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Interactive comment on "Fire risk modulation by long-term dynamics in land cover and dominant forest type in Eastern and Central Europe" *by* Angelica Feurdean et al.

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Reviewer 3 BGD Biogeosciences Discuss.,https://doi.org/10.5194/bg-2019-260-RC3, 2019 © Author(s) 2019. This work is distributed under the Creative Commons Attribution 4.0 License. Interactive comment on "Fire risk modulation by long-term dynamics in land cover and dominant forest type in Eastern and Central Europe" by Angelica Feurdean et al. Christoph Schwörer (Referee) christoph.schwoerer@ips.unibe.ch Received and published: 5 November 2019

General comments The manuscript by Feurdean and colleagues compiles a large dataset of charcoal and pollen records to quantify the effect of climate and vegetation

on fire regimes in Central and Eastern Europe. The authors apply generalized additive models (GAMs) to explore the relationships between biomass burned and changes in climate and land cover. They conclude that tree cover is a first order predictor of fire occurrence probability and that land cover management can reduce future fire risks. I've greatly enjoyed reading this relevant and well-written article. However, I feel that the manuscript would profit from a more process-based view of the drivers of fire occurrence in the study region. I fully agree with the authors that tree cover is a good predictor of fire occurrence in the past, however, this does not mean that there is a direct causal link. As recognized in a vast number of paleoecological articles, climate and human impact are the main drivers of both vegetation and fire dynamics during the Holocene, with climate being the primary forcing factor during the Early Holocene and anthropogenic impact becoming increasingly dominant during the Late Holocene. Since these two drivers affect both the response variable (biomass burned) and the predictor (tree cover) a high correlation is not surprising and should not be confused with causality. Although a decrease in tree cover indeed coincides with an increase in the amount of biomass burned, I would argue that changes in tree cover are itself caused by climate (during the Early Holocene) and human impact (during the Late Holocene). I do not see any evidence that would support the claim that total forest cover has a direct effect on fire dynamics, although I do concur that the type of vegetation (broadleaf vs needleleaf) has indeed an effect. I believe that a more cautious and less simplistic phrasing of the conclusions and abstract, highlighting the direct impact of human land-use on forest cover and fire occurrence would be highly beneficial for the article and not detract from the tremendous amount of work that has been put into compiling and analyzing such a large dataset.

R: Firstly, we would like to thank the three reviewers for constructive and thorough reviews of our manuscript. We also thank them for the encouraging words about our work.

This is an interesting point and one that we have considered at various times during the

development of the research. We admit that land cover is affected by both climate and human-driven changes, and therefore refined some of our statements in the revised paper (chapter 4.2 Fire-fuel relationship: the effect of tree cover composition). some indicated below.

Specific comments Introduction: L.116-118: You state here that ": : :an increase in tree cover beyond a specific threshold can reduce fire hazard,: : :", implying that tree cover itself has a direct effect on fire regimes. I agree that there is certainly a correlation, but would be very careful in assigning causation. Just in the previous sentence you mention that ": : :fire hazard is lowest in productive and moist regions: : :". From a mechanistic point of view, I would argue that the main driver in reducing fire hazards is the moist climate, which leads to lower flammability of fuels, and not just tree cover alone. In order not to confuse the readers I would recommend elaborating on how an increase in tree cover can lead to a reduction of fire, independent from climatic conditions (e.g. local microclimate, reduction of evapotranspiration under closed canopies, etc.).

R: Thank you. In response to your comments as well to R1 we have made it clearer how the tree cover can alter biomass burning throughout a climate-fuel feedback and independently. It should be noted that although the composition and spatial distribution of plant communities are determined by climatic conditions, vegetation composition leads to heterogeneous patterns of fuels and flammability across space and time. A higher tree cover can provide cooler, moister and more wind-protected microclimates on the forest floor, all of which will decrease flammability, irrespective on climate conditions. In addition, open forests favor a more dry microclimate close to the ground, as radiation can penetrate deeper into the canopy and boundary layer conductance is augmented close to the ground, which allows wind to dry the understory vegetation and litter more effectively (Ryan, 2002). Lower radiative properties of the land surface at higher tree cover, reduce evaporation and/or enhance cloud formation, which also contribute to a moister local climate (Bosman et al., 2019). All in all it appears that drought- conditions

favourable for fire spread can be achieved only is the forest is not too dense. Please see our revised explanations in the chapter 4.2 Fire-fuel relationship: the effect of tree cover composition.

Discussion: Fire-fuel relationship: the human impact What I miss a bit in this subchapter is the direct link between human land-use and sedimentary charcoal records. Fire was the primary method used to convert closed forests of arable land, therefore greatly increasing the natural fire occurrence and releasing large amounts of charcoal. - L. 391-393: I'm a bit confused here. In this sentence you state that ": : :the human caused change in land-cover [: : :] has resulted in a decline in biomass burned." But this is contrary to your data, which clearly shows a steady increase in biomass burned during the last 3ka, when this transition to a cultural landscape occurred. However, if you refer to present-day observational data, please provide a reference and also a sense of the timescales involved. I would imagine that a decline of biomass burned due to fuel limitations as a result of the conversion of forests to arable land would only apply to the last 150 years or so, a timeframe that cannot be resolved by your millennial-scale charcoal record.

R: We have tried to link more evidently land use and biomass burning. It should be noted that the fire regime perception from sedimentary charcoal is limited and if humans probably significantly increase fire frequency since the prehistory (Vannière et al 2016) or as early as the protohistory in some place, after deforestation stage the mosaic landscape heritage from land use and land use impact on fuel (reduction) may have reduced the possibility of large fire to spread and thus the amount of sedimentary charcoal.

Indeed this sentence does not refer to our own results but to those referenced. We made this clear by starting the next sentence with "Our results show that biomass burning mostly shows a positive response with increases in arable and grassland cover in all ecoregions, however, this relationship is dynamic and may illustrate a complex fire-human interaction (Figs. 3, 4)." Lines 447.

- L.402-405: From my point of view, the rise in biomass burned in the ATL ecoregion at 1.5ka coincides with a sharp increase in both grassland and arable land, indicating an intensification of land-use with the help of fire for deforestation, contrary to your statement here. I would argue that high charcoal values are a result of intensive landuse, caused by the widespread deforestation that led to the conversion of forest to arable land that started during the Bronze or Iron Age and reached its maximum during the Early modern period. A decrease in area burned due to the establishment of forest protection laws in the late 19th century will not be possible to observe due to the 500-year smoother applied to the data, but might be apparent in the raw data. However, after rereading this sentence a few times I realized that you might actually be referring to the period between 4 and 1.5ka. In that case, ignore my comment, but rephrase the sentence to spare other readers the same confusion.

R: We have clarified this sentence to show its reference to the 4-1.5ka. It now reads “In the ATL ecoregion, arable and grassland cover rose steady from ∼4 to 1.5 ka BP, but biomass burned remained constant during the same time (Fig. 2), which is consistent with percentages in arable and grassland cover at which biomass burned shows no responses in the GAMs (Fig. 2)”. This may reflect a local intensification in land use between 4 and 1.5 ka BP that did not involve major use of fire for deforestation (Fig. 2).” Lines 458-462.

Conclusions I would be very hesitant to make a direct causal link between land cover per se and biomass burned. I totally agree that you make a compelling case for a strong connection between land cover and fire hazard. However, the underlying driver of changes in land cover (and biomass burned) in the Late Holocene is, from my point of view, intensifying human impact. Although land cover can be used as a predictor of fire occurrence in the past (as you nicely show), it is less suited to derive conclusions for future management options, since the underlying drivers might change. In the future I would expect no-analogue conditions, since the combination of higher-than-present temperatures and anthropogenic land-use never previously existed.

R: We did refine this slightly to better accommodate our refined discussion chapter. However, knowledge of past conditions is a necessary precursor to understanding how systems may change in the future. No-analogue conditions will certainly appear, but surely it is better to face these with knowledge derived from 12000 years of observations?

Technical comments: - L. 111: “: : :the effect that vegetation properties have in: : :”

R: Done.

- L. 277-280: I would suggest rephrasing this sentence, since it is rather confusing with the subclause. R: Done, it now reads “The reduction in biomass burned accompanied a decrease in JJA temperature and an increase in summer moisture availability (around 8 ka BP) in all ecoregions (Fig. 2B-D).”

- L. 401: “: : :coincides with: : :”

R: Done.

- Figure 2C: For reasons of comparison, I would suggest to plot the needleleaf and broadleaf tree percentages on the same scale, as in the other plots.

R: We have tried to plot this but because the % vary among ecoregions the trends are not so as clear as with using a differed scale. Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2019-260

References. Vannière, Boris, et al. "7000-year human legacy of elevation-dependent European fire regimes." Quaternary Science Reviews 132 (2016): 206-212.

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