

Interactive comment on “Quantifying the relative importance of greenhouse gas emissions from current and future savanna land use change across northern Australia” by M. Bristow et al.

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Reply to reviews – Bristow et al bg-2016-191 Greenhouse gas emissions from savanna land use change across northern Australia

We thank both reviewers for their comprehensive assessment of our paper.

Reviewer 1 (R1)

R1 contended that the ms provided very interesting data from the paired flux tower sites but suggested we did “. . . not emphasise the strengths of their work, which is the detailed time series that can compare processes for the two sites. Rather they attempt to extrapolate the results across northern Australia in ways that are not transparent and

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appear to have a number of flaws”

This was a reasonable criticism but this ms is part of the OzFlux Special Issue and here we wanted to highlight the use of flux observations in refining GHG emissions and impacts on national accounts, a management focus rather than a detailed physiological analysis.

The flux observations were used to highlight respiration differences between sites, the magnitude of soil CO₂ emissions during tillage and preparation for cropping, the continued uptake of carbon post-deforestation from grass growth and woody re-sprouting, as well as the net loss of the natural C sink that we observed at the uncleared analogue site.

Other papers in the Special Issue have documented the flux characteristics of north Australian savannas – data from four savanna flux towers were included in the overview paper of Beringer et al. 2016 (doi:10.5194/bg-2016-152).

R1 provided very useful comments aimed at improved descriptions and estimation of fuels and associated emissions from the debris burning post deforestation, an important component of the total emission from this LUC. As a result the Methods section has been re-written and restructured and broken into 8 sections instead of 6. The revised ms also features a new Table, Table 3, that describes in a more transparent manner, the distribution of fuels as measured across the deforested site using fuel classifications as defined by the Australian Government’s savanna abatement methodology and latest emissions factors. Table 3 includes data for each fuel type (fine, coarse, heavy) including fuel mass and the associated emissions factors for each GHG (CO₂ CH₄ and N₂O), N:C and %C content with the emissions calculation described by an equation, Equation 1.

The emission calculation is now based on emission factors as recommended by R1, namely those of Meyer et al. 2012 and the Savanna Abatement Methodology Determination, March 2015, a methodology that is now legislated by the Commonwealth

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government (www.legislation.gov.au/Details/F2015L00344). This is a more robust and transparent reporting of emissions from the debris fire, although the new estimate (121.9 Mg CO₂-e ha⁻¹) differs by only 5% (now smaller) when compared to the original estimate. The new estimate has a higher contribution from non-CO₂ fluxes.

These improvements are in response to R1's comments arising from text on P7 to P12 of the original ms and we believe this has improved the clarity of the Methods section.

We suspect R1 (and R2) assumed we had one or two large stockpiles of heavy fuels that burnt very hot for 10 days or more. This was not the case as burning of the site consisted of ignition of the cured grasses and woody fuels in situ, with no stock-piling as an initial phase of burning. To ensure safety, ignition was done in blocks, which is why the process took 20+ days. After an initial burn, unburnt woody debris was then stockpiled and re-burnt until incinerated in a second phase. As such we had multiple debris piles distributed across the 295 ha block as opposed to one or two large piles burning at very high temperatures. Again, this has been described more fully in the revised text and to aid in the description of the LUC phases, in particular the fire event and aftermath, a colour Plate, Plate 1, has now been included. Plate 1 consists of 4 images of the site showing the initial deforestation event, the debris fire and stockpiling and the finalised state of the site prior to bed preparation for cropping.

Descriptions of the data sources for savanna-specific deforestation emissions across north Australia have been improved as R1 (and R2) found this hard to follow. All data were sourced from the NGGI in collaboration with staff from the Commonwealth government's departmental reporting team, as was acknowledged in the Acknowledgements. References to the methodology are given. In short, the savanna boundary that was defined by Fox et al. 2001 was applied as a spatial 'mask' to constrain the area of emissions estimates to the savanna region only. These were then compared to emissions from savanna burning from the same area.

R1 queried how the value of 78, 605 ha y⁻¹ in Table 4 (now Table 5) was derived. It is

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described in text in the Methods section, in Table 4 (5)'s caption and footnote for the table - this value is derived from the savanna constrained deforested area and is the mean savanna area deforested per year 1990-2013.

R1 also queried our LUC emission figure for 2013 and suggested our reported value was low. Firstly we report the mean from 1990 to 2013 and secondly we are not reporting emissions from all activities with the LUC sector – only emissions from Activity 2 'Deforestation' are relevant to our study. This was indicated in the original text. Plus our emissions estimate is specifically limited to the savanna land area across WA, NT and Queensland. If R1 looked up reportable emissions for these states in their entirety, there would be a significant difference compared to our reported value as the standard data reported by the Commonwealth includes the non-savanna (non-tropical) areas of each state where there have been significantly higher deforestation rates. Comparing with Cook et al 2010 may be problematic as the area included in each study would need to be identical, especially areas of Queensland, which have experienced significant clearances in southern and central Queensland, outside of our study area. It should also be noted that for the regional savanna estimates, we are simply compiling emissions data for either savanna burning or deforestation as estimated by the Commonwealth, but constrained to the savanna area as defined by Fox et al.

There were a number of other inconsistencies R1 commented on and these have all been addressed: fire frequency data were inconsistent and have been corrected; the citation for biomass allometry is confined to Williams et al. 2005; reference to fire-line intensities has been deleted given our fuel load is a mixture of grass and heavy fuel, with heavy fuel dominating.

We have also improved text in the Methods describing CWD estimation, in particular dealing with hollowing of large CWD fragments – we do not 'add missing biomass' as R1 queried, our method is designed to estimate the missing volume to ensure we do not provide a large overestimate of CWD. This was not entirely clear in the original ms and the text is now improved. We are estimating the volume for each CWD fragment

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that is then converted to biomass using specific wood densities assigned to our 5 rot classes that we define.

R1 also commented on our text re stand replacement events such as cyclones and/or floods which would take 4 decades to recover the lost carbon. The original text was confusing as given the site locations, neither of these events / scenarios is feasible and this sentence has been modified accordingly. The only agent of stand replacement in the region of our sites would be deforestation and conversion for agricultural production.

We include both CO₂ (not reportable) and non-CO₂ emissions (reportable) for savanna burning for comparison with deforestation emissions.

Reviewer 2 (R2)

Comments by R2 related to improvements in expression and typographical errors throughout the ms as well as an inclusion of a statement of potential errors.

All suggested changes of R2 have been implemented.

Fig 2 on energy balance closure was removed as suggested by R2 and text describing slope statistics from the closure analysis has now been incorporated included in the revised text.

R2 queried the nature of the gap filling approach used – a unique ANN model was developed for each LUC phase given the significant change in canopy and microclimatic characteristics of each phase. Text describing this has been improved. Errors associated with gap filling using the DINGO system were minimal as we had less than 10% of data that was missing.

In this study we used 30 minute covariance data for the calculation of fluxes not the raw data as is inferred from the paper of Isaac et al. in the Special Issue.

We can confirm fire emissions were not included in the NEE measurements and the

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value of 0.9 (BEF) was derived from an assessment of remaining heavy fuel levels post-fire. This value influences calculations of both CO₂ and non-CO₂ as described in the new methods section and the new Table 5 that gives emissions factors.

R2 queried the value of 2.75 Mg ha⁻¹ – this is the combined emission from the soil tillage phases over the last 6 months of the measurements, as is described in the text.

As requested by R2, a statement on potential errors associated with our emissions estimate from the debris fire has been included, which is based on uncertainty measures as described Russell-Smith et al. (2009) for key parameters used in the Australian savanna emissions methodology. Given a number of key parameters were measured on site in this study, with fuels measured across a well-defined area, our errors will be relatively low when compared with catchment scale to regional scale projects that the methodology has been designed for.

As R2 suggested, we statistically tested for site differences for each LUC phase (1-way ANOVA) with all phases significantly different except the pre-clearing phase, Phase 1. Significantly different mean NEE are identified in Table 3.

Figure 1 has been improved as requested, with latitude and longitude lines marked and a higher resolution coastline used.

We thank both reviews for their very constructive comments on the paper.

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