Dear Reviewer 2,

Thanks for the comments during the review process of the manuscript (MS No.: bg-2013-366).

While we have addressed all the specific points systematically, we have significantly revised the Discussion based on your suggestion to broaden its scope. These changes are described in the accompanied document.

We hope that these changes have improved the clarity of the manuscript. We have uploaded the responses attached as bg-2013-366-Supplement file.

We look forward to your further comments and will be happy to make further amendments, as needed.

Sincerely,
Sanjay

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Author’s response to the comments rose by Reviewer 2 during the review process for the manuscript (MS No.: bg-2013-366) are as follows:

1. p. 14012 LINES 9 TO 12 – Better phrased as: Carbon density is relatively high in tropical compared to temperate or boreal peatlands; this is largely a consequence of deeper peat layers in the former, with peat thickness up to 20 m (Page et al., 2002).

   Author’s response: Thanks for this suggestion. We will include this text as suggested.

2. p. 14012 LINE 16 – “…which crossed all past records in 2013…” – it is unclear what this phrase is referring to? Presumably the Singapore smog event of June 2013 - if so, this needs to explained.

   Author’s response: Yes, this refers to the smog event in Singapore and Malaysia due to burning of tropical peatlands in June 2013.

   We will change the above text to the following on p. 14012 (line 14):
   “Forest fires and biomass burning linked to land-use change exacerbate these threats. These fire events in Indonesia crossed all past records hitting the Pollutant Standards Index (PSI) to 371 in Singapore, based on daily average, during the smog event that engulfed neighboring countries, such as Singapore and Malaysia (Schmaltz, 2013).”

3. p. 14012 LINES 16 to 18 – Perhaps better phrased as: Such land-use changes and hydrological interventions have resulted in a drastic decrease in peatland water tables, exposing the biomass sequestered in the peat to aerobic microbial oxidation.

   Author’s response: Thanks for this suggestion. We will include this text as suggested.

4. p. 14013 LINE 4 – second use of the term biomass should presumably be replaced with ‘peat organic matter losses …’?

   Author’s response: Thanks for this suggestion. We will change the above text to the following:
   “Estimates ……, excluding forest biomass losses, fire losses and peat organic matter losses in the initial years after drainage.

5. p. 14014, LINE 2 – Delete “In” at start of sentence. Also, it is very unlikely that the studies in Thailand and Malaysia are of “pristine” peat swamp forests, since throughout the region remaining peat swamp forests have all been affected to greater or lesser extent by on- and off-site anthropogenic impacts. Perhaps they are better described as “intact, forested peatlands”.

   Author’s response: We will change the above text to the following on p. 14014 (line 2):
   “Two recent studies of intact, forested peatlands from Thailand (Kanokratana et al., 2011) and Malaysia (Jackson et al., 2009) used pyro-sequencing and fingerprinting approaches to describe their microbial diversity and functional properties, respectively.”

6. p.14014, Line 8 – There is rather a clunky link from intact peatlands to degraded peatlands. What is meant by the term 'degraded'? And surely, even if there have been two studies of intact peatlands, there is still a considerable gap in knowledge of the microbial ecology of forested tropical peatlands across most of the SE Asian region? Stronger justification and link here for investigation of degraded peatlands in this study.

   Author's response: Thanks for pointing this out. By term 'degraded', we include those peatlands that are undergoing massive land-use change due to drainage and deforestation. As suggested, we will clarify the meaning of 'degraded' and include the gap that intact tropical peatlands are also less explored with respect to microbial ecology.

   We will change the text to the following on p. 14014 (lines 8-14):

   "In degraded temperate peatlands (i.e.) those peatlands that have undergone massive land-use change due to drainage and deforestation, much is known…. In contrast, for tropical peatlands, ……. community structure for intact as well as tropical peatlands under land-use change. Given both the ecological ….. various land-use patterns in degraded tropical peatland with respect to microbial ecology."

7. p. 14014, Line 15 – The justification for wanting to "classify peat" in order to conserve pristine peatlands seems rather weak. Surely one would not resort to microbial methods as the key methodology for site classification? In conjunction with other methods (e.g. field surveys of biodiversity, forest structure etc) they could, however, be a useful complementary method. I do, however, agree with the authors that microbial characterisation could be a useful tool in assessing (i) the degree to which peatlands under different forms of land-use have moved away from the original, intact condition and (ii) the progress and effectiveness of ecosystem restoration interventions.

   Author's response: We agree to the point you have raised. We will change the text to the following on p. 14014 (lines 14-17):

   "Towards this direction, it is critical to develop scientific methods to manage the rapid change in land-use from pristine conditions of peatlands and monitor the progress as well as effectiveness of ecosystem restoration interventions. In conjunction with existing methods, such as field surveys of flora and fauna of tropical peatlands that are undergoing land-use change (Posa et al., 2011), these combined approaches needs to be adopted to classify peat in order to conserve remaining pristine peatlands."

   Reference to be added: *Posa M.R.C., Wijedasa L.S., and Corlett R.T.: Biodiversity and conservation of tropical peat swamp forests, BioScience, 61, 49–57, 2011.*

8. p. 14014, line 21 – not effect of water table, but effect of water table depth.

   Author's response: Thanks for this suggestion. We will include this text as suggested.

9. p.14014 – LINE 23 and onwards - the description of the study locations could be made clearer. In particular (b) degraded land – how does this differ from (a)? Presumably (b) is deforested, drained peatland that has not yet undergone conversion to agricultural use?

   Author's response: Thanks for pointing this out. Yes, (b) degraded land is the land-use that has undergone deforestation, drainage and is yet to undergo conversion for agricultural use.

   We will add a sentence describing each land-use type. We will change the text to the following rephrasing line 22-24 on p. 14014:

   "We focus on five land-use patterns from a contiguous study site: (a) degraded forest, which includes drained and heavily deforested peat swamp forest, (b) degraded land, which includes deforested and drained peatlands that are yet to undergo conversion for agricultural use, (c) oil palm plantation, which includes peatland area under palm plantations, (d) settlements, which includes peatland area under palm plantations interspersed with human settlements, and (e) mixed crop plantation, which includes peatland area under palm plantations, pineapple and tapioca."

10. p.14014, LINE 26 et seq – "… we studied **the** influences **of** eleven physicochemical (not physiochemical?) parameters.

    Author's response: Thanks for pointing this out. As suggested, we will change the text to the following:

    "…..bacterial communities, we studied the influences of eleven physicochemical parameters."

11. p.14015, LINE 19 – "….nearly pristine and moderately degraded (omit word pristine) peat swamp forest". I found the rest of the site location and land cover description section confusing. How do the land cover classes relate to the chosen land use types described at the end of the introduction? Degraded forest is in both land cover class (1) and (2), and land cover class (2) appears to contain both degraded forest and degraded land use categories. What specific land uses were present at sites A and B and how were the study areas chosen? Were they chosen because each contained a representative range of the main land use classes? It seems that only heavily degraded forest was sampled. Why were no study sites located in slightly or moderately degraded peat swamp forest? At least the absence of any samples from these land cover classes should be justified (especially since they would have provided potential 'control' sites against which the effects of drainage, deforestation, agricultural management could be compared).

    Author's response: The land cover described in Miettinen et al. (2012b) was re-grouped and subset of those land-use patterns falls in Site A and Site B, which were chosen for this study.

    The intention in this study was to choose contiguous land-use types of varying degrees of land-use change so as to keep other confounding variables to be low. Site A and B

constitute such contiguous land-use patterns, namely, 'degraded forest', 'degraded land', 'oil palm plantations', 'mixed crop plantations' and 'settlements'.
As rightly pointed out, less degraded sites (intact peat swamp forest) from other non-contiguous areas will likely provide better separation of the effect of land-use change. Hence, we will include such sites in the follow-up studies.

As suggested, we will change the text on line 19-24 on p. 14015 to the following:

"The land-cover classes used in Miettinen et al. (2012b) were regrouped and reclassified for this study. The land-cover comprising of (1) slightly and moderately degraded peat swamp forest (PSF) (1656 km^2 or 49% of total mapped area) was classified as 'intact PSF', (2) heavily degraded PSF and secondary forest (543 km^2 or 16%) was classified as 'degraded forest', (3) shrubs, fern/grass and clearance area (712 km^2 or 21%) was classified as 'degraded land', (4) industrial plantation (279 km^2 or 8%) was classified as 'oil palm plantation' or 'mixed crop plantation', depending on land-cover in that area and (5) small holder mosaic and built-up areas (188 km^2 or 6%) was classified as 'Settlements'. For this study, the contiguous land-use types were chosen that were present in Site A and Site B. Intact PSF was not included in this study because of being non-contiguous."

12. The study area description is also the place for more detail on climate and, in particular, rainfall patterns. How the annual water table measurements were obtained (Fig 3)? I got the impression from the field sampling description that only one-off measurements of water table were made on site, but Fig 3 presents monthly values for one year.

Author's response: Thanks for bringing this point. We have now added these details in the M&M section.

As suggested, we will add the following paragraph from Line 7 on p.14016:
"In order to monitor the hydrological parameters, both rainfall and water table depths were measured periodically using rain gauges at strategic locations and dipwells in each transect. The dipwells that consisted of perforated PVC pipes anchored into peat and reaching the mineral subsoil. These dipwells were used to monitor bi-monthly water table depth changes since 2009. Rainfall measurements were monitored on a daily basis. Average water table depths and total rainfall were calculated on a monthly. Data from Aug 2009- Aug 2010 is being reported in this study. Sampling was performed in March 2010, preceding which, highest monthly rainfall (370±25 mm) in the period studied was recorded in Feb 2010."

13. p.14015, LINE 19 – in the paragraph on site description the authors should indicate whether there is any evidence that the study sites had been affected by fire (e.g. as part of the sequence of land cover / land use change from forest to degraded, open land or agriculture) as this could have an influence on the peat microbial community (e.g. cf. Neff *et al.*, 2005).

Author's response: Thanks for suggesting this follow up. There were indeed fire events in past in these sites. We will therefore, add a brief description as follows from line 2 on p. 14016:

"….Site B (Fig. 1). All study sites (Fig.1) have been affected by fire in the past. The only exception is the degraded forest (DHFN). The fire events have occurred in the past in degraded land (DHAN) in Site A and B in 2004 and 2005, respectively. Such experience of burning have occurred in oil palm and mixed crop plantation sites in Site B (MHPN, DHPN, MHXN and SHXN) in 2004, sites with oil palm plantations in Site A in low water table depth (MLPO) in 2001 and sites in oil palm plantations (DHPO) and in settlements (DHTO) in 2000. As part of routine management practices……"

14. p.14016, LINE 10 – transects not transect. How many replicate pits were sampled on each transect?
p.14016, LINE 7 onwards – You state that 3 peat subsamples were collected from 10 cm depth and pooled. You then state that peat was collected 20-30 cm AWT and similarly BWT. So, at each location were 3 peat depth samples obtained – at 10 cm, at 20-30 cm AWT and at 20-30 cm BWT or only two at the 20-30 cm depths AWT and BWT – in which case, what is the relevance of the 10 cm depth? The sampling strategy needs to be made clearer. Also, at the oil palm plantation locations, you state that two AWT positions were sampled – this was, presumably, in addition to a BWT location?

Author's response: Thanks for pointing this out. We have revised the text to indlude the details of the sampling strategy. Hope our revised text provides a much clearer description.

"At each sampling location, a $1m^3$ pit was dug. Three equidistant pits were used for sampling in each transect. These transects ranged between 120m to 550m at different sampling locations. We took samples at a predetermined distance from the water table along the wall of the pit. At this distance, we reached horizontally 10 cm into the peat to collect least disturbed samples. This process was repeated for each of the four walls of the pit at the same distance from the water table. A composite was then prepared using these four samples. The number of specified distances in sampling varied according to the water table depths in different sites. Samples using above mentioned strategy, were collected at a distance of 20–30 cm above water table (AWT) and from 20–30 cm below water table (BWT) in sterile 50mL tubes from all sites, with exceptions at 4 sites. At three oil palm plantation sites in MLPO transect (Fig.1), the water table was extremely low (80cm below peat surface level), hence samples were collected from 20–30 cm and 50 cm AWT, respectively. One location within a mixed crop plantation was flooded; hence, only one sample was collected BWT and none from AWT position. Peat water samples for metabolic profiling were collected from dipwells adjacent to each pit. All samples were shipped on ice to the laboratory and processed immediately. In order to analyze the oxygen availability at each sampling point, an OX-N Clark-type oxygen sensor (Unisense, Aarhus, Denmark) was used and data was recorded manually."

15. p. 14023, LINE 17 – salinity had an influence in mixed crop and settlement sites. In these locations, what might be the cause of enhanced salinity levels? This could be discussed in

more detail in the discussion. Is the source riverine as a result of tidal movements at some distance inland from the coast and occasional riverine flooding?

Author's response: Based on our monitoring of the peat water from the dipwells, this entire study site does not have tidal influences. Salinity was high mainly in mixed crop plantations and settlements. Both these land-cover types have most intense human activities. Hence, salinity is likely to be high due to anthropogenic factors.

We will add these details in the Discussion from lines 12-15 on p.14026:

"In contrast to plantations, salinity is a major influencing factor in settlements and mixed crop plantations. Both these land-cover types have most intense human activities. Salinity is therefore likely to be due to anthropogenic activities. Nearly 2.5 km^2 out of the total study area in Site A and B (48 km^2), belong to settlements and mixed crop plantations, thus representing a significant influence on the microbial communities in this region."

16. p. 14024, LINE 26 – emissions of what?

Author's response: By emissions, we mean greenhouse gas emissions, such as CO_2, N_2O and CH_4.
We will change the text as follows from line 26-27 on p. 14024:

"While there have been reports of effects of land-use change and hydrology on CO_2, N_2O and CH_4 emissions (Jauhiainen et al., 2008; 2012a and 2012b) and hydrology on subsidence (Hooijer et. al., 2010 and 2012)….."

Reference added: *Jauhiainen J., Silvennoinen H., Hamalainen R., Kusin K., Limin S., Raison R. J., and Vasander H.: Nitrous oxide fluxes from tropical peat with different disturbance history and management, Biogeosciences, 9, 1337–1350, 2012b.*

17. p. 14025, LINES 5 and 6 – "Along peat dome…." – please clarify what is meant here. Position on peat dome was not one of the variables used in this study.

Author's response: Thanks for pointing this out. We meant "across peatland area under hydrological management".
We will change the text as follows from line 5 on p. 14025:

"Across degraded peatland that are under hydrological managements, water table fluctuates due to drainage, rainfall……"

18. p. 14025, LINES 8 to 10 – I think this is the first time that 'fluctuations in water level' at the study sites have been referred to. Are the authors able to provide an indication of the likely range of fluctuation for water table depth at the study sites? How do the authors know that water tables were at a maximal level at all sites – surely this is only true for the year in question (i.e. Aug 2009-Aug 2010, as indicated in Fig 3)? There is a statement that the previous month "received the highest rainfall" – presumably this is the highest monthly total in the year in question? Please clarify. All of this study area contextual

information should also be referred to in the methodology section – i.e. timing (month) of sample collection, antecedent rainfall, average monthly rainfall for the study location etc.

Author's response:

- Thanks for this point. By fluctuation in water level, we mean the range of changes in water table depth (Fig. 3A). We will make this clearer as follows by rephrasing lines 9-14 on P14021 in the **Result section**:

  "….sites (Fig. 3a). Sampling was performed during the time when water table was highest in the entire period under study. Variation in the water table pattern was similar for all sites (DHFN, DHPO, DHAN, DHTO, SHXN, MHXN, DHPN and MHPN) except for five oil palm plantation sites (MLPO) that had low water table (> 50 cm). The water table in sites with high water table depths fluctuated from -0.1m to -0.7m in the period under study. However, these fluctuations ranged from -0.75 and -1.6m in the sites with low water table depths in the same period. Hence, exposing the low water table sites to different durations of oxic and anoxic regimes compared to high water table sites. Between-site comparisons…….."

- Similarly, we will rephrase as follows in the discussion section from line 6-10 on P14025:

  "The ability of microbial markers to distinguish the low and high water table sites show their robustness to capture differences in community structures despite the differences in the range of fluctuations in water level at these sites. Fluctuations in water table are likely to influence bacterial community structure through oxygen and nutrient availability on one hand and selection of bacteria that can withstand drying-wetting cycles on the other hand. ~~Incidentally, sampling was done when the water table was at its highest levels and prior month received the highest rainfall.~~ Such changes in…."

- Regarding your comment to add these contextual information in M&M section, we have addressed this in our reply for Comment no. 12.

19. p. 14025 – lines 11 and 12 – the Yu & Ehrenfeld study took place in a New Jersey pineland – I guess this could be described as a forested, temperate wetland. What "rapid fluctuations in water table" are being referred to in line 12 – are you referring to temporal or spatial changes? If the former, can you justify the use of the term 'rapid'?

    Author's response: Thanks for bringing this point. We meant temporal fluctuation due to rainfall. However, we agree to your comment about the use of word 'rapid' needs further justification. As rainfall induced fluctuations in temperate wetlands are not as rapid as those in tropical systems, we have removed the word 'rapid'.

    We will change the text as follows from lines 10-13 on p.14025:

    "Such changes in microbial community structure along a hydrological gradient have been reported in other natural ecosystems, such as in forested, temperate pine wetlands (Yu and Ehrenfeld, 2010). However, temporal fluctuations in water table in high and low water table sites leading to rapid drying and wetting, as seen here, were not present in the pine wetland study."

20. p.14026 and 14027. The last paragraph of the discussion is over long and contains a large number of ideas. It would benefit from being split up into several paragraphs and the various ideas being unpacked and explained more coherently. In general, the discussion section could be strengthened by expanding on what I feel are some of the key observations from this study – e.g.:
(i) of the various land uses, oil palm plantations had the lowest bacterial diversity. This seems to be a key finding and one that could have been discussed in more detail. Could the authors speculate on the reasons for this – e.g. is it a consequence of monoculture cropping, high fertiliser applications, use of fire in land conversion, length of time under deep drainage etc.?
(ii) bacterial communities in the oil palm plantations were associated with nitrate levels in both the oxic and the anoxic peat layers - could the authors speculate on the implications of a possible fertiliser-driven change in the bacterial community not just above but also below the water table? How might changes in bacterial communities influence emissions of greenhouse gases from OP plantations and other land uses?
(iii) in the anoxic zone, land-use had an equally strong influence as water table on bacterial community structure. Could the authors speculate on the ways in which land-use likely has this influence – what specific aspects of land-use (other than water table management) are likely to be important?
(iv) anoxic zones supported more complex bacterial communities than oxic zones – can the authors speculate on why this might be the case and what the implications of this result might be for more 'sustainable' forms of peatland management? Throughout the discussion, I suggest that the authors consider placing their results in the wider context of other studies on the effects that land use change and fire have on the microbiology and chemistry of organic soils.

Author's response: Thanks for your suggestion for the discussion part.

Based on your suggestion, we have made changes in the **Discussion** section, **mainly** from 3rd paragraph of the Discussion section (i.e.) from **line 16 on p. 14025 to line 15 on p. 14027**. However, we are pasting below the entire Discussion, which is as follows:

Discussion:

Microbial and metabolic markers that represent the complex nature of bacterial communities and their metabolic processes, respectively, provided the resolving power to distinguish different habitats. This resolution ranged from centimeter scale in depth measurements to kilometer scale, where sites were distributed within the 48 km^2 of the study area. Thus, the same set of molecular markers provided a dynamic range of resolution at four orders of magnitude. Microbial markers have been extensively used to study alteration in community structures due to changes in land-use patterns at large scales of spatial distribution, such as, in Pacific Northwest marine sediment communities (Braker et al., 2000), in high levels of nuclear waste-contaminated vadose sediments at the Hanford Site in the US (Fredrickson et al., 2004), in Western Amazon soils (Jesus et al., 2009) and in Antarctic dry valley (Chan et al., 2013), among other biogeographic locations. In comparison, there are relatively few studies that have used metabolites as function-based markers for understanding variation at large scale of spatial distribution. Both sets of molecular markers distinguished different land-use types, but with different levels of resolution. Compared with microbial profiles, those of metabolites were additionally able to separate land-use types from locations that are separated by nearly 8 km distance. Our findings about bacterial profiling have led us to identify geochemical factors that influence the state of degraded peatlands. In addition, metabolic profiling, which relies on markers derived from bacterial functions provide a finer classification of peatland sites. Metabolic profiling can, therefore, be used in developing better practices for mapping peatlands, which can be a tool for both management and policy development.

While there have been reports of effects of land-use change and hydrology on CO_2, N_2O and CH_4 emissions (Jauhiainen et al., 2008; 2012a and 2012b) and hydrology on subsidence (Hooijer et. al., 2010 and 2012), our approach allows multiple parameters to be evaluated simultaneously using a single molecular profiling approach. Our findings show that microbial profiles from peatland sites are most influenced by variations in water table and land-use patterns. These two are followed by age of drainage and peat thickness in influencing the bacterial community structure. Across degraded peatland that are under hydrological managements, water table fluctuates due to drainage, rainfall and other physical parameters (Jauhiainen et al., 2008; Hooijer et al., 2010). The ability of microbial markers to distinguish the low and high water table sites show their robustness to capture differences in community structures despite the differences in the range of fluctuations in water level at these sites. Fluctuations in water table are likely to influence bacterial community structure through oxygen and nutrient availability on one hand and selection of bacteria that can withstand drying-wetting cycles on the other hand. Such changes in microbial community structure along a hydrological gradient have been reported in other natural ecosystems, such as in forested, temperate pine wetlands (Yu and Ehrenfeld, 2010). However, temporal fluctuations in water table in high and low water table sites leading to rapid drying and wetting, as seen here, were not present in the pine wetland study. Hence, microbial profiling presents a practical approach to monitor peat responses to both rapid short-term and long-term hydrological changes.

Mechanisms by which water table influences microbial communities are likely to be different in a depth profile, depending on oxygen availability. In the oxic zones, low water table sites undergo more pronounced cycles of drying and wetting compared to high water table sites. Drying and wetting of peat leads to alternating aerobic and anaerobic physiological responses of the microbes. Thus, drying-wetting process selectively enriches those resilient members of microbial communities that can tolerate these changes both in physical environment and physiological functions. Examples of such successful resilient bacterial taxa are *Actinobacteria* and *Firmicutes* that have very thick peptidoglycan layer to withstand changes in physical environment and adapt to broad range of oxygen availability. Hence, they thrive well in diverse and extreme environments from deep sea to dry deserts (Cowan and Tow, 2004; Bull A., 2011). Both *Actinobacteria* and *Firmicutes* were the most represented taxa groups in all our study sites, irrespective of water table depth, land-use pattern or oxygen availability. Physiologically, aerobic-anaerobic cycling can affect both nitrogen and carbon metabolism. Denitrifying assemblages are favored under the wetter and low oxygen conditions of the drying-wetting cycles, as shown in clay loam of wetland mesocosms (Peralta et al., 2013). Likewise, in carbon metabolism, this cycling is known to activate different pathways in oxic and anoxic conditions. Enzyme systems, such as phenol oxidase and β-glucosidase that are involved in the degradation of recalcitrant phenolic (lignin and its derivative) and cellulosic materials, respectively, are active in high oxygen conditions (McLatchey and Reddy, 1998). On the other hand, activities of many hydrolases that degrade complex carbon polymers are high under low oxygen conditions, such as in boreal river system (Sinsabaugh et al., 1991), in anaerobic sludge digestor (Nybroe et al., 1992) and in the rumen of cattle (Lee et al., 1999). Such activation of different groups of enzymes in drying-wetting has been reported from mesocosms of peat in boreal region (Fenner and Freeman, 2011). Combined oxidation of recalcitrant and labile carbon, accompanied with outgassing of carbon dioxide can lead to direct loss of peat. This extrapolation directly predicts that peat loss will be higher in low water sites, where these pronounced cycles of drying-wetting are prevalent, compared to high water table sites. From sites in the Sumatran region, peat subsidence that is considered as proxy for carbon loss is indeed higher in low water sites (water table depth: -0.7 ± 0.2 m and subsidence rate: 5 ± 2 .2 cm y^{-1}), when compared to high water table sites (water table depth: -0.56 ± 0.06 m and subsidence rate: 3.9 ± 0.5 cm y^{-1}) (Couwenberg and Hooijer, 2012).

In contrast to the oxic zones in low water table sites that experience fluctuations, the anoxic conditions present in the water saturated zones of low and high water table sites, affect microbial communities through possibly different mechanisms. First is through exposure of microbial communities to prolonged stable anoxic conditions. Such conditions can support both high bacterial diversity and abundance, as shown in this study. Consistent with our findings, similar increase in bacterial diversity with decreasing oxygen availability along a depth profile has been reported in a stratified lake (Garcia et al., 2013). The second mechanism is through direct effects of water saturation in the anoxic zones, where dissolved organic matter becomes freely available for microbial communities. Availability of dissolved organic matter in the water saturated anoxic zone plays a major role in shaping microbial communities, through its the quantity and composition. Both, root exudation from plant communities and degradation products of lignocellulosic materials, contribute to the dissolved organic matter that drives microbial assemblages (Farrar et al., 2003). Hence, dissolved organic matter provides a critical link between the above and below ground communities (Wardle et al., 2004). Microbial and metabolic profiling approaches in our study, therefore, capture the outcomes of these plant-microbial-peat interactions. Such interactions are heavily impacted by changes in land-use patterns, where different plant communities support their land-cover specific microbial populations (Bardgett et al., 2005).

The nutrient pool for microbes is influenced not only by root exudates and lignocellulosic degradation products, but also, by the carbon products resulting from fire events. Both aliphatic and aromatic carbons are added to the pool of dissolved organic matter present in the ecosystems that have experienced fire events, as shown for pine forest (Czimczik et al. 2003) and boreal ecosystems (Neff et al., 2005). All our sites, with the exception of degraded forest, also have fire histories of 5-10 years, respectively, which likely contributed fire-related carbon forms to the nutrient pools. While such carbon joins the carbon pool after fire events, as expected, there is a concomitant decrease in abundance and activity of microbial communities immediately after the fire events in forest soils (Certini G., 2005). The present state of microbial assemblages at our sites, therefore, reflects the recovered and adapted communities over a period of time. Southeast Asian peatlands have a unique history of experiencing repeated fires, which can be both spatially extensive and can affect specific sites at multiple occasions. Our findings that the bacterial communities and metabolic profiles could not separate the sites based on fire history, indicates resilience of the microbial communities to recover over 5-10 year period, since the sites first experienced a fire event. This duration of recovery is consistent with that reported for boreal forest fires (Dooley and Treseder, 2012). Whether functionally important, yet non-resilient bacteria are lost in this process cannot be ascertained from our current approach and will require metagenomics approaches.

Anthropogenic chemical inputs, such as by fertilization, in these managed peatlands had a great influence on bacterial community structure. Nitrates and phosphates, contributed by fertilizer applications, were among the top three factors that influenced overall bacterial diversity in oil palm plantations. Similar influence of organic manure and mineral fertilizer treatment occurs on the abundance and diversity of gram-negative bacteria, *Actinobacteria* and fungal communities in the red soil of China (Zhong et al., 2010). Since nitrogenous fertilizers are heavily used in the management of plantations on tropical peatlands, N_2O is likely to be released, as demonstrated from other agricultural lands, such as, from agricultural soils in Australia (Dalal et al., 2003), India (Aggarwal

P., 2008) and Africa (Hickman et al., 2011). One of the most abundant taxa in our study, *Actinobacteria* have been shown to actively reduce N_2O to N_2, not only in the anoxic zone of palsa peat (Palmer and Horn, 2012), but also in other habitats, such as, agricultural soils (Philippot et al., 2002) and in Uranium contaminated sediments (Akob et al., 2008). Hence, it will be important to estimate N_2O emissions from tropical peat plantations that use mineral fertilizers and also the utility of N_2O reducing bacteria in such plantations. In contrast to plantations, salinity is a major influencing factor in settlements and mixed crop plantations. Both these land-cover types have most intensive human activities. Salinity is likely to be due to anthropogenic contributions. Nearly 2.5 km^2 out of the total study area of 48 km^2 belongs to settlements and mixed crop plantations, thus representing a significant influence on the microbial communities in this region. Hence, microbial profiling can help reveal influences of both management-related and anthropogenic activities on peat.

One of the major findings of our study is that monoculture of oil palm plantations supported the least diverse bacterial communities and consisted of lowest levels of dissolved carbon content. On the other hand, mixed crop plantations consisting of upto five plant species only, supported most diverse bacterial communities and had the highest levels of dissolved carbon content. In tropical peatlands of Kalimantan, land conversion from secondary forest to paddy field (monoculture plantations) led to the decrease in carbon content, together with a decrease in microbial abundance (Hadi et al., 2001), which is consistent with our findings. Carbon levels increased, when paddy-soybean rotation cropping was followed with a further decrease in microbial abundance. This possibly underlines the importance of adopting simultaneous mixed plantations rather than sequential crop-rotations, as evident in our study. Similar decrease in microbial diversity from mixed crop plantations to monoculture of crops has been reported for many cases such as *Lolium*, *Trifolium spp.*, *Plathymenia*, Sudan grass and tall fescue (Marilley et al., 1998; Meimei et al., 2008; Pagano et al., 2009; Zarea et al., 2009). Similarly, microbial diversity is lower in fallow and woodland, when compared to grassland with multiple plant communities on temperate peatlands (Brake et al., 1999). Low bacterial diversity in oil palm plantations, as seen in our study, can be sensitive to environmental pressures thereby leading to reduction in their productive period. These findings provide a good basis to adopt microbial ecology principles to encourage mixed crop planting in the existing plantations, in order to increase their microbial diversity, especially of beneficial microbes, which can lead to sustainable use of these plantations.

Reference added:

- *Brake M., Hoper H., Joergensen R. G.: Land use-induced changes in activity and biomass of microorganisms in raised bog peats at different depths, Soil Biology and Biochemistry 31, 1489-1497, 1999.*
- *Bull A. T.: Actinobacteria of the Extremobiosphere, Extremophiles Handbook, 1203-1240, 2011*
- *Certini G.: Effects of fire on properties of forest soils: a review, Oecologia, 143, 1–10, 2005.*
- *Cowan D. A., and Tow L. A.: Endangered Antarctic environments, Annual Review of Microbiology, 58, 649-690, 2004.*
- *Czimczik, C.I., Preston, C.M., Schmidt, M.W.I., and Schulze, E.D.: How surface fire in Siberian Scots pine forests affects soil organic carbon in the forest floor: stocks, molecular structure, and conversion to black carbon (charcoal), Glob. Biogeochem. Cycles, 17, 1020-1034, 2003.*
- *Dooley S. R., and Treseder K. K.: The effect of fire on microbial biomass: a meta-analysis of field studies, Biogeochemistry, 109, 49–61, 2012.*
- *Hadi A., Haridi M., Inubushi K., Purnomo E., Razie F. and Tsuruta H.: Effects of land-use change in tropical peat soil on the microbial population and emission of greenhouse gases, Microbes and Environment, 16, 79–86, 2001.*
- *Lee S.S., Shin K.J., Kim W.Y., Ha J.K., and Han I.K.: The rumen ecosystem: as a fountain source of noble enzymes—review, Asian–Australasian Journal of Animal Sciences, 12, 988–1001, 1999*
- *Marilley L., Vogt G., Blanc M., and Aragno M.: Bacterial diversity in the bulk soil and rhizosphere fractions of Lolium perenne and Trifolium repens as revealed by PCR restriction analysis of 16S rDNA, Plant and Soil, 198, 219–224, 1998.*
- *McLatchey G. P., and Reddy K. R., Regulation of organic matter decomposition and nutrient release in an wetland soil, J. Environ. Qual., 27, 1268-1274, 1998.*
- *Meimei C., Baodong C., and Petra M.: Plant growth and soil microbial community structure of legumes and grasses grown in monoculture or mixture, Journal of Environmental Sciences 20, 1231–1237, 2008.*
- *Neff J. C., Harden J. W., and Gleixner G.: Fire effects on soil organic matter content, composition, and nutrients in boreal interior Alaska, Can. J. For. Res., 35, 2178–2187, 2005.*
- *Nybroe O., Jorgensen P.E., and Henze M.:Enzyme-activities in waste-water and activated-sludge, Water Research, 26, 579–584, 1992*
- *Pagano M. C., Scotti M. R., and Cabello M. N.: Effect of the inoculation and distribution of mycorrhizae in Plathymenia reticulata Benth under monoculture and mixed plantation in Brazil, New Forests, 38, 197–214, 2009.*
- *Peralta A. L., Ludmer S., Kent A. D.: Hydrologic history influences microbial community composition and nitrogen cycling under experimental drying/wetting treatment, Soil Biology and Biochemistry, 66, 29–37, 2013.*