from Acacia plantation sites was 178 tons CO_2 ha^{-1} yr^{-1} at an average water depth of 70 cm, 262% greater than carbon loss 5-8 years after drainage. Until more studies are able to contribute information about the magnitude of these initial emissions within oil palm and similar plantation ecosystems, multiplying the base emissions rate (based on water table depth) by 2.6 offers a potential emissions estimate during the first five years after peat draining. It has to be noted that

this modification is highly uncertain. These results are strictly applicable only to peat with low mineral content and low bulk density (Hooijer et al. 2012).

2. Consider a cross-check with a meta-analysis of all available literature that fulfills strict (quality and method) criteria, and includes chamber-based research. The soil subsidence methods has advantages, but nonetheless it is an 'indirect' measure, or 'proxy' for the actual emissions and includes certain assumptions in the calculations (e.g. carbon fraction and bulk density) and besides, it cannot separate between carbon losses released as CO_2 and CH_4. Since CH_4 emissions are important in the consideration of the total warming potential (it is a 24 times stronger GHG) it is important to consider the height of these emissions. The chamber based method is used to measure the gas exchange between the soil and atmosphere 'directly'. By using this method the different GHG's (CO_2, CH_4 and N_2O) can be measured separately if done properly on land and on water (e.g. Jauhiainen et al. 2012). For fulfilling the criteria set by EPA for chamber based research, the total carbon cycle shall be considered and therefore also losses through water should be added (DOC losses, CH_4 from ditches, CO_2 from ditches (with no double counting)) as well as the initial pulse emissions directly after drainage. In all cases fire based emissions resulting from drainage should be added (either by using the new IPCC EF's provided or by using numbers that are and will be published for specific areas). In summary the meta-analysis should include:

    - Soil subsidence research: CH_4 and CO_2 should be separated and it is recommended to establish a separate multiplication factor for the first five years after drainage.
    - Chamber based research: DOC should be considered as well as ditch fluxes (avoiding overlap between DOC transported to the oceans and carbon released from drainage ditches and rivers) as well as the initial pulse emissions.
    - Research on fire emissions
        a. IPCC provides DOC TIER 1 values for drained tropical peat (Baum et al. 2008; Alkhatib et al. 2007; Yule et al. 2009; Moore et al. 2003)
        b. IPCC provides TIER 1 values for CH_4 released from ditches in tropical regions (0.449 t CH_4-C ha-1 yr-1 for drained abandoned tropical peat and 2.939 t CH_4-C for drained tropical pulp wood plantations on peat).
        c. IPCC provides default values for the initial pulse emissions following drainage, as well as Hooijer et al. 2012.

    Note that currently Carlson et al. (Union of Concerned Scientists and University of Minnesota) prepare a manuscript that involves a meta-analysis of current available peer reviewed and grey literature for the EF for oil palm on peat. This manuscript is in the second round of review and will be published approximately mid- 2014.

3. Recommended is to update the EF based on the crosschecks with available literature and based on the most recent publications and new knowledge on the different components of the total balance. A large part of the currently available research is too short term, or is concept research. Although the research of Hooijer et al. 2012 is robust, large scale and long term and perhaps currently the best study to base the EF on, there are still uncertainties around this study (initial pulse, the contribution of CH_4, DOC) that need to be updated by recent and new studies and it is better to have a broader spatial coverage of different peats and climate zones. The main issue with soil subsidence studies is that the different components of the total GHG and carbon balance cannot be separated and therefore also chamber based studies shall be considered in the establishment of a robust EF.

4. It is recommended for EPA to establish, besides a fixed EF for drained peat, also a water table dependent EF. Previous work suggests that the relationship between drainage depth and C loss is non-linear, especially at high (>80 cm) or low (<20 cm) water table depths (Jauhiainen et al. 2008, Verwer et al. 2008, Couwenberg et al. 2009, Hirano et al. 2009, Jauhiainen et al. 2012a). Note that currently, in many plantations in SE Asia the water table is varying between 100 cm and 50 cm (average around 75 cm) below field level. Therefore a linear least squares model relating emissions ($CO_{2OP>4yrs}$, tons CO_2 ha^{-1} yr^{-1}) to water table level (WT, cm) could be established at least for the range 20-80 cm. Like a few previous models (Wosten et al. 1997, Couwenberg et al. 2009, Hooijer et al. 2010). Given the relation between water table and CO_2 emissions, lower emission can be expected at higher water tables. The main question will be if a zero intercept can be assumed and besides if drains are not spaced properly and dams have not been built in the right way, and also because of the large seasonal variation of rainfall in Indonesia, over- or under-drainage is a common problem.

    a. Note that RSPO has launched its Best Management Practices in 2012, and the Malaysian Palm Oil Board has launched its Best Management Practices in 2011. RSPO advises to keep the water table between 40 and 60 cm below field level, or 50 – 70 cm in collection drains. MPOB advices in their management practices a water table of 30-50 cm below the peat surface in the field or 40 and 50 cm in the collection drain. Given the water table – emission relation of Hooijer and Couwenberg, reducing the average drainage depth to 50 cm compared to the current 75 cm could potentially lead to a future reduction of over 20 t CO_2 ha^{-1} yr^{-1} or even almost 30 tons CO_2 ha^{-1} yr^{-1} if a water table of 45 cm could be maintained. The reality is that maintaining the water table at 40-50 cm in a large plantation is generally not feasible with most current drainage lay outs. Therefore, RSPO and MPOB encourage plantation owners to optimize their drainage systems.

2. Potential adjustment of emission factor from Hooijer et al. (2012)

My recommendation would be to **NOT** use different values for organic carbon content and peat bulk density and oxidation percentage in the study of Hooijer et al. (2012), unless the authors of the publication agree on this.

Related to oxidation: The value of 92% oxidative contribution as proposed by Hooijer et al. (2012) is on the high end of published values, but until now it is the most robust study that was specifically designed to determine the contribution of oxidation to soil subsidence since drainage started. Note that in the method set out by Couwenberg & Hooijer (2013) an estimate of the oxidative component is not needed to determine emissions. Only subsidence rate, bulk density and carbon content of the peat below the water table have to be known. Nevertheless, the authors did calculate an oxidative contribution to subsidence of 80%. Jauhianen et al. (2012) calculated that around 80% of subsidence was a result of oxidation in a stabilized situation. Other, more short term studies calculated between 40 and 80% oxidative loss. It is clear that more research is needed to establish (if needed) a correction factor. Future research should focus on disentangling these different processes that result in soil subsidence and under what conditions they are different (rain fall, length of dry/wet period, peat type, mineral content).

Related to Carbon fraction: Page et al, 2011 (white paper) quotes carbon densities of 0.068 and 0.138 g C cm^{-3}. Couwenberg et al. (2010) gives a value of 0.068, who later corrected this value to 0.061 for C-Kalimantan and 0.044 for coastal peat swamp forests (Dommain et al. 2011). Note that this value would be applicable to the peat below the water table only and is (very) conservative when applied to the upper peat layer. The value of 0.138 g C cm^{-3} is taken from Ywih et al. (2009); this value is caused by very high peat bulk densities of ~0.300 g cm^{-3}. In summary, carbon concentration values on a dry weight basis of around 55% were found representative for hemic and fibric tropical peat in SE Asia. Similar values were reported by Couwenberg et al. (2010), Wösten et al. (1997), Warren et al. (2012), Hooijer et al. (2012), Dommain et al. (2011), Page et al. (2004) and Yulianto et al. (2007). Hergoualch and Verchot (2011) used a value of 50% (IPCC, 2003) if no C concentration was provided in a publication. Overall, carbon content of tropical peat ranges between 40% and 60% depending on the nature, mineral content and location of the peat. Lower values of 40% (Sajarwan et al., 2002), 23.8% (Jaya, 2007) and 26.0% (Sajarwan et al., 2002) are associated with samples taken near to the underlying mineral substrate or for peaty soils with a large proportion of inorganic material. Lower values that have been found in the past can be attributed to the method that was used to determine the carbon fraction. The basic principle for the quantification of soil organic carbon relies on the destruction of organic matter, which can be performed chemically (which was often used in the past) or via heat (which is currently used). In studies where chemical destruction was used the carbon fraction was underestimated with reported values of 20-30% in tropical peat. Currently, the method with elevated temperatures (loss-on ignition) is most common to determine the C fraction. Warren et al. (2012) suggest using values established by element elemental analysers only.

Related to peat bulk density: Page et al., 2011 (white paper) presented a comprehensive overview of bulk density (BD) values of tropical peat. In the given overview, only the study of Melling et al. (2007) provides values for BD in oil palm plantations (mean 0.20 g cm^{-3}, SD 0,007 g cm^{-3}). The lowest average bulk density values below the water table reported for large plantation areas are those in Hooijer et al. (2012) and Couwenberg & Hooijer (2013) which vary from 0.073 to 0.078 g cm^{-3} and are well within the range suggested by Page et al. (2011). Overall, in many studies a BD of around 0.1 g cm^{-3} is being assumed the most comprehensive value for the BD of tropical, drained peat. Note that plantation development on peat requires compaction before planting of trees to create optimal conditions to anchor the roots of palm trees. The compaction by heavy machinery starts after removing the vegetation and is in many cases practiced over a period of years before planting starts. Therefore, the density of the upper soil is higher in plantations compared to undisturbed peat soils. Othman et al. (2011) reported BD values before and after land development for oil palm of 0.14 - 0.09 g cm^{-3} and 0.26 - 0.16 g cm^3, respectively.

It is recommended to EPA to not amend or correct the study of Hooijer et al. (2012) with other numbers and/or defaults and/or multiplication factors for oxidation fraction, Bd or C fraction of the peat. Instead, the recommendations described under Charge Question 1 should be considered. It is recommended in the near future to not base the EF for oil palm on peat on 1 study, but to do a meta-analyses including soil subsidence based research and chamber based research added with values for the ‘missing’ components of the total C- and GHG balance.

3. Directionality of estimate

In summary: the EF for drained tropical peat provided by EPA (based on Hooijer et al. 2012) is an underestimation of the reality. The number provided by EPA excludes non-CO_2 emissions, it excludes emissions related to fire and off-site impacts.

a. *Variation in the type of peat soil (mineral content, carbon content, depth, extent of degradation, etc.).*

b. *Precipitation regime (annual rainfall, timing of rainfall, etc.).*

Add a+b. See earlier suggestion for performing a meta analyses to capture the spatial and temporal variability. The results of the meta analysis (including variations in peat soil and variations in climate) will result in a similar or slight overestimation of the EF provided by EPA (Hooijer et al., 2012).

c. Differing water management practices at plantations.

Add c. See earlier comments and discussion on the water table dependency of CO_2 and CH_4 emissions for tropical peats.

d. Different types of plantations (e.g., oil palm versus acacia).

Add d. The Wetlands Supplement of IPCC provides in its current and first version EF's for both oil palm and *Acacia*. However, the cited references do not support the numbers provided (see also discussion under Question 4).

The significant difference between the established EFs for oil palm and *Acacia* on peat provided by IPCC in the new Wetlands Supplement (11 vs 20 t C ha-1 yr-1) is in sharp contrast with the EFs given in available (scientific) literature. Available information suggests an almost similar EF for oil palm and *Acacia.* Hooijer et al. 2012 was the only study available in December 2013 that reported on EF's for oil palm and *Acacia* in the same study site:

Oil palm: 21.2 t C ha-1 yr-1

Acacia: 18.5 t C ha-1 yr-1

Husnain et al. (2014) is the second study that reports on the difference between oil palm and *Acacia* in the same area, which was not published at the time of writing of Chapter 2 of the Wetlands Supplement, but is now available:

Oil palm: 18 t C ha-1 yr-1

Acacia: 16.1 t C ha-1 yr-1

In conclusion: the only studies that measured in the same area on both oil palm and *Acacia* do not report a major difference between the EFs for oil palm and Acacia plantations on peat, but the slight difference reported indicates actually a higher EF for oil palm than for Acacia on peat. Tropical peat experts and government reviewers have expressed disagreement with IPCC on the large difference in IPCC report for oil palm and *Acacia* on peat. However, no explanation or scientific justification has been provided for the discrepancy yet. If the TIER 1 numbers of IPCC are going to be used, the Hooijer et al. numbers and thus EPA EF for oil palm is overestimated. However, I argue that the IPCC number is a wrong interpretation of the available literature (see discussion under Charge Question 4).

e. The approach used by Hooijer et al. (2012) to estimate emissions during the first five years after drainage.

f. Omission of methane and nitrous oxide emissions.

Add e+f. See discussion earlier. The recommendation to EPA is to include IPCC TIER 1 default values for

- N_2O (from drained peatlands): IPCC Wetlands Supplement, Table 2.5: summary of TIER 1 EF's for drained tropical peat
- CH_4 (from drained peatlands): IPCC Wetlands Supplement, Table 2.3: summary of TIER 1 EF's for drained tropical peat
- CH_4 (from drainage ditches in plantations): IPCC Wetlands Supplement, Table 2.4: summary of EF's for drainage ditches in drained tropical peats
- DOC (in plantation peat areas): IPCC Wetlands Supplement, Table 2.2: Default DOC emission factors for drained organic soils in tropical peatlands.

g. Omission of emissions due to fire.

Add g. Emissions due to fire

IPCC provides TIER 1 information for the EF directly to drainage related peat- and forest fires.

Although it is known that 'wet' peats do not burn, it is uncertain what part of the peat fires are directly related to drainage for oil palm and/or Acacia and what part is a direct result of the severe droughts that are a result of climate change. Given the fact that a main part of the peat- and forest fires is a direct result of drainage, the EF used by EPA is underestimated in this respect. EPA could indeed use the IPCC value provided in the Wetlands Supplement which later could be updated by more recent and more focused research.

The increased human interventions such as drainage of peat and the changes in climate (increase in temperature and droughts) are two main reasons that in many areas peat starts drying and becomes very susceptible to fire. Peat drainage is expected to continue at a high rate in the future since more and more peatland is developed for agricultural or excavation purposes. The high greenhouse gas (GHG) emissions that result from peat drainage and peat fires might entail positive feedbacks such as accelerating climate changes because of the increase in radiative forcing. In other words, negative impacts that arise from peat fires are expected to increase in the future since future climate change scenarios predict drought events of greater severity and frequency in many areas, including those with the potential for peat fires to occur. Emissions from peat fires currently have been estimated at roughly 15% of human induced emissions (Poulter et al., 2006; Hadden et al., 2013).

Since the 1980s, large scale fires in the peatlands of Indonesia have increased in frequency and intensity and have caused serious damage (Page et al., 2002). The largest peat fires registered took place in Indonesia during the El Niño dry season of 1997-1998 (previous severe fire events occurred in 1982, 1991, and 1994, and later in 1998, 2002, 2004, 2006 and 2010) and lasted for several months, destroyed over 10^4 km^2 of peat swamp with a loss of peat layers between 0.2 and 1.5 m in depth (Reins et al., 2009). Studies have shown that there is a direct link between the peat and forest fires and the peat drainage needed for the development of oil palm and timber plantations. Although burning for land clearing is forbidden by law in Indonesia, fire is commonly used in oil palm and timber plantations because it is cheap and effective (Tomich et al., 1998). By removing or disturbing the peat swamp forest, the risk of large-scale fires increases because such disturbances dry peat and leave much plant debris, which is flammable (Page et al., 2002). Also in Brunei, peat soils make up 18% of the land area and fire has been identified as a major threat. Studies show that fires in the dry El Niňo years started easily in accessible degraded peat areas, especially those close to roads and other infrastructure developments in peat swamp forest areas.

Estimates of carbon losses during peat fires differ, but are within a certain range per climate zone. It has been estimated that for example the 1997-1998 fires in Indonesia released between 0.8 to 2.6 Gton of carbon into the atmosphere in total, equivalent to 13–40% of the global fossil fuel emissions of that year (Page et al., 2002). Specified per square meter area of burn, Couwenberg (2010) estimated a release of 26 kg C m^{-2} yr^{-1} during the 1997 peat fires in Southeast Asia. Heil (2007) estimated that the mean burn depth and rate of fire related peat loss amounted to 34 cm per fire event and 26,1 kg C m^{-2} yr^{-1} averaged for the years 1997, 2001 and 2002 in an abandoned, degraded peat area in tropical SE Asia.

Some sources report that fire is not a dominant source of methane (CH_4) (e.g., Forster et al., 2007; Dlugokencky et al., 2011). Others report that CH_4 represents a significant contributor to the seasonal variability of atmospheric methane (e.g., Bousquet et al., 2006) and vd Werf et al. (2004) concluded in their study that over the period 1997-2001, Central America, South

America, Southern Africa, Southeast Asia, Canada and the Russian Far East where substantial contributors to the emissions of both CO_2 and CH_4. Van de Werf et al. (2004) concluded also that although previous studies have identified wetlands as the primary source of methane during the 1997-1998 anomaly in the tropics, all of the CH_4 anomalies observed in this period in SE Asia can be attributed to fires. This finding is confirmed by Worden et al. (2013) for the year 2006 based on methane observations over Indonesia.

Knowledge of peat fires and their huge impacts has increased in recent years, however, available scientific research is scattered and for the purpose of understanding and tackling the main problems related to peat fires, there is a need for a summary of this information. The just launched Wetlands Supplement of IPCC for the first time reports on the carbon impacts of fire for tropical peat:

Lfire = A * Mb * Cf * Gef * 10-3
Lfire = amount of CO_2 or non-CO_2 emissions, e.g., CH_4 from fire, tonnes
A = total area burned annually, ha
MB = mass of fuel available for combustion, tonnes ha^{-1} (i.e. mass of dry organic soil fuel) (default values in Table 2.6)
Cf = combustion factor, dimensionless
Gef = emission factor for each gas, g kg^{-1} dry matter burnt
With Gef for Tropical peat (Christian et al., 2003):

464 g per kg dry matter (CO_2-C)
210 g per kg dry matter (CO-C)
21 g per kg dry matter (CH_4-C)

and MB for tropical peat
Tropical
Wildfire (undrained peat): No literature found
Wildfire (drained peat): 353 (mean in t dry matter per ha peatland burnt)
Prescribed fire (agricultural land management): 155 (mean in t dry matter per ha peatland burnt)

h. Omission of incidentally drained peat swamps adjoining the plantations.

Add h. Off-site impacts of drainage (e.g. hydrological leakage impacts) are not yet included in EPA's EF. This is conservative (underestimation of emissions). The recommendation to EPA is to wait with amending the EF with off-site impacts until research becomes available. However, the conservativeness of omitting these emissions should be clearly mentioned.

4. IPCC report (Wetlands Supplement).

a. Would it be appropriate for EPA to use the IPCC Tier 1 default emission factor of 40 tCO_2/ha/year, or is it scientifically justified to use a different number based on more detailed information?

Add a. NO. There are major concerns regarding the IPCC emissions factor for oil palm on peat.

1. The emissions factor (EF) for oil palm on peat is not consistent with the emissions reported in literature for the drainage depths that are required for oil palm plantations on peat. No scientific or other justification is provided for the established EF.
2. This low EF for oil palm on peat also results in a large difference between the EFs for oil palm and *Acacia* on tropical peatland, which is not supported by literature and which is very unlikely. No scientific justification is provided for the large discrepancy.

It is not possible to track down how the final EF for oil palm on peat was established, or to follow the logic/rationale behind the chosen EF. The EF options for oil palm reported in the first order draft and the second order draft and the EF published in the final draft (resp. FOD, SOD and FD) of Chapter 2 all differed substantially: the EF for Oil palm shifted from 5.24 in the FOD, to 11 OR 14 with 'no consensus' in the second order draft (in the Annex of this SOD), to 11 t C ha^{-1} yr^{-1}in the FD with no specification of water table /drainage depth (see Annex 2 for an overview of the process) and lacking a scientific justification or substantiated explanation.

Detailed concerns:

The significant difference between the established EFs for oil palm and Acacia on peat (11 vs 20 t C ha^{-1} yr^{-1}) is in sharp contrast with the EFs given in available (scientific) literature (see earlier comments and discussion on this issue)

Many (tropical) peat experts raised concerns on the first order and second order draft, and have independently expressed their deep concerns on the robustness of the EF for oil palm on peat.

Many expert reviewers raised the concern that recent literature was not considered and some (tropical) peat experts have responded that the EF for oil palm on peat shall be in the range 16-25 t C ha^{-1} yr^{-1} given the available literature. Many reviewers have provided useful comments, suggestions and references. The selection of literature used in the analyses is not clear

In the second order draft, experts expressed their deep concerns, because the 'options' given for the EF for oil palm on peat were not supported by scientific literature, nor explained; and moreover, it was stated in the SOD that there was no consensus between the authors.

Process:

The writing process of the IPCC Wetlands Supplement was carried out in 2011-2013 over four Lead Author meetings and two rounds of expert review followed by a round of written comments by governments.

The IPCC Government and Expert Review of the First Order Draft (FOD) started 17-4-2012 and of the Second Order Draft (SOD) 11-2-2013. The final round of submission of written comments by Governments on the Final Draft of the Wetlands Supplement was 12 August - 8 September 2013.

Below a description is provided for how the EF's for oil palm and *Acacia* on peat changed in a very intransparent way during the various writing and review stages.

1. **First Order Draft** of Chapter 2 of the Wetlands Supplement.

Reported EFs in table 2.1 in the 1st order draft, establishment unclear.

- Cropland 9.11 t C ha^{-1} yr^{-1}
- Oil palm Plantation 5.24 t C ha^{-1} yr^{-1}
- Plantation, e.g. *Acacia* 11.67 t C ha^{-1} yr^{-1}

  - First Round of expert review on the FOD

2. **Second Order Draft**, EF's for oil palm and *Acacia* reported in Chapter 2 of the Wetlands Supplement, with NO CONSENSUS.

Emissions factors 'under discussion' reported by IPCC in the 2nd order draft in the Appendix 2a.2 (CO_2 emission factors for drained tropical peatlands: Basis for future methodological development)

- *Acacia* Plantation Alternative 1: 22 or Alternative 2: 19 t C ha^{-1} yr^{-1}
- Oil palm Plantation Alternative 1: 11 or Alternative 2: 14 t C ha^{-1} yr^{-1}
- Cropland, Drained Alternative 1: 21 or Alternative 2: 16 t C ha^{-1} yr^{-1}

  - Second Round of expert review on the SOD

3. **Final Draft**, EF's for oil palm and *Acacia* in Chapter 2 of the Wetlands Supplement.

Emissions factors reported by IPCC in final draft in Table 2.1, establishment unclear

- Forest plantation — $20\ t\ C\ ha^{-1}\ yr^{-1}$
- Oil palm Plantation — $11\ t\ C\ ha^{-1}\ yr^{-1}$
- Cropland, Drained — $14\ t\ C\ ha^{-1}\ yr^{-1}$

  - Round of governments review

Batumi meeting for acceptance by governments of the final draft of the Wetlands Supplement.

b. *Should the emission factor that EPA uses include the emissions pulse that occurs in the first several years immediately following drainage?*

Add b. No. Its more robust to have an additional multiplication factor for the first 5 years after drainage and is increased the certainty of EF for the continues emissions related to cultivation of peat.

c. *Should EPA include DOC and fire emission factors in the overall emission factor? If so, are the IPCC emission factors appropriate to use, or are there better estimates for EPA's purpose?*

Add c. Yes, as well as non-CO_2 emissions (expressed in warming potential impacts (CO_2-equivalents)). It is recommended to use IPCC defaults and EF's until more research becomes available.

d. *There are also erosion losses of particulate organic carbon (POC) and waterborne transport of dissolved inorganic carbon (primarily dissolved CO_2) derived from autotrophic and heterotrophic respiration within the organic soil. The IPCC concluded that at present the science and available data are not sufficient to provide guidance on CO_2 emissions or removals associated with these waterborne carbon fluxes. Do you agree that the science on these factors is not sufficient for EPA to consider losses of POC and dissolved inorganic carbon in its peat soil emission factor?*

Add d. Yes. Science related to this issue is not sufficient yet. It should be omitted from the EF.

5. Additional input:

All additional scientific information that I believe EPA should consider is mentioned in the former text. The meta analysis of Carlson et al. (in prep) should be considered as soon as it becomes available.

Annex 1. Available literature related to the EFs of oil palm and *Acacia*

Citation	Pub Type	LU	Loc (s)	Measures CO_2	Autotrophic respiration correction	Period of Measurement	Frequency of Measurement
Couwenberg, J. and A. Hoosier. 2013. Towards robust subsidence based and soil carbon factors for peat soils in South-East Asia, with special reference to oil palm plantations. *Mires and Peat* 12:1-13.	Peer Review	oil palm, *Acacia*	Jambi, Riau	Subsidence	not applicable	2007-2012	every 2-4 weeks
Dariah, A., S. Marwanto and F. Agus. 2013. Root- and peat-based CO_2 emissions from oil palm plantations. *Mitigation and Adaptation Strategies for Global Change* 18.	Peer Review	oil palm	Jambi	Closed Chamber	yes	2011-2012	8 times
Hooijer, A., S. Page, J. Jauhianen, W. A. Lee, X. X. Lu, A. Idris, and G. Anshari. 2012. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences* 9:1053-1071.	Peer Review	*Acacia* and oil palm	Riau and Jambi	Subsidence	not applicable	2007-2010	variable
Othman, H., A. T. Mohammed, F. M. Darus, M.H. Harun, and M.P. Zambri. 2011. Best management practices for oil palm cultivation on peat: ground water-table maintenance in relation to peat subsidence and estimation of CO_2 emissions at Sessang, Sarawak. *Journal of Oil Palm Research* 23: 1078-1086.	Peer Review	oil palm	Sarawak	Subsidence	not applicable	2001-2008	
Comeau, L. P., K. Hergoualc'h, J. U. Smith and L. Verchot. 2013. Conversion of intact peat swamp forest to oil palm plantation - effects on soil CO_2 fluxes in Jambi, Sumatra. Working Paper 110, CIFOR.	White Paper	primary forest, logged forest, oil palm	Jambi	Closed Chamber	yes	Jan-Sept 2012	monthly, 9:00-14:00
Jauhiainen, J., A. Hooijer, and S.E. Page. 2012. Carbon dioxide emissions from an *Acacia* plantation on peatland in Sumatra, Indonesia. *Biogeosciences* 9: 617-630.	Peer Review	*Acacia* plantation	Riau	Closed Chamber	yes	Apr 1997 to Apr 2009	2-weekly to monthly
Agus, F., E. Handayani, M. van Noordwijk, K. Idris, and S. Sabiham. 2010. Root respiration interferes with peat C02 emission measurement. 19th World Congress of Soil Science, Soil Solutions for a Changing World. 1-6 Aug 2010. Brisbane.	Conference Proceedings	oil palm	Aceh	Closed Chamber	yes	Nov-Oct 2008	

Citation	Pub Type	LU	Loc (s)	Measures CO_2	Autotrophic respiration correction	Period of Measurement	Frequency of Measurement
Ali, M., D. Taylor, and K. Inubushi. 2006. Effects of environmental variations on CO_2 efflux from a tropical peatland in Eastern Sumatra. *Wetlands*26: 612-618.	Peer Review	logged forest, cleared forest, agriculture (banana, cassava, coconut, rice)	Jambi	Closed Chamber	no	Mar-Aug 2001	5-7 am, 11-2 pm, 4-6 pm
Chimner, R. 2004. Soil respiration rates of tropical peatlands in Micronesia and Hawaii. *Wetlands* 24: 51-56.	Peer Review	forest, shrub, taro	Micronesia, Hawaii	Closed Chamber	no	2001-2002	2-4 times
Chimner, R. and K. Ewel. 2004. Differences in carbon fluxes between forested and cultivated Mironesian tropical peatlands. *Wetlands Ecology and Management* 12: 419-427.	Peer Review	secondary forest, taro	Micronesia	Closed Chamber	no	May 2001-June 2002	4 times
Dariah, A., F. Agus, E. Susanti and Jubaedah. 2012. Relationship between sampling distance and carbon dioxide emission under oil palm plantation. *Journal of Tropical Soils* 18: 125-130.	Peer Review	oil palm	Jambi	Closed Chamber	no	2011	7 times, before and after fertilizer
Darung. 2005. The effect of forest fire and agriculture on CO_2 emission from tropical peatlands, Central Kalimantan, Indonesia. Proceedings of the International Workshop on Human Dimension of Tropical Peatland Under Global Environmental Change. 8-9 Dec 2004. Bogor, Indonesia.	Conference Proceedings	annual crops, natural forest, burnt forest	Central Kalimantan	Closed Chamber	no	Mar 2002-2004	monthly
Furukawa, Y., K. Inubushi, M. Ali, A.M. Itang and H. Tsuruta. 2005. Effect of changing groundwater levels caused by land-use changes on greenhouse gas fluxes from tropical peat lands. *Nutrient Cycling in Agroecosystems* 71: 81-91.	Peer Review	drained forest, cassava, paddy	Jambi	Closed Chamber	no	Oct 2000-Mar 2002	monthly
Hadi, A., K. Inubushi, E. Purnomo, F. Razie, K. Yamakawa and H. Tsuruta. 2000. Effect of land-use change on nitrous oxide emission from tropical peatlands. *Chemosphere - Global Change Science* 2: 347-358.	Peer Review	secondary forest, converted paddy, upland cassava, converted uplands	South Kalimantan		not applicable	1998-1999	December

Citation	Pub Type	LU	Loc (s)	Measures CO_2	Autotrophic respiration correction	Period of Measurement	Frequency of Measurement
Hadi, A., K. Inubushi, Y. Furukawa, E. Purnomo, M. Rasmadi and H. Tsuruta. Greenhouse gas emissions from tropical peatlands in Kalimantan, Indonesia. *Nutrient Cycling in Agroecosystems* 71:73-80.	Peer Review	secondary forest, paddy, upland crop, fallow, rice-soy	South Kalimantan	Closed Chamber	no	Dec 1998, Dec 1999, Nov 2000	
Hadi, A., L. Fatah, Syaiffudin, Abdullah, D. N. Affandi, R. A. Bakar and K. Inubushi. 2012 greenhouse gas emissions from peat soils cultivated to rice field, oil palm, and vegetable. *Journal of Tropical Soils* 17: 105-114.	Peer Review	oil palm, vegetable field, rice field	South Kalimantan	Closed Chamber	no	July-Nov 2009	weekly
Hadi, A., M. Haridi, K. Inubushi, E. Purnomo, F. Razie, H. Tsuruta. 2001. Effects of land-use change in tropical peat soil on the microbial population and emission of greenhouse gases. *Microbes and Environments* 16: 79-86.	Peer Review	secondary forest, paddy field, paddy-soy	South Kalimantan	Closed Chamber	no	Nov-99	once
Hirano, T., H. Segah, K. Kusin, S. Limin, H. Takahashi and M. Osaki. 2012. Effects of disturbances on the carbon balance of tropical peat swamp forests. *Global Change Biology* 18: 3410-3422.	Peer Review	intact forest, drained forest, drained burnt forest	Central Kalimantan	C02	no	2004-2008	half hour
Hirano, T., H. Segah, S. Limin, H. Takahashi and M. Osaki. 2007. Comparison of CO_2 balance among three disturbed ecosystems in tropical peatlands. Proceedings of International Workshop on Advanced Flux Network and Flux Evaluation, 19-22 Oct 2007.	Conference Proceedings	swamp forest and drained cut area	Central Kalimantan	C02	not applicable	2004-2005	unknown
Hirano, T., H. Segah, T. Harada, S. Limin, T. June, R. Hirata and M. Osaki. 2007. Carbon dioxide balance of a tropical peat swamp forest in Kalimantan, Indonesia. *Global Change Biology* 13: 412-425.	Peer Review	forest	Central Kalimantan	C02	no	Nov 2001-Jan 2005	1 min
Hirano, T., J. Jauianen, T. Inoue and H. Takahashi. 2009. Controls on the carbon balance of tropical peatlands. *Ecosystems* 12: 873-887.	Peer Review	forest, drained forest, agricultural land	Central Kalimantan	Closed Chamber	no	2002-2005	
Hirano, T., K. Kusin, S. Limin and M. Osaki. 2014. Carbon dioxide emissions through oxidative peat decomposition on a burnt tropical peatland. *Global Change Biology* 20: 555-565.	Peer Review	burned peat	Central Kalimantan	Closed Chamber	no	2004-2009	half hour

Citation	Pub Type	LU	Loc (s)	Measures CO_2	Autotrophic respiration correction	Period of Measurement	Frequency of Measurement
Inubushi, K. and A. Hadi. 2007. Effect of land-use management on greenhouse gas emission from tropical peatlands- carbon-climate-human interaction on tropical peatland. Proceedings of the International Symposium and Workshop on Tropical Peatland, 27-29 Aug 2007. Yogyakarta, Indonesia.	Conference Proceedings	secondary forest, paddy field, rice-soybean rotation	South Kalimantan; Jambi	Closed Chamber	no		
Inubushi, K., Y. Furukawa, A. Hadi, E. Purnomo, and H. Tsurata. 2005. Factors influencing methane emission from peat soils: comparison of tropical and temperate wetlands. *Nutrient Cycling in Agroecosystems*71:93-99.	Peer Review	crop, abandoned paddy, abandoned crop, drained forest	South Kalimantan; Jambi		not applicable	Nov 2001	once
Inubushi, Kazuyuki et al. 2003. Seasonal changes of CO_2, CH_4 and N_2O fluxes in relation to land-use change in tropical peatlands located in coastal area of South Kalimantan. *Chemosphere* 52: 603-608.	Peer Review	secondary forest, paddy field, upland field	South Kalimantan	Closed Chamber	no	November 1999; Jan 2001	monthly
Ishida, T., S. Suzuki, T. Nagano, K. Osawa, K. Yoshino, K. Fukumara and T. Nuyim. 2001. CO_2 emission rate from a primary peat swamp forest ecosystem in Thailand. *Environ Control Biol* 39: 305-312.	Peer Review	primary forest	Southern Thailand	Closed Chamber	yes	unknown	unknown
Ismail, A.B., M. Zulkefli, I. Salma, J. Jamaludin and M.J. Hanif. 2008. Selection of land clearing technique and crop type as preliminary steps in restoring carbon reserve in tropical peatland under agriculture. Proceedings of the 13th International Peat Congress, June 2008, Tullamore, Ireland.	Conference Proceedings	oil palm, jackfruit, pineapple	Sarawak	Closed Chamber	no	June 2002 - Sept 2004	unknown
Jauhiainen, J. 2002. Carbon fluxes in pristine and developed Central Kalimantan peatlands. *Peatlands for people: natural resource functions and sustainable management*. Proceedings of the international symposium on tropical peatlands, 22-23 August 2001, Jakarta.	Conference Proceedings	peat swamp forest, clear cut peat drained for agriculture	Central Kalimantan	Closed Chamber	no	1999-2001	four month-long measurements

Citation	Pub Type	LU	Loc (s)	Measures CO_2	Autotrophic respiration correction	Period of Measurement	Frequency of Measurement
Jauhiainen, J., H. Silvennoinen, R. Hamalainen, K. Kusin, R.J. Raison and H. Vasandres. 2012. Nitrous oxide fluxes from tropical peat with different disturbance history and management. *Biogeosciences* 9: 1337-1350.	Peer Review	undrained forest, drained forest, drained recovering forest, drained burned, drained for ag	Central Kalimantan		no	2001-2007	variable
Jauhiainen, J., H. Takahashi, J. E. P. Heikken, P. J. Martikainen and H.Vasandres. 2005. Carbon fluxes from a tropical peat swamp forest floor. *Global Change Biology* 11: 1788-1797.	Peer Review	mixed-type peat swamp forest	Central Kalimantan	Closed Chamber	no	wet and dry season, 1999, 2000, 2001	3-5 weeks
Jauhiainen, J., S. Limin, H. Silvennoinen and H. Vasander. 2008. Carbon dioxide and methane fluxes in drained tropical peat before and after hydrological restoration. *Ecology* 89: 3503-3514.	Peer Review	peat swamp forest and deforested burned area	Central Kalimantan	Closed Chamber	no	April 2004 to April 2006	frequent
Kwon, M. J., A. Haraguchi and H. Kang. 2013. Long-term water regime differentiates changes in decomposition and microbial properties in tropical peat soils exposed to short-term drought. *Soil Biology & Biochemistry* 60: 33-44.	Peer Review	intact and degraded peat forest	Central Kalimantan	Other	no	??	28 day incubation
Kyuma, K. 2003. Soil degradation in the coastal lowlands of Southeast Asia. Taipei City, Taiwan: Asian and Pacific Council.	Peer Review	degraded swamp forest, agriculture	Johore, Malaysia	Closed Chamber	yes		
Kyuma, K., N. Kaneko, A.B. Zahari and K. Ambak. 1992. Swamp forest and tropical peat in Johore, Malaysia. Proceedings of the International Symposium on Tropical Peatland. 6-10 May 1991. Kuching, Sarawak, Malaysia.	Conference Proceedings	forest, reclaimed field	Johore, Malaysia	Other	yes	Sep 1988-Aug 1989	every 2 weeks
Lovelock, C., R. Ruess and I. C. Feller. 2011. CO_2 efflux from cleared mangrove peat. *PLOSone* 6.	Peer Review	cleared mangrove	Belize	Closed Chamber	no	Feb 2004 and Jan 2007	once
Marwanto, S. and F. Agus. 2013. Is CO_2 flux from oil palm plantations controlled by soil moisture and or soil and air temperatures? *Mitigation and Adaptation Strategies for Global Chang.* DOI: 10.1007/s11027-013-9518-3.	Peer Review	oil palm plantation	Jambi	Closed Chamber	no, but minimizes root interference	2010	

Citation	Pub Type	LU	Loc (s)	Measures CO_2	Autotrophic respiration correction	Period of Measurement	Frequency of Measurement
Melling, L., A. Chaddy, K. J. Goh and R. Hatano. 2013. Soil CO_2 fluxes from different ages of oil palm in tropical peatland of Sarawak, Malaysia as influenced by environmental and soil properties. *Act Horticult* 982.	Peer Review	oil palm	Sarawak	Closed Chamber	no	July 2006-June 2008	monthly
Melling, L., K. J. Goh, C. Beauvais and R. Hatano. 2008. Carbon flow and budget in young mature oil palm agroecosystem on deep tropical peat. *The Planter.*	Peer Review	oil palm	Sarawak	Closed Chamber	yes	one year	monthly
Melling, L., R. Hatano and K. J. Goh. 2005. Soil CO_2 flux from three ecosystems in tropical peatland of Sarawak, Malaysia. *Tellus* 57:1-11.	Peer Review	mixed forest, oil palm plantation, sago plantation	Sarawak	Closed Chamber	no	August 2002 to July 2003	monthly
Melling, L., R. Hatano, K.J. Goh. 2005. Global warming potential from soils in tropical peatland of Sarawak, Malaysia. *Phyton (Austria)* 45: 275-284.	Peer Review	mixed forest, oil palm plantation, sago plantation	Sarawak	Closed Chamber	no	August 2002 to July 2003	monthly
Mezbahuddin, M., R.F. Grant and T. Hirano. 2013. Modelling effects of seasonal variation in water table depth on net ecosystem CO_2 exchange of a tropical peatland. *Biogeosciences Discussions* 10: 13353-13398)	Peer Review (undergoing)	degraded peat forest	Central Kalimantan				
Murayama, S. and Z.A. Bakar. 1996. Decomposition of tropical peat soils 2. estimation of in situ decomposition by measurement of CO_2 flux. *Agricultural Research Quarterly* 30: 153-158.	Peer Review	forest, oil palm, maize, okra, fallow	Peninsular Malaysia	Closed Chamber	no	1991-1992	unknown
Sumiwinata, B. 2012. Emission of CO_2 and CH_4 from plantation forest of *Acacia crassicarpa* on peatlands in Indonesia. Proceedings of the 14th International Peat Conference. 3-8 June 2012. Stockholm, Sweden.	Conference Proceedings	*Acacia*	Riau, Jambi	Closed Chamber	no	one year	every 1-2 weeks
Sundari, S., T. Hirano, H. Yamahada, M. Kamiya, and S. H. Limin. 2012 effect of groundwater level on soil respiration in tropical peat swamp forests. *Journal of Agricultural Meteorology*68: 121-134.	Peer Review	undrained and drained peat forests	Central Kalimantan	Closed Chamber	no	July 2004-April 2006	daily

Citation	Pub Type	LU	Loc (s)	Measures CO_2	Autotrophic respiration correction	Period of Measurement	Frequency of Measurement
Suzuki, S, T. Ishida, T. Nagano and S. Wahharoen. 1999. Influences of deforestation on carbon balance in a natural tropical peat swamp forest in Thailand. *Environmental Control in Biology* 37: 115-128.	Peer Review	peat swamp forest, secondary forest	Thailand	C02	not applicable	1995-1996	unknown
Takakai, F., T. Morishita, Y. Hashidoko, U. Darung, K. Kuramochi, S. Dohong, S. Limin and R Hatano. 2006. Effects of agricultural land-use change and forest fire on N_2O emission from tropical peatlands, Central Kalimantan. *Soil Science and Plant Nutrition* 52:662-674.	Peer Review	grassland, cropland, forest, burned forest, regenerated forest	Central Kalimantan		not applicable	March 2002 to March 2004	1 to 3 monthly
Takakai. 2005. The effect of forest fire and agriculture on CH_4 and N_2O emission from tropical peatlands, Central Kalimantan, Indonesia -Proceedings of the International Workshop on Human Dimension of Tropical Peatland Under Global Environmental Change. 8-9 Dec 2004. Bogor, Indonesia.	Conference Proceedings	arable, natural forest, burnt forest	Central Kalimantan				
Toma, Y., F. Takakai, U. Darung, K. Kuramochi, S. Limin, S. Dohong and R. Hatano. 2011. Nitrous oxide emission derived from soil organic matter decomposition from tropical agricultural peat soil in Central Kalimantan, Indonesia. *Soil Science and Plant Nutrition* 57: 436-451.	Peer Review	cropland, bare, grassland	Central Kalimantan	Closed Chamber	no	April 2004 to March 2007	1 to 2 x per month
Ueda, S., C. S. U. Go, T. Yoshioko, N. Yoshida, E. Wada, T. Miyajama, A. Sugimoto, N. Boontanon, P. Vijarnsorn, S. Boonprakub. 2000. Dynamics of dissolved O_2, CO_2, CH_4, and N_2O in a tropical coastal swamp in southern Thailand. *Biogeochemistry* 49: 191-215.	Peer Review	swamp forest, reclaimed, paddy, tidal gate, arable land,	Thailand			1990 to 1993	dry and wet season

Citation	**Pub Type**	**LU**	**Loc (s)**	**Measures CO_2**	**Autotrophic respiration correction**	**Period of Measurement**	**Frequency of Measurement**
Vien, D.M., N.M. Phoung, J. Jauhianen and V.T. Guong. 2008. Carbon dioxide emissions from peatland in relation to hydrology, peat moisture, humidification at the Vodoi National Park, Vietnam. *Carbon-climate-human interaction on tropical peatland*. Proceedings of the International Symposium and Workshop on Tropical Peatland. 7-29 August 2007. Yogyakarta, Indonesia.	Conference Proceedings	secondary peat swamp forest	Vodoi Nat Park Vietnam	Closed Chamber	yes	Oct 2006 to July 2007	once
Wantanabe, A., B. H. Purwanto, H. Ando, K. Kakuda and F. Jong. 2009. Methane and CO_2 fluxes from an Indonesian peatland used for sago palm (Metroxylon sagu Rottb.) cultivation: effects of fertilizer and groundwater level management. *Agriculture, Ecosystems & Environment* 134: 14-18.	Peer Review	sago	Riau	Closed Chamber	no	2004 to 2007	various
Warren, M.W. 2012. A cost-efficient method to assess carbon stocks in tropical peat soil. *Biogeosciences* 9:4477-4485.	Peer Review						
Wosten, J.H.M., A.B. Ismail and A.L.M. van Wijk. 1997. Peat subsidence and its practical implications: A case study in Malaysia. *Geoderma*78: 25-36.	Peer Review	drained peat (agriculture)	Western Jorhore Malaysia	Subsidence	not applicable	21 years	various
Wright, E., C. R. Black, B. L. Turner and S. Sjogersten. 2013. Environmental controls of temporal and spatial variability in CO_2 and CH_4 fluxes in a neotropical peatland. *Global Change Biology* 19: 3775-3789.	Peer Review	intact peat	Panama	Closed Chamber	no	2007	each month
Chin, K. K. and H.L. Poo. 1992. The Malaysian experience of water management in tropical peat. Proceedings of the International Symposium on Tropical Peatland, 6-10 May 1991, Kuching, Sarawak, Malaysia.	Conference Proceedings	oil palm, pineapple, rice, agriculture	Peninsular Malaysia, Sarawak	Subsidence		1980s	n/a
Husen, E., S. Salma and F. Agus. 2013. Peat emission control by groundwater management and soil amendments: evidence from laboratory experiments. *Mitigation and Adaptation Strategies for Global Change* 18.	Peer Review	oil palm	Riau	Other	no		

Citation	Pub Type	LU	Loc (s)	Measures CO_2	Autotrophic respiration correction	Period of Measurement	Frequency of Measurement
Jauhiainen, J., H. Silvennoinen, R. Hamalainen, K. Kusin, R.J. Raison and H. Vasandres. 2012. Nitrous oxide fluxes from tropical peat with different disturbance history and management. *Biogeosciences* 9: 1337-1350.	Peer Review	undrained forest, drained forest, drained recovering forest, drained burned, drained for ag	Central Kalimantan		no	2001-2008	
Lamade, E. and J.P. Bouillet. 2005. Carbon storage and global change: the role of oil palm. *Oléagineux, Corps Gras, Lipides* 12: 154-160.	Peer Review	oil palm	multiple				
Lamade, E., N. Djegui and P. Leterme. 1996. Estimation of carbon allocation to the roots from soil respiration measurements of oil palm. *Plant and Soil* 181: 329-339.	Peer Review	oil palm	Benin				
Lim, C.H. 1992. Reclamation of peatland for agricultural development in West Johor - Proceedings of the International Symposium on Tropical Peatland, 6-10 May 1991, Kuching, Sarawak, Malaysia	Conference Proceedings	oil palm, pineapple, others	Peninsular Malaysia	Subsidence	not applicable	12 years of measurement	unknown
Melling, L., R. Hatano and K. J. Goo. 2005. Methane fluxes from three ecosystems in tropical peatland of Sarawak, Malaysia. *Soil Biology & Biochemistry* 37: 1445-1454	Peer Review	mixed forest, oil palm plantation, sago plantation	Sarawak		not applicable	August 2002 to July 2003	monthly
Melling, L., R. Hatano and K. J. Goo. 2007. Nitrous oxide emissions from three ecosystems in tropical peatland of Sarawak, Malaysia. *Soil Science and Plant Nutrition* 53: 792-805.	Peer Review	mixed forest, oil palm plantation, sago plantation	Sarawak		not applicable	August 2002 to July 2003	monthly
Melling, L., R. Hatano, K. J. Goo. 2006. Short-term effect of urea on CH_4 flux under the oil palm (elaeis guineensis) on tropical peatland in Sarawak, Malaysia. *Soil Science and Plant Nutrition*52: 788-792.	Peer Review	oil palm	Sarawak		not applicable	August 2002 to July 2003	monthly
Mutalib, A.A, J.S. Lim, M.H. Wong and L. Koonvai. 1992. Characterization, distribution, and utilization of peat in Malaysia - Proceedings of the International Symposium on Tropical Peatland. 6-10 May 1991. Kuching, Sarawak, Malaysia	Conference Proceedings	oil palm, others	Peninsular Malaysia	Subsidence	not applicable	unknown	unknown

Citation	Pub Type	LU	Loc (s)	Measures CO_2	Autotrophic respiration correction	Period of Measurement	Frequency of Measurement
Wosten, J.H.M. and H.P. Ritzema. 2001. Land and water management options for peatland development in Sarawak, Malaysia. *International Peat Journal.*	Peer Review		Sarawak				
Dradjad, M. 2003. Subsidence of peat soils the tidal swamplands of Barambai, South Kalimantan. *Jurnal Ilmu Tanah dan Lingkungan*4: 32-40.	Peer Review						
Hadi, A., I. Kazuyuki, P. Erry, F. Yuchiro and T. Haruo. 2002. Emission of CH_4 and CO_2 from tropical peatland and factors affecting them. Proceedings of the 17th World Congress on Soil Sciences, Bangkok.	Conference Proceedings						
Hooijer, A. 2008. Master plan for the conservation and development of the ex-mega rice project area in Central Kalimantan, cluster 3 - hydrology and peatland water management. Euroconsult MottMacDonald/Deltares.	White Paper						
Jauhiainen, J. 2012. Greenhouse gas emissions from a plantation on thick tropical peat. 14th International Peat Congress. 3–8 June 2012. Stockholm, Sweden.	Conference Proceedings						
Jauhiainen, J., H. Silvennoinen, S.H. Limin and H. Vasander. 2008. Effect of hydrological restoration on degraded tropical peat carbon flux. Proceedings 13th International Peat Congress. Dec 2008. Tullamore, Ireland.	Conference Proceedings						
Jauhiainen, J., H. Vasander, J. Heikkinen and P. J. Martikainen. 2004. Carbon balance in managed tropical peat in Central Kalimantan, Indonesia. Proceedings of the 12th International Peat Congress. Tampere.	Conference Proceedings						4 three week periods
Jauhiainen, J., J. Heikkinen, P. J. Martikainen and H. Vasander. 2001. CO_2 and CH_4 fluxes in pristine peat swamp forest and peatland converted to agriculture in Central Kalimantan. *International Peat Journal* 11.	Peer Review						4 month-long periods with measurements 1-5 times a week

Citation	Pub Type	LU	Loc (s)	Measures CO_2	Autotrophic respiration correction	Period of Measurement	Frequency of Measurement
Maswar, M. 2010. Kajian cadangan karbon pada lahan gambut tropika yang didrainase untuk tanaman tahunan. Bogor, Indonesia. Sekolah Pasca Sarjana Institut Pertanian Bogor.	Dissertation						
Melling, L. 2008. Characteristics of natural tropical peatland and their influence on C flux on Loaan Bunut National Park, Sarawak, Malaysia. Proceedings of 13th International Peat Congress. Dec 2008. Tullamore, Ireland.	Conference Proceedings						
Rumbang, N. 2008. Emission of CO_2 from tropical peat soil under different land use types. Proceedings 13th International Peat Congress. Dec 2008. Tullamore, Ireland	Conference Proceedings						
Taylor, D. and M. Ali. 2001. Biogeochemical responses to land cover changes in coastal peatland catchments: spatial and temporal fluxes in greenhouse gas emissions and peat subsidence, Jambi Province, Sumatra. SARCS/UNOP Final Report: GLO/92/G31-C-ENV-PS609.	White Paper						
Western Johore Integrated Agricultural Development Project. 1996. Peat soil management study. Department of Irrigation and Drainage, Kuala Lumpur and Land and Water Research Group, Wageningen.	White Paper						