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Interactive comment on "Landscape-scale changes in forest canopy structure across a partially logged tropical peat swamp" *by* B. M. M. Wedeux and D. A. Coomes

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We thank M. Disney, R. Hill, F. Espirito-Santo and M. Hayashi for their comments, which have helped improve the manuscript. We thank the handling associate editor A. Ito for considering the revised manuscript and hope he will now find it suitable for publication. We respond to the comments in detail below. Additions to the manuscript are marked in blue, both in this response and the manuscript.

Response to M. Disney's comments

[Referee comment] General comments This paper presents an interesting analysis of canopy height and structure (layering, gap size) from airborne laser scanner data,

particularly in relation to peat depth and logging intensity. This is a rare opportunity to study the response of forest regrowth in relation to peat depth. The authors do a really good job of the analysis and there are some interesting findings, particularly the strength of correlation of height to peat depth, and the distinction between the regrowth patterns. One or two things arise which could perhaps be better explained/illustrated - particularly the empirical relationship with which peat depth is inferred (not measured). The rest of the analysis depends on this, and yet it isn't included in the main paper, in the supplement only. There is some validation of this in the Supplementary but I'd like to see this brought into the main paper and discussed in more detail, as pretty much everything else follows from this.

[Author response] This issue, also raised by R. Hill, has been addressed by adding more information from SI in the methods section of the main text, as follows: 10993 l.10: We disposed of an independent data set of more than 300 peat depth measurements across the study area and measured canopy top height (99th quantile of height) within a 100 m neighbourhood. We first tested for the effect of logging on canopy top height in this independent dataset by fitting generalised linear models containing peat depth and additive or multiplicative effects of logging as a factor (yes, no). No significant logging effect was detected. We found that canopy top height was closely related to peat depth (R2=0.79) except on shallow peat within 3000 m of the Kapuas river (Fig. S3a). On shallow peat, distance to river was linearly related to peat depth (R2 = 0.59; Fig. S3b). Peat depth for our study plots was thus inferred as (Eq. 3): Peat depth= {(26.0-0.7$\times$top.height for dist.riv>3000 m, or 0.31+0.002$\times$dist.riv for dist.riv$\leq$3000m)} where top.height is canopy top height (99th quantile) and dist.riv is distance to the large Kapuas river. The inference of peat depth from canopy top height was thus done from an independent data set to the plot data further used for analyses. This approach was validated, as it yielded a fit going through the origin and with an R2 = 0.88 between predicted and measured peat values in 33 plots where peat data was available.

[Referee comment] One question I had was whether there may be a confounding factor

of logging on deeper peat being more tricky in terms of accessibility for vehicles etc so that logging intensity/rate is lower?

[Author response] Commercial logging operations on peats use light railways to extract logs. The main determinant of logging effort is likely the distance to the river, and usually that means logging is predominantly on shallow peats that occur near rivers. The taller forests on these shallower peats are easier to navigate and have a higher density of large stems, so are more suitable for logging. However our research site is unusual in having a river cutting through deep peat (it formed after the peat swamp had developed) so logging did take place in areas that would normally be avoided. We find that these forests experience longer-lasting and more severe damage from selective logging, which we relate to their ecology. We added a couple of sentences in the discussion: 11002 l.17: PSF on deep peat were deemed unsuitable for commercial logging operations due to low density of poles and fragility of the system (Bruenig & Droste, 1995). Yet we detected concessionary logging railways on deep peat in our study area, and we are developing new techniques to better monitor illegal logging (unpublished data).

[Referee comment] Otherwise, I think this paper is clear, sound and of broad interest to readers interested in tropical forests, peat and the use of lidar to estimate forest canopy structural characteristic. I only have a few very minor technical comments which should be addressed before final publication.

Technical comments

Abstract

[Referee comment] High-fidelity doesn't really mean anything to me.

[Author response] This word was removed in the abstract and replaced by 'detailed' in the main text (10988 l. 20): Airborne Laser Scanning (ALS) has opened new avenues for canopy research, as it provides detailed information on canopy height, layers and

the location of canopy gaps over entire landscapes (Drake et al., 2002; Dubayah et al., 2010; Kellner and Asner, 2009; Lefsky et al., 2002).

[Referee comment] l13: consistent

[Author response] Corrected.

[Referee comment] l18: long sentence

[Author response] Split into two sentences, now reads: Areas subjected to concessionary logging until 2000, and illegal logging since then, had the same canopy top height as old growth forest, indicating the persistence of some large trees, but mean canopy height was significantly reduced. With logging, the total area of canopy gaps increased and the GSFD scaling exponent was reduced.

[Referee comment] l24: canopy structure recovery, as observed by lidar, modulated...

[Author response] Corrected according to suggestion, the full sentence now reads as: This relationship breaks down after selective logging, with canopy structural recovery, as observed by ALS, modulated by environmental conditions.

Main [Referee comment] 10987 l5: just light

[Author response] [Author response] Deleted 'energy'.

[Referee comment] 10988 l1: obviously limited - how many?

[Author response] Difficult to give a precise number but we site the major studies, sometimes spanning several peat domes but likely fewer than 10 in total: Yet this current understanding of forest structural changes is based on very few field studies (Anderson, 1961; Bruenig and Droste, 1995; Bunyavejchewin, 1995; Page et al., 1999; Whitmore, 1975).

[Referee comment] 10989 l21: new paragraph from "We mapped ..."?

[Author response] Implemented.

[Referee comment] 10990: why 100 plots?

[Author response] This was an arbitrary choice, but allowed a good coverage of the whole area while avoiding spatial clustering of plots and plots overlapping with land class boundaries. We added this justification in the text 10990 l.22: A total of 100 virtual plots of 1×1 km were positioned throughout the research area to yield a good coverage of the landscape and avoid having plots crossing land cover boundaries (Fig. S4).

[Referee comment] 10991: why 10 000 points? Why height cutoff at 12m? How sensitive are results to these choices & are they arbitrary?

[Author response] The number of points was chosen arbitrarily; it is sufficient to give a robust estimate of 99th quantile height while being computationally efficient: Within each plot, canopy height was extracted from 10,000 random selected pixels (to optimise computing time and provide a representative sample) ... The 12 m cut-off was selected based on the fact that gaps from different origins (e.g. corresponding to separate gaps reaching down to the ground) start merging above 12 m (Fig. S5), creating huge gaps above the canopy of many trees. This causes these huge gaps to be truncated at plot edges, which we wanted to avoid. We clarified the main text: The upper CHM cross-section considered was 12 m to avoid the coalescence of gaps from distinct origins and truncation of those huge gaps at plot edges, observed above this threshold (see Fig. S5 for a fuller explanation).

[Referee comment] 10992 l2: most? Or just various?

[Author response] To our knowledge, all of them have fitted power laws. We removed 'most'. The sentence is now: Recent studies using ALS to detect canopy gaps have fitted a power law to describe the GSFD (Asner et al., 2013; Boyd et al., 2013; Espírito-Santo et al., 2014; Kellner and Asner, 2009; Kellner et al., 2011; Lobo and Dalling, 2013).

[Referee comment] 10996: visual inspection - any way of doing this quantitatively?

[Author response] We reanalysed the data in order to address this question and noticed that we had made a small error in the calculation of the canopy shape coefficient. The new result is very similar to 'standardised mean canopy height', so the latter was removed. We have simplified the figure accordingly and have made amendments in the text and in Table S3. In the text we now have:

10996 l.9: The canopy shape, derived from the complete ALS point cloud, did not change along the peat depth gradient in old-growth forest (grey line, Fig. 3b) suggesting that the height of the main canopy volume decreased in parallel to canopy top height (Fig. 3a).

10997 l.14: However a marked decrease of canopy shape was observed (Fig. 3b), indicating the removal of canopy volume in logged plots. In the 8 m cross-section...

10998 l.6: Logging had a constant effect on canopy shape across the peat dome (Fig. 3b; model M2 selected), ...

11002 l.3: Canopy top height remained unaltered after selective logging probably because some tall low-value timber trees remain unharvested, but the relative vertical distribution of canopy volume was reduced by tree removal under logging.

[Referee comment] 10996 l13: increasingly closer? Clumsy.

[Author response] The sentence is now: The canopy shape, derived from the complete ALS point cloud, did not change along the peat depth gradient in old-growth forest (grey line, Fig. 3b) suggesting that the height of the main canopy volume decreased in parallel to canopy top height (Fig. 3a).

[Referee comment] 10996: do you mean significant in a statistical sense here?

[Author response] We rephrased the sentence to include 'statistically significant' and refer to Table S3, clarifying that this analysis was based on generalized linear mod-

elling. The sentence now reads: The GSFD transition parameter, θ, decreased significantly with peat depth for cross-sections up to 8-m height above ground (Fig. 4d, Table S3), but the trend was not statistically significant in the 8-m cross-section (Table S3).

[Referee comment] 10997 l3: define weak or just give values.

[Author response] This was rephrased as: Negative correlations between α and θ in cross-sections $\geq$ 6 m height (Pearson correlation coefficient r = -0.25—0.35) indicated that θ was greatest in sites containing large gaps.

[Referee comment] 10997 l7: define good or just give values. Avoid qualitative statements like this.

[Author response] Since the R2 values are given in the second part of the sentence, we rephrased the first part as: Canopy top height accounted for a large proportion of the variation in canopy gap metrics along the peat dome (recalling that peat depth is negatively related with canopy top height and mean gap area) and was linearly related to mean gap size (Fig. 5a, R2=0.82, p < 0.001) and to α (Fig. 5b, R2 = 0.75, p < 0.001) (Table S5).

[Referee comment] 10997 l27: indices

[Author response] Corrected.

[Referee comment] 10998 l7: differing?

[Author response] Corrected.

[Referee comment] 11000 l20: also, rather than additionally

[Author response] Corrected.

[Referee comment] 11001 l17: "more ecologically meaningful scales" - meaning?

[Author response] Rephrased as: Combining ALS-derived forest structure measurements with ground data of major environmental drivers opens new avenues for re-

searchers to explore ecological processes, e.g. disturbance dynamics, at spatial scales at which such processes take place, rather than being confined to small-scale plot studies.

[Referee comment] 11003 l21: no "yet"

[Author response] Corrected.

[Referee comment] Fig 2 - maybe too much info in here to process properly in 1 fig. Would also be useful to have the pareto distribution plots (lower row) for the various cases above ie the different height layers.

[Author response] We followed the reviewer's suggestion and replaced the first panel of the gap size distribution examples with a panel showing gap size distributions at different heights above ground. We have inserted more spaces between the different parts of the figure, but decided against split it into two. The figure caption is adjusted accordingly (see attached).

[Referee comment] Fig 3 - the 'logged' symbols are red on the plots but not in the legend which is a bit confusing. This is also the case for figs 4 and 5.

[Author response] This has been changed (see attached).

[Referee comment] Fig 3 d is not very useful as it's too hard to tell the difference of the overlaid lines in terms of the colour. This needs to be displayed differently in some way. And why is old-growth grayscale and logged in colour?

[Author response] To improve the readability of this figure, we selected a subset of representative plots at different peat depths for both old-growth and logged forest and only show the canopy profiles for those plots. The grey and red colour code in this figure is consistent with the colour code of other figures throughout the paper (old-growth = grey, logged = red).

Interactive comment on Biogeosciences Discuss., 12, 10985, 2015.

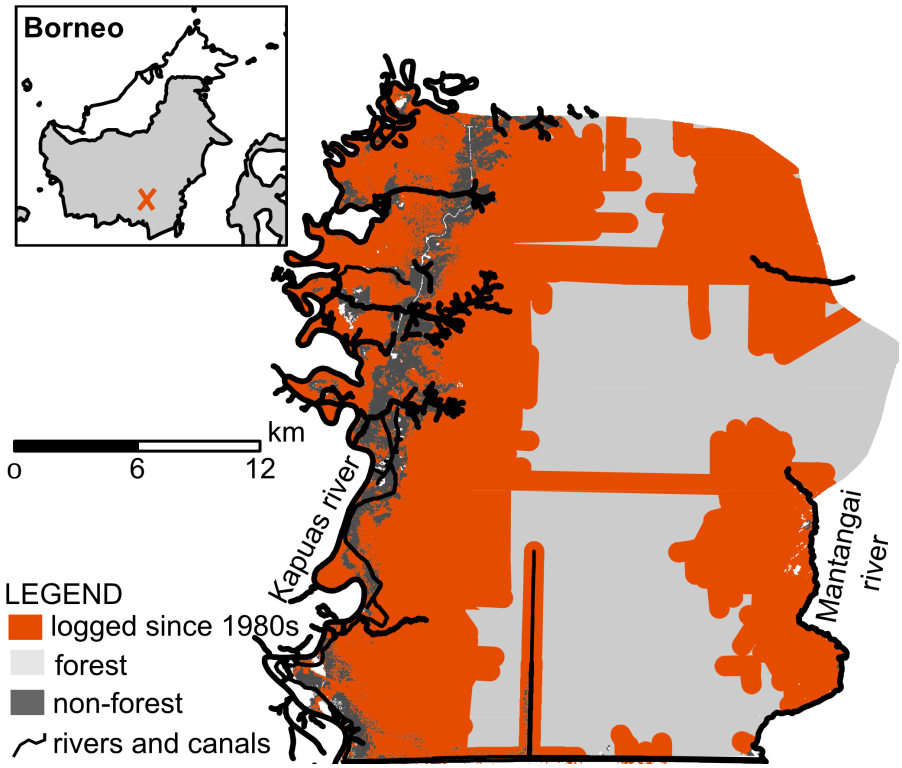
Borneo
km
0
6
12
Kapuas river
Mantangai river
LEGEND
logged since 1980s
forest
non-forest
rivers and canals

Fig. 1.

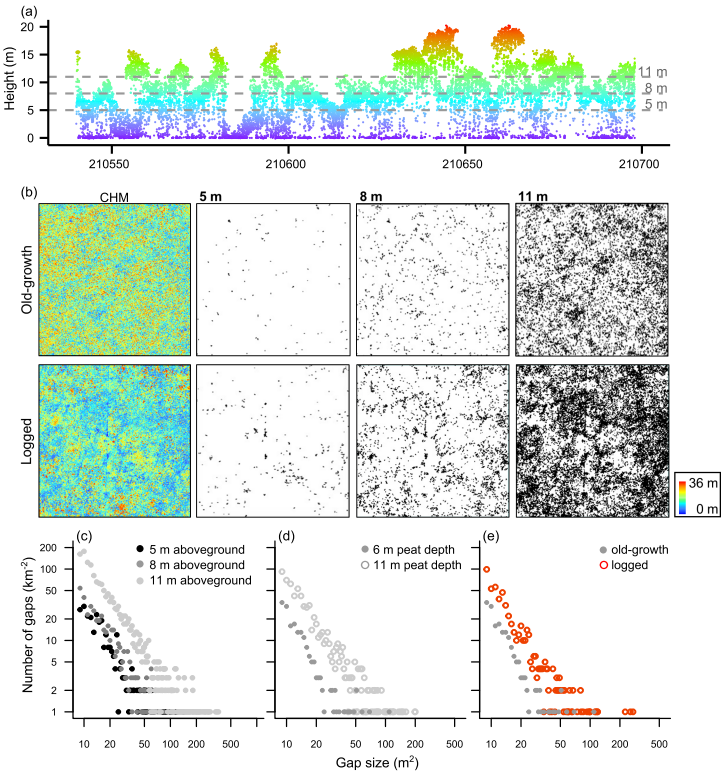
(a)
Height (m)
11 m
8 m
5 m
210550
210600
210650
210700
(b)
CHM
5 m
8 m
11 m
Old-growth
Logged
36 m
0 m
(c)
5 m aboveground
8 m aboveground
11 m aboveground
Number of gaps (km²)
(d)
6 m peat depth
11 m peat depth
(e)
old-growth
logged
Gap size (m²)

Fig. 2.

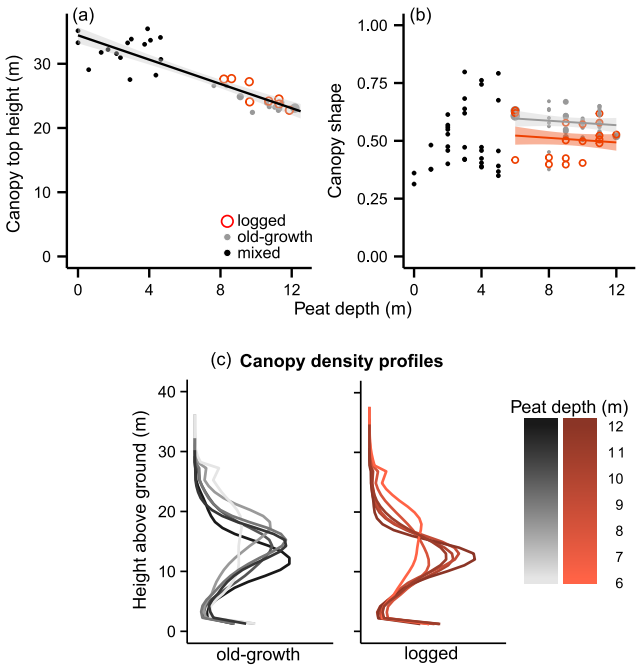
(a)
(b)
Canopy top height (m)
Canopy shape
logged
old-growth
mixed
Peat depth (m)
(c) Canopy density profiles
Height above ground (m)
Peat depth (m)
old-growth
logged

Fig. 3.

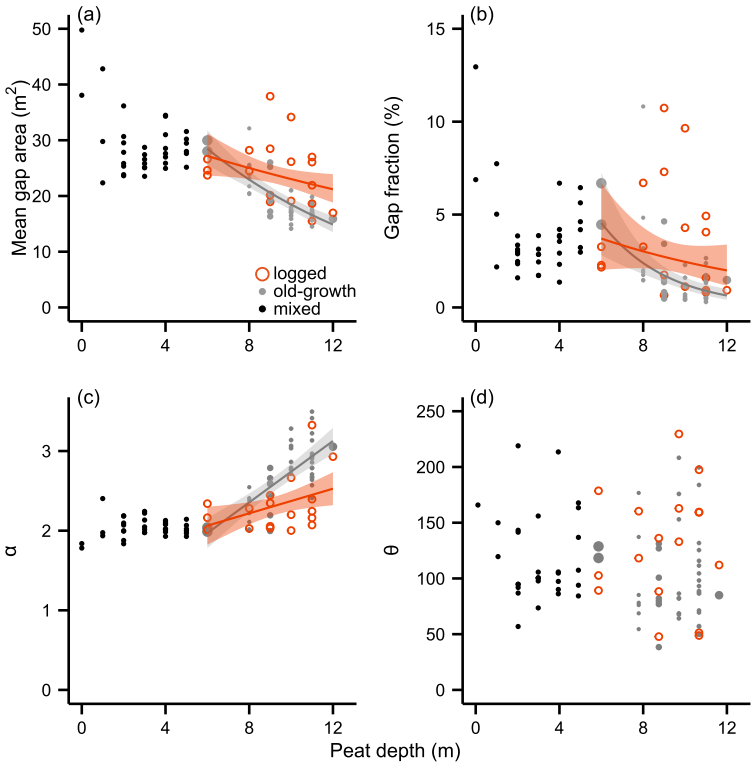
(a)
(b)
(c)
(d)
Mean gap area (m²)
Gap fraction (%)
α
θ
logged
old-growth
mixed
Peat depth (m)

Fig. 4.

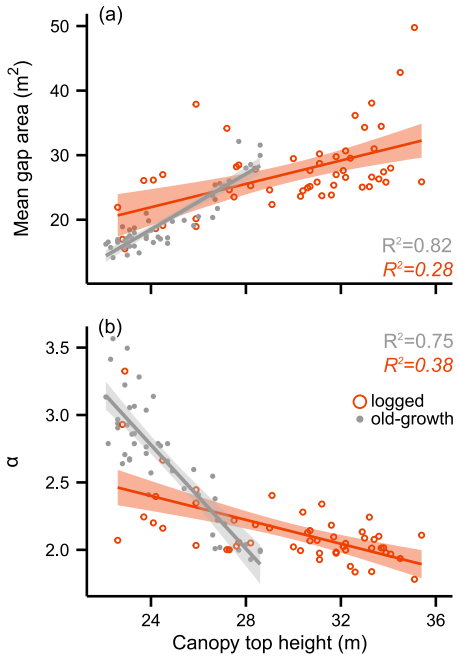
(a)
Mean gap area (m2)
50
40
30
20
R2=0.82
R2=0.28
(b)
R2=0.75
R2=0.38
logged
old-growth
α
3.5
3.0
2.5
2.0
24
28
32
36
Canopy top height (m)

Fig. 5.