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Interactive comment on "Combining multi-spectral proximal sensors and digital cameras for monitoring grazed tropical pastures" *by* R. N. Handcock et al.

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AUTHOR RESPONSES TO REVIEW #1

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REVIEWER #1: In this manuscript the authors describe measurements from two sensor network locations in grazed tropical pastures. The motivation of the analysis is sound; sensor networks provide an alternative to remote sensing in areas where spatial scales do not match and or cloud interferes. However, the implementation leaves a lot to be desired. In short, I think there was no due-diligence in terms of experimental design and or practical engineering.

AUTHOR RESPONSE: With respect to Review#1, the project described in the paper is a pilot deployment of multiple sensors in this environment, with the intention of exploring what technical issues must be overcome for a full deployment. This study aims to address the problem of pasture monitoring in these very large and remote cattle grazing systems by a pilot project to test in-situ autonomous proximal sensors.

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REVIEWER #1: Experimental design / engineering: I'll highlight a few of the issues that are most obvious. For example, although the sites were outfitted with Skye multi-spectral sensors, basic meteorological measurements were largely omitted. I quote "our nodes showed a strong correlation with the average of the precipitation recorded at 'Charters Towers Airport' and 'Townsville Airport' stations, so this station average precipitation was used as the best of the available options for precipitation." I would argue that the best available option would have been physical measurements at both locations. REVIEWER #1: Given the cost of some of the other sensors, I was surprised that no basic meteorological measurements were made. Given the nature of the sensor network, all infrastructure to transmit data from basic precipitation and temperature sensors would be in place. The lack of reliable precipitation data surely decreases the overall value of the measurements made.

AUTHOR RESPONSE: While we agree with Review #1 that meteorological variables such as rainfall are ideally measured onsite, as we in an earlier response to the reviewer, there was a weather station at the study site that had recently been installed as part of the standard operating equipment at the research station, but as it's calibration had not yet been confirmed data from this station was not available for use. Unfortunately it was not possible to re-run the multi-year experiment with a replacement weather station, so we used the best available data that we had. As the goal of the study was the pilot deployment rather than developing final models for operational use, the national weather station data, and the in-situ soil moisture sensors described below, were suitable for this modelling.

Secondly, in this environment the soil moisture is a critical variable, so the authors installed the soil moisture sensors which provided surrogate temperature and moisture data. As described in the text, we compared climate data from the different sources in a robust way. For example, only when the interpolated temperature data were shown to be in correspondence with the soil temperature data was the decision made to use those datasets interchangeably. The precipitation data from nearby stations was selected in the same way. Given the spatial heterogeneity of precipitation events, the nationally available interpolated climate surfaces were thought to be too coarse for our small study site. A comparison of data from nearby weather stations with the in-situ soil moisture sensors at our nodes showed a strong correlation with the average of the precipitation recorded at two stations, so this station average precipitation was used as the best of the available options for precipitation. Following the earlier comments from Reviewer #1 we expanded this section in the text to clarify these topics. Apart from re-running the multi-year experiment to replace the failed metrological station initially installed on-site, we have used all available data sources. Additionally, the in situ soil moisture sensors provided a robust data source and would be a viable alternative to deploying a weather station.

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REVIEWER #1: Furthermore, the lack of data transmission from all sensors further weakens the case made for networked sensors (e.g. visual imagery).

AUTHOR RESPONSE: Please see earlier comments and the manuscript introduction which indicate that this was a pilot deployment of the equipment. The technology around sending image data back across the network was not the focus of this pilot deployment, and the digital camera images were intended as a supplementary data source to the multi-spectral data. We did send the multispectral and soil moisture sensor data back across the wireless sensor network, which shows the utility of the method and proved that the infrastructure worked. To have developed and deployed a method to send the image data back across the network would not have added to the project goals of this pilot deployment, but would have taken away from the main project goals. Additionally, we describe in section 4.2 of the manuscript that this is what can be deployed in an operational setting: "In our pilot study the digital camera images were downloaded manually, but as described by Gobbett et al. (2013) in an operational system the cameras could be solar powered and deliver data across a network that had sufficient bandwidth, particularly if daily image capture rather than every 30 minutes was found to be adequate."

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REVIEWER #1: Physical (biomass) measurements: I wonder why a proxy method was used to assess the total biomass?

AUTHOR RESPONSE: In tropical pasture environments which are both dense and heterogeneous, visual assessment of pasture biomass is a commonly used method compared to the pasture cuts that are more common in temperature pastures. For example, see Tothill and Partridge (1998). We will add this reference to the text to provide further information on this topic:

Tothill, J, and Partridge, I. (Eds.) 1998. "Monitoring grazing lands in northern Australia". Occasional Publication No.9, Tropical Grassland Society of Australia, Brisbane." http://www.tropicalgrasslands.asn.au/Monitoring%20book/06monitoring%202%203%20pp44-56%20LR.pdf

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REVIEWER #1: Physical (biomass) measurements: I would argue that samples could have been taken from locations outside the sensor range for at least the ungrazed location. The grazed locations might show more variability, but might still have been

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equally valid (given a large and random sample).

AUTHOR RESPONSE Given that visual assessments are widely used in these northern Australian grasslands, and that it was critical not to destroy the area under the nodes, we applied visual assessment to measure vegetation under the nodes. See section 2.8 for a list of vegetation measurements which include both 2D and 3D vegetation assessments and the height of the pastures taken using multiple methods. While it might be possible to take a number of destructive samples of the pastures surrounding the sensors and average these to form a proxy for the area under the node itself, this method would need to be tested to determine the correlation of such data to the biomass under the node itself. Particularly given the heterogeneity of the tropical pastures at the fine spatial scale.

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REVIEWER #1: Data processing: Previous research has shown a strong correlation between GPP and camera derived greenness (Toomey, M. et al. Greenness indices from digital cameras predict the timing and seasonal dynamics of canopy-scale photosynthesis. Ecol. Appl. 25, 99–115 (2015).). However, the approach taken by the authors (mainly an auto white balance setting) would make such an analysis far harder if not impossible. Consequently, there was a need for an additional arbitrary parameter to calculate GLA.

AUTHOR RESPONSE: Our results showed the GLA derived from the digital images to be a useful parameter with strong relationships to the field measurements of the pastures. The threshold value used in deriving a GLA was a single value applied across the whole time-series of camera images, and is a necessary feature of using the GLA, as well as having been applied in other vegetation studies (as cited).

In relation to the camera white balance setting, other authors have used auto white balance in similar studies (e.g. Macfarlane & Ogden, 2012). Automated estimation of foliage cover in forest understorey from digital nadir images. Methods in Ecology

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and Evolution 3, 405-415.), however, we note that other studies (Toomey et al, 2015) have used a fixed white-balance setting. This is an aspect which we would investigate further in future deployments, as it may enable even stronger correlations to be derived from the digital imagery. Our paper would benefit from the addition of this point to the discussion.

Macfarlane, C., Ogden, G.N., 2012. Automated estimation of foliage cover in forest understorey from digital nadir images. Methods in Ecology and Evolution 3, 405-415.

Toomey, M. et al. Greenness indices from digital cameras predict the timing and seasonal dynamics of canopy-scale photosynthesis. Ecol. Appl. 25, 99–115 (2015)

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REVIEWER #1: Final analysis: Given the the known relationship between vegetation greenness (or spectral indices) and the strong regression results are no surprise. More so, the lack of an analysis which differentiates between the two treatments (grazed / non-grazed) is rather surprising. No reference is made to grazing intensity in any model as a potential confounding factor. At least some measure of grazing intensity as -interacting- covariate should have been in place (cows /ha?).

AUTHOR RESPONSE: The aim of one of the two nodes being grazed was to generate differences in vegetation biomass/height as would be typical in the study environment, so that we would get a range of vegetation heights on which to test the pilot sensor deployment. We do not make any claims to be testing how well the sensor-vegetation relationship holds between grazed and un-grazed pastures. During the sensor deployment there were a number of documented grazing periods. However, these were during the dry season where feed is low. Examination of field data from each node indicated that there was no discernible impact from the grazing on the measured vegetation values. We therefore did not mention the grazing in the paper as it was not the focus of our study.

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REVIEWER #1: Although I think the authors are right to recognize the potential of sensor networks, their research fails to illustrate this successfully (technically / methodologically / statistically). Sadly, most of the highlighted issues are methodologically and/or technically, limiting potential ways in which to salvage a field season of measurements.

AUTHOR RESPONSE: We are clear in the paper that this is a pilot deployment designed to test the deployment of multiple sensor types and processing methodology within a challenging tropical pasture environment. We developed a robust method of quality control of the noisy data that is typical from these environments. Finally, we describe in detail the technical methods that we used to overcome the issues we encountered and make recommendations for how future deployments can avoid these technical limitations. Without pilot projects such as our study it would not be possible to develop better methods for future deployments. For example, as a result of this study the authors were in correspondence with the suppliers of the Skye sensors, and as described in the discussion secion we recommend that the new enclosed sensor design is used. Without field deployments such as our study it would not be possible to push the boundaries of both the technical requirements and more challenging environments such as in our pilot deployment.

Interactive comment on Biogeosciences Discuss., 12, 18007, 2015.