Modelling Catchment-Scale Evapotranspiration and Net Primary Production in Sub-Humid African Grasslands: Towards Understanding Carbon and Water Trade-Offs in Communal Rangelands

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Modelling catchment-scale evapotranspiration and net primary production in sub-humid African grasslands: towards understanding carbon and water trade-offs in communal rangelands

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Abstract
Being able to confidently predict net primary production within intensively used rangeland systems has become the goal of many rangeland scientists. The communally-managed rangelands of Africa, with their very high livestock numbers, represent such a challenge, as above-ground biomass is most often depleted before it has had chance to accumulate. In order to provide more accurate estimates of NPP for these rangelands, we explored the use of direct measurements of canopy cover, standing biomass and leaf area index, against standard vegetation indices from the Sentinel 2 sensors. Following intensive field surveys, we developed regression models of the relationships between Sentinel 2 NDVI and these three bio-physical attributes. Repeated measurements along an NDVI gradient revealed a good relationship between NDVI and LAI, which was used to predict the ET across landscapes under communal tenure arrangements. Although un-improved grasslands and abandoned cultivated lands are the dominant land cover classes in the study area, woody invasive alien plants (IAPs) along seep-lines have increased in spatial extent since their introduction in the middle of the last century. These IAPs are now responsible for most of the catchment ET in these highly modified ecosystems. Grass biomass production for the upper reaches of the Umzimvubu catchment was calculated using the relationship between Sentinel 2 NDVI and grass canopy cover.

Introduction
Predicting above-ground net primary production (ANPP) within intensively used rangeland systems is vital to understanding the trade-offs associated with different rangeland management options (Stringer et al., 2012). The communally-managed rangelands of southern and eastern Africa experience very high stock numbers where ANPP is often depleted before it can accumulate to ameliorate the impact of forage shortages (Vetter, 2013). One way of providing real-time estimates of ANPP to graziers is to calibrate indices from satellite imagery to ground-based measurements. In order to improve the estimates of ANPP available to the graziers, we verified the relationship between fraction of vegetative cover (FVC) (Flombaum and Sala, 2007), the disk pasture meter (DPM) (Bransby and Tainton, 1977) and ANPP. The results from these estimates were then used to scale up to the landscape against standard vegetation indices from the European Space Agency's Sentinel 2 satellite.

Methods and Study Site
The growing season field sampling took place from 24 to 29 February 2019 in the Cedarville area, Eastern Cape, South Africa. Thirty-eight pre-determined sample sites were surveyed along a Sentinel 2 NDVI (S2 NDVI) gradient to ensure a wide range of grassland condition within five NDVI classes (Table 1). Several new sample locations were identified based on the adjusted NDVI intervals (Table 1) and accessibility. To ensure consistency between satellite and ground-level measurements, each sampling point corresponded to the Sentinel-2 pixel bounds were recorded to locate and delineate the 10m by 10m pixel at ground-level during field survey. All relevant biophysical parameters were then recorded within the field-delineated pixel. Four biophysical parameters were measured at each sample point: fraction of vegetation cover (FVC) using the line-intercept method (Hardy, 1995); leaf area index (LAI) and fraction of absorbed photosynthetically active radiation (fAPAR) using an Accupar Ceptometer (Decagon, USA); and disk settling height using the DPM (Bransby and Tainton, 1977). Two additional parameters were derived from grass height, namely green-dead biomass proportions and dry matter (DM) production.

Results

The region had started recovering from severe drought conditions at the time of the survey, and the study site received 280mm of precipitation in the month of February 2019. Grasslands were lush and green with little to no woody encroachment. However, due to heavy rains during the month of February, NDVI values within the region increased notably until the period of collection. Figure 1 illustrates this increase, showing NDVI calculated using Sentinel-2 imagery for the beginning of the month (2019/02/01; Figure 1a) compared with two days before data collection (2019/02/23; Figure 1b). This heavy rainfall also resulted in flooding and wetland-like conditions in the low, flat grassy plains situated around the Umzimvubu River, as shown by the increased number of NDVI pixels with values lower than 0.1 in the East of Figure 1b. To account for the overall increase in NDVI, sampling intervals had to be adjusted accordingly. Table 1 shows the original NDVI intervals (from Sentinel-2 image 2019/02/01), the adjusted intervals (from Sentinel-2 image 2019/02/23) and the description of grassland condition for the NDVI interval. The relationships between disk settling height and ANPP (Figure 2), as well as relationship between FVC and ANPP (Figure 3)(Gwate, 2017) were used to compute ANPP for each Sentinel 2 pixel (Figure 4 and Figure 5). The almost identical slopes (y=997,47x and y=992,24x) from two fully independent methods of determining ANPP, supports the use of S2 NDVI to predict ANPP.

Discussion

Repeated measurements along an NDVI gradient revealed a sound relationship between S2 NDVI and herbaceous ANPP (Figure 4 and 5), which was used to predict the annual herbaceous ANPP in grasslands under communal tenure arrangements. Although un-improved grasslands and abandoned cultivated lands are the dominant land cover classes in the study area, woody invasive alien plants (IAPs) along seep-lines have increased in spatial extent since their introduction in the middle of the last century. These IAPs are now responsible for most of the catchment ET in these highly modified ecosystems. The annual herbaceous biomass production estimates for the upper reaches of catchment will be compared with the production and water loss associated with areas invaded by IAPs.

Acknowledgements

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Table 1 Original and adjusted NDVI intervals for field sampling

Original NDVI	**Adjusted NDVI**	**Grassland Condition**	
0.1 – 0.2	0.1 – 0.3	Bare	degraded
0.2 - 0.3	0.3 – 0.4	Recently grazed	overgrazed
0.3 – 0.4	0.4 – 0.6	Good condition	most common
0.4 – 0.5	0.6 – 0.7	Very productive	well-rested
0.5 – 0.6	0.7 – 0.8	Very dense grasslands	areas where water run-off accumulates

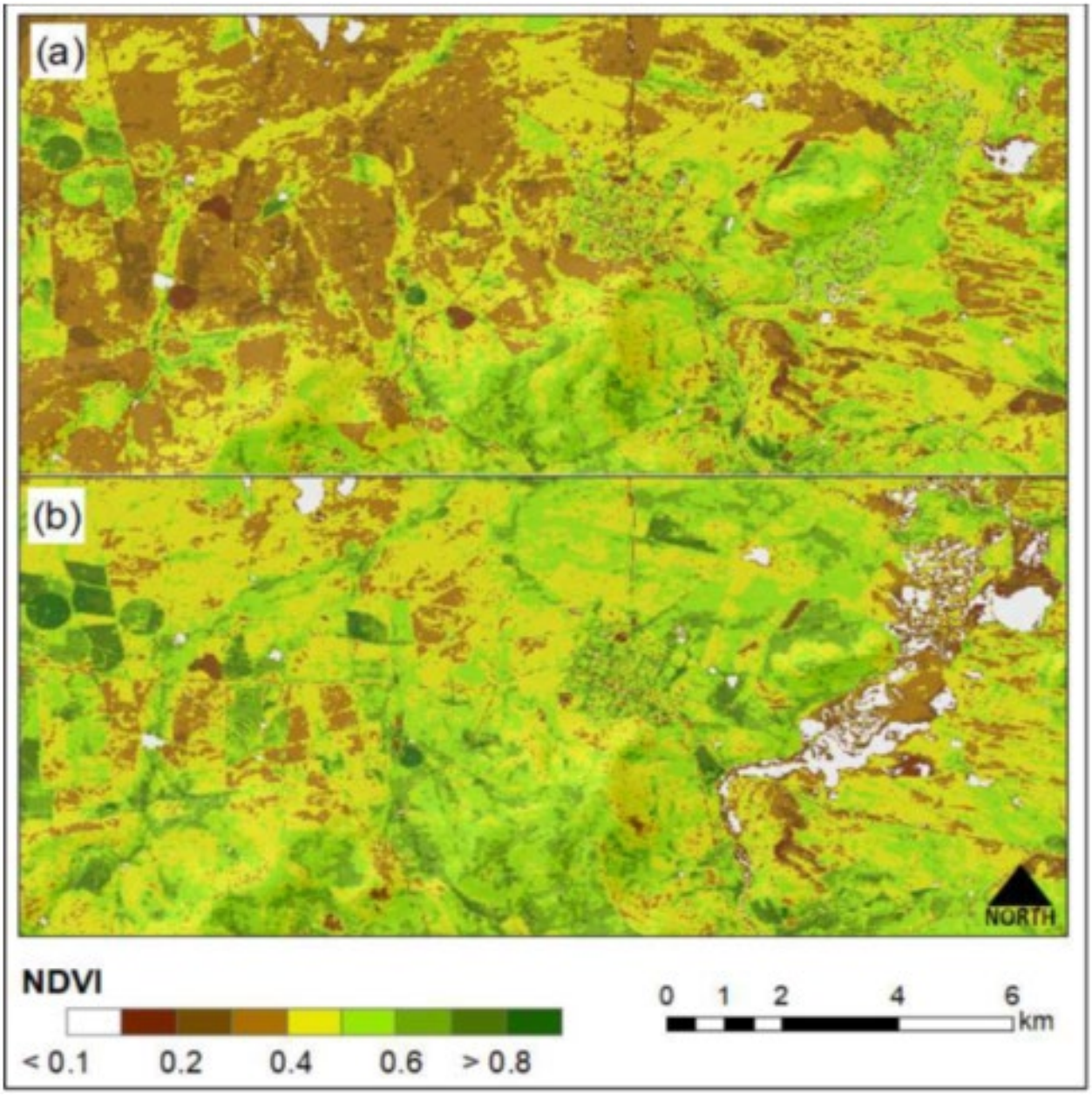

Figure 1 NDVI derived from Sentinel-2 imagery for the Cedarville region for (a) 2019/02/01 and (b) 2019/02/23, showing the rapid greening up of the highly productive floodplain.

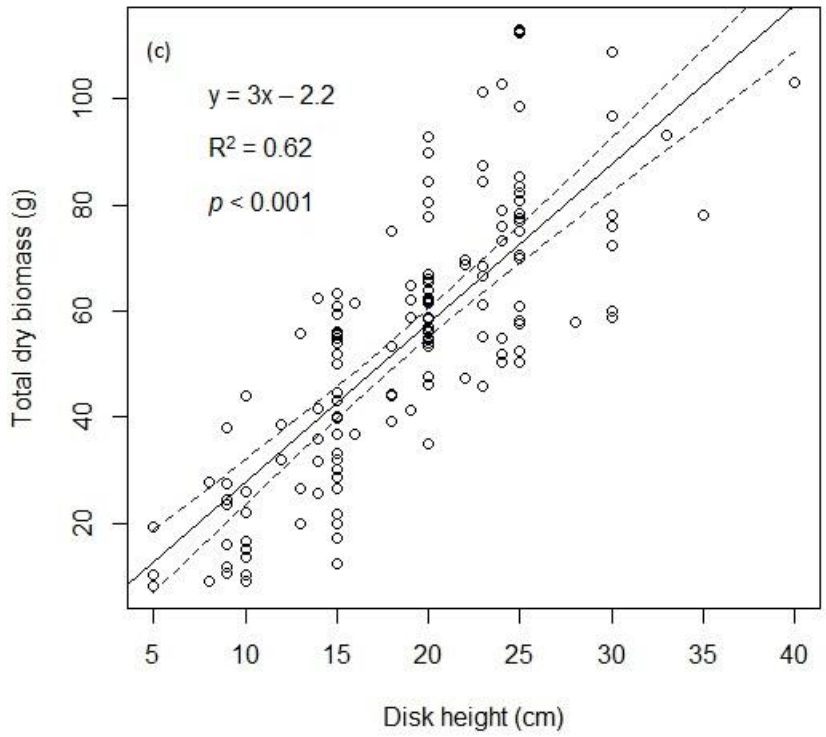

Figure 2. Disk settling height and associated dry matter (DM) for mesic grasslands in the Umzimvubu River catchment (Gwate, 2017).

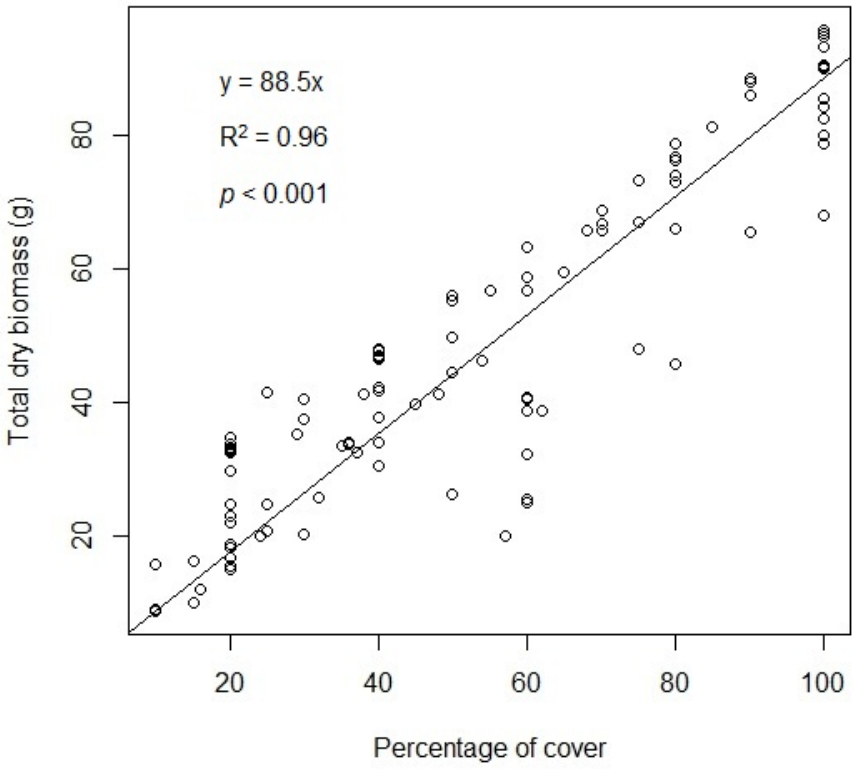

Figure 3. Fractional vegetation cover (FVC) and ANPP (DM) for mesic grasslands in the Umzimvubu River catchment (Gwate, 2017).

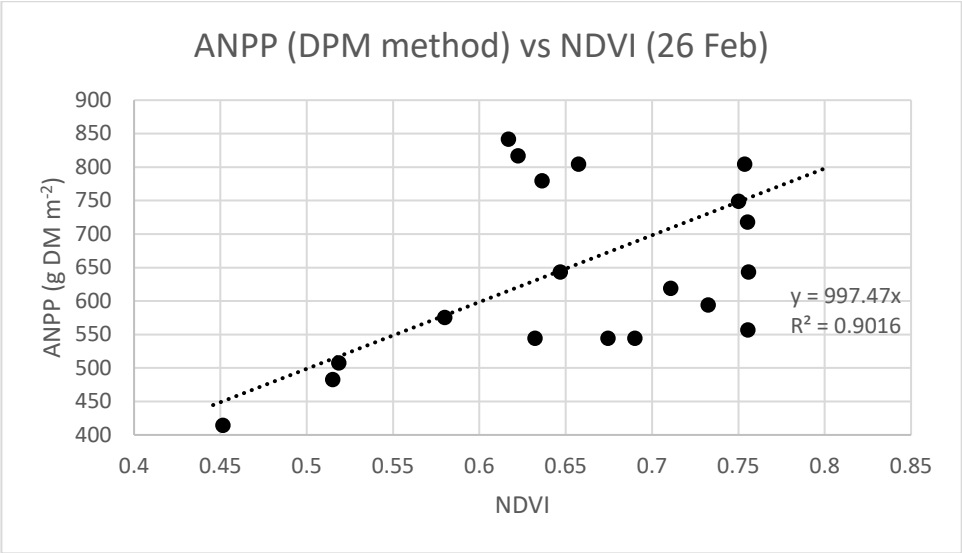

Figure 4. Sentinel 2 NDVI (26 Feb 2019) and ANPP (g DM m^{-2}) (using DPM method) for mesic grasslands in the upper reaches of the Umzimvubu river catchment, Eastern Cape, South Africa.

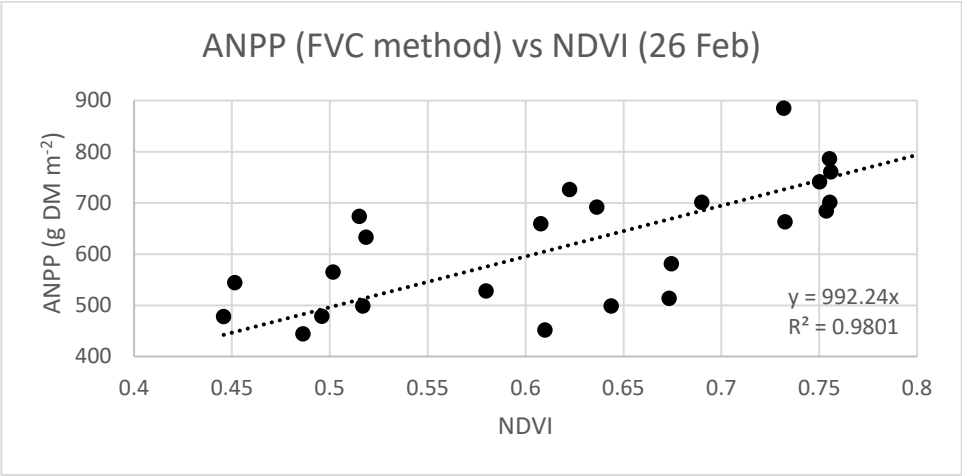

Figure 5. Sentinel 2 NDVI (26 Feb 2019) and ANPP (g DM m^{-2}) (using FVC method) for mesic grasslands in the upper reaches of the Umzimvubu river catchment, Eastern Cape, South Africa.