Ground penetrating radar measurements show a spatial relationship between coarse root biomass and soil carbon abundance

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Motivation

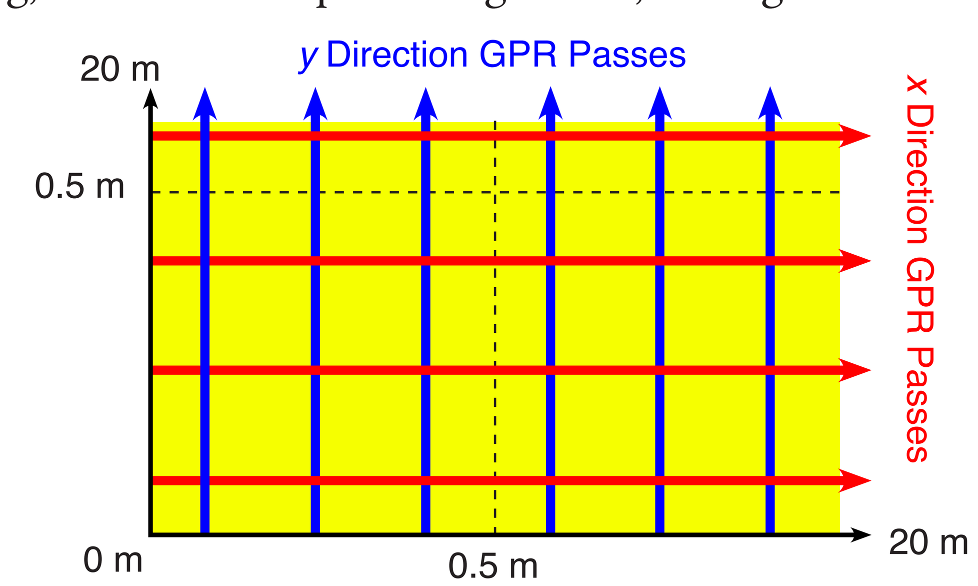
The patchy configuration of vegetation in savannas leads to a spatially heterogeneous distribution of soil carbon, nutrients, and moisture. Many studies that attempt to quantify this heterogeneity divide the landscape into "under canopy" and "between canopy" patches. However, roots determine much of a plant's influence on the soil environment and may extend well beyond the canopy. Most methods for measuring roots in a natural ecosystem can only directly sample small areas, making it difficult to determine their spatial distribution. Ground penetrating radar (GPR) presents a promising method for mapping coarse roots non-destructively over large areas.

Study Site: Tshane, Botswana

24°01'01"S, 21°52'08"E,
Vegetation: Open shrub savanna   Woody Cover: 14%
Soil Texture: Sandy (>90% sand)
Dominant Woody Species: *Acacia mellifera, Boscia albitrunca, Lycium* spp.
Annual Rainfall: mean 358 mm, std dev. 133 mm
(Bhattachan *et al.* 2012)

GPR Survey Methodology

We surveyed three 20 x 20 m square plots using a Noggin Plus 1000 Mhz GPR system (Sensors and Software Inc.; Mississauga, ON) set to a velocity of 0.134 m/nsec and a depth of 82 cm. Prior to surveying, we cleared the plot of vegetation, cutting all stems as close to the ground as possible, and covered the ground with a thin polyester mesh to improve the traction of the GPR odometer wheel. We divided the plot into perpendicular 0.5 m swaths and ran three GPR passes over each swath using a string anchored at opposite ends of the plot to guide the GPR.



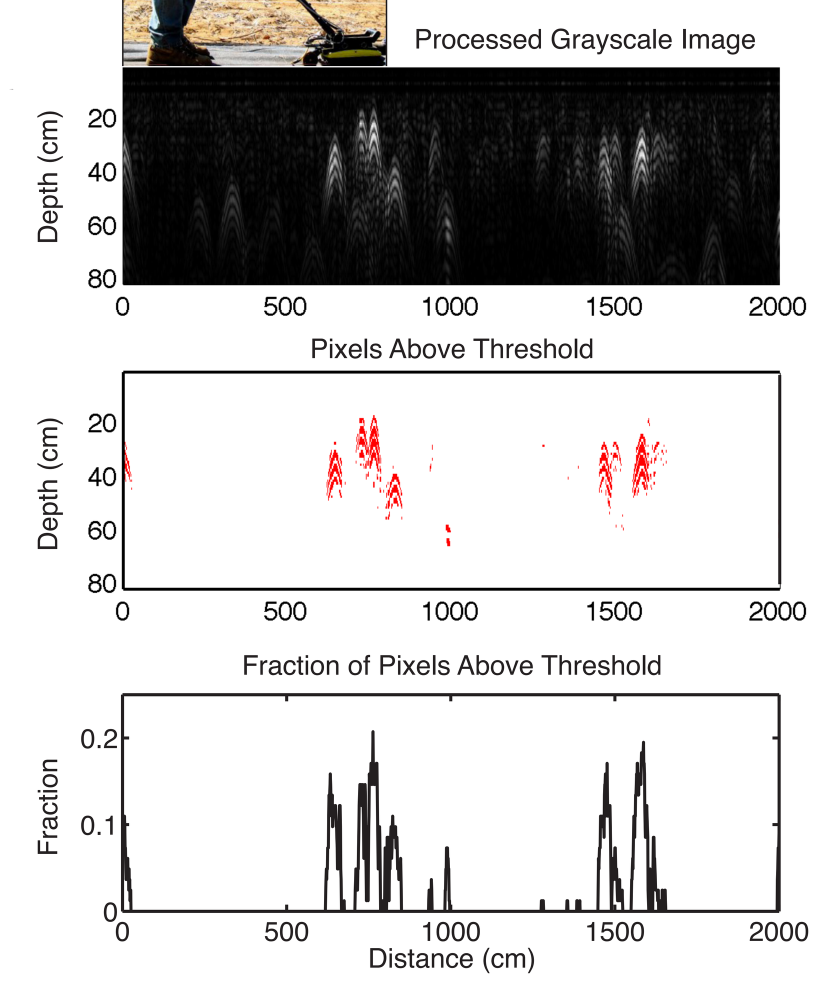
Validation Methodology

We used sampling pits to develop a relationship between GPR return and coarse root biomass. In each of the three 20 x 20 m plots, we randomly selected and excavated 20 1 x 1 m quadrats to a depth of 1.1 m.

We measured all roots greater than 2 mm in diameter for length, diameter, mass, *x*-*y* direction and depth layer (0-30, 30-50, 50-70, 70-90, or 90-110 cm). We oven dried a sample of the excavated roots to determine a green-to-dry biomass conversion factor.

Image Analysis

The GPR returns included hyperbolic reflectors representing roots and horizontal reflectors from the ground surface, which we reduced with background removal processing. Following Neto and de Madeiros (2006), we amplified the deeper reflectors to correct for the attenuation of the GPR signal with depth.



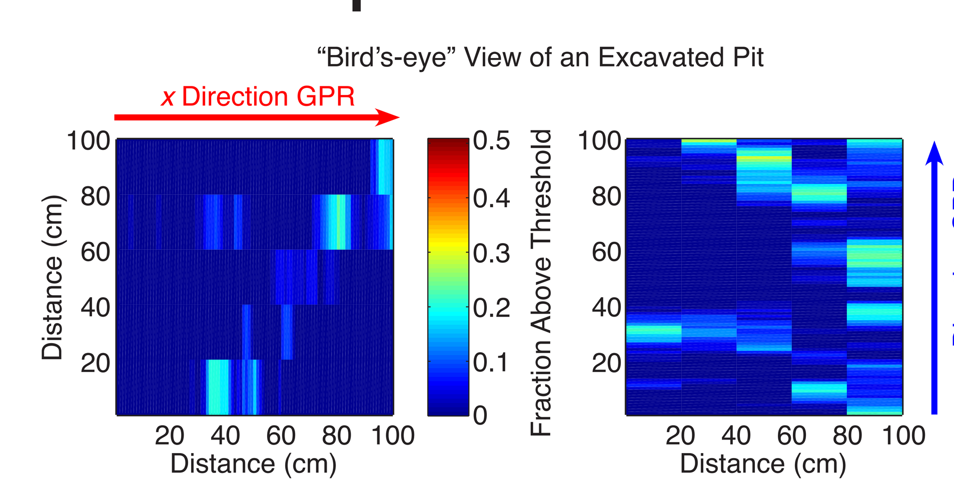
We converted the processed radar returns to 8-bit grayscale images using the Matlab Image Processing Toolbox (Mathworks; Natick, MA). Each pixel in the grayscale image has an intensity value between 0 (black) and 255 (white).

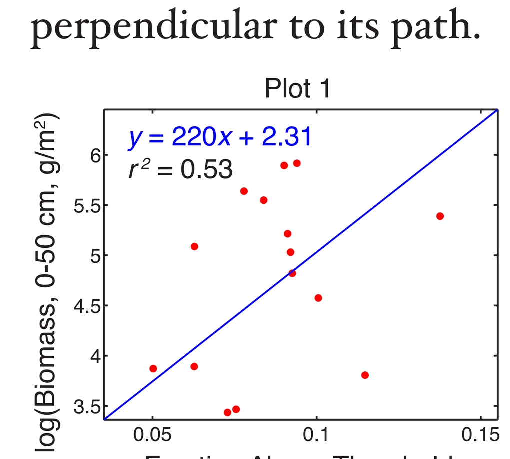
Following Stover et al. (2007), we set an intensity threshold of 91 above which pixels would be counted to differentiate large roots from echoes and noise.

For each centimeter of horizontal distance in the GPR pass, we determined the fraction of pixels above the threshold. This produces a vertically-integrated measure of return intensity.

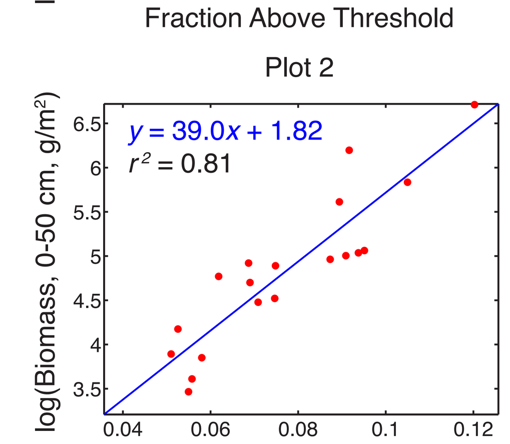
GPR-Biomass Relationships

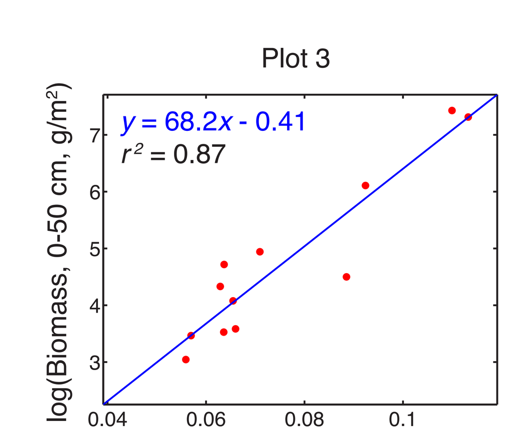
We isolated the portions of the 6 *x*-direction and 6 *y*-direction GPR passes going over each of the excavated pits. We averaged the two directions to be representative of the pit, because the GPR is better at "seeing" roots perpendicular to its path.





We found the best relationship between GPR return and log-transformed biomass in the 0-50 cm depth layers. The GPR was unable to detect amounts of biomass below 20 g/m², so we excluded those pits. We found a much better relationship between GPR return and biomass when we considered the three plots separately.





The need for separate relationships for three plots in the same area suggests that **GPR may not be a suitable replacement for cores or pits in quantifying total coarse root abundance.**

References

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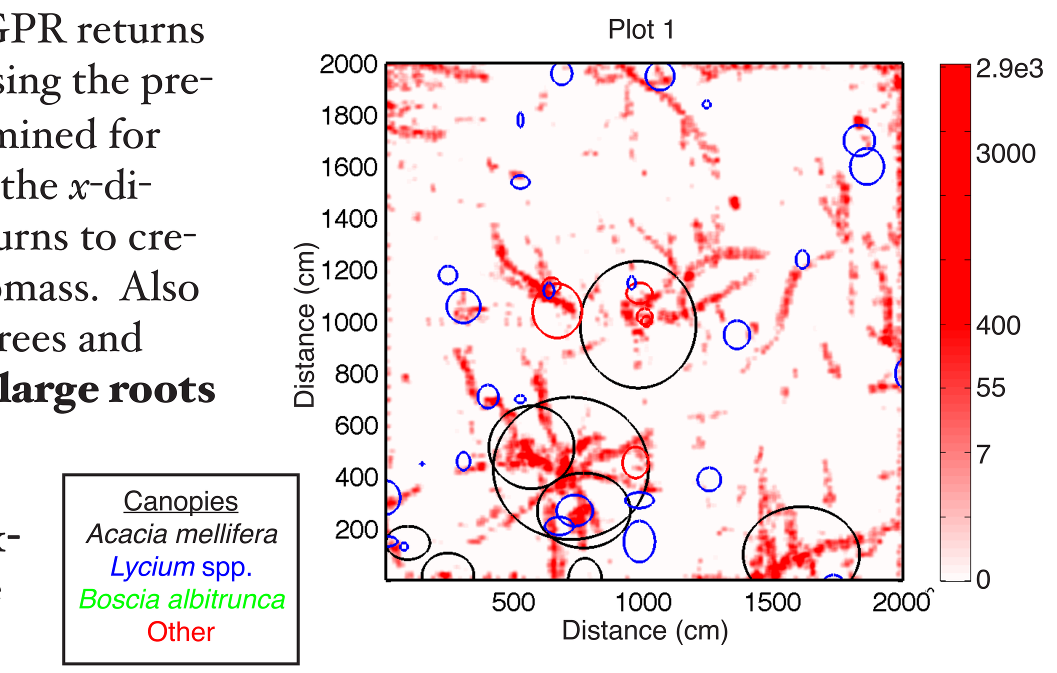
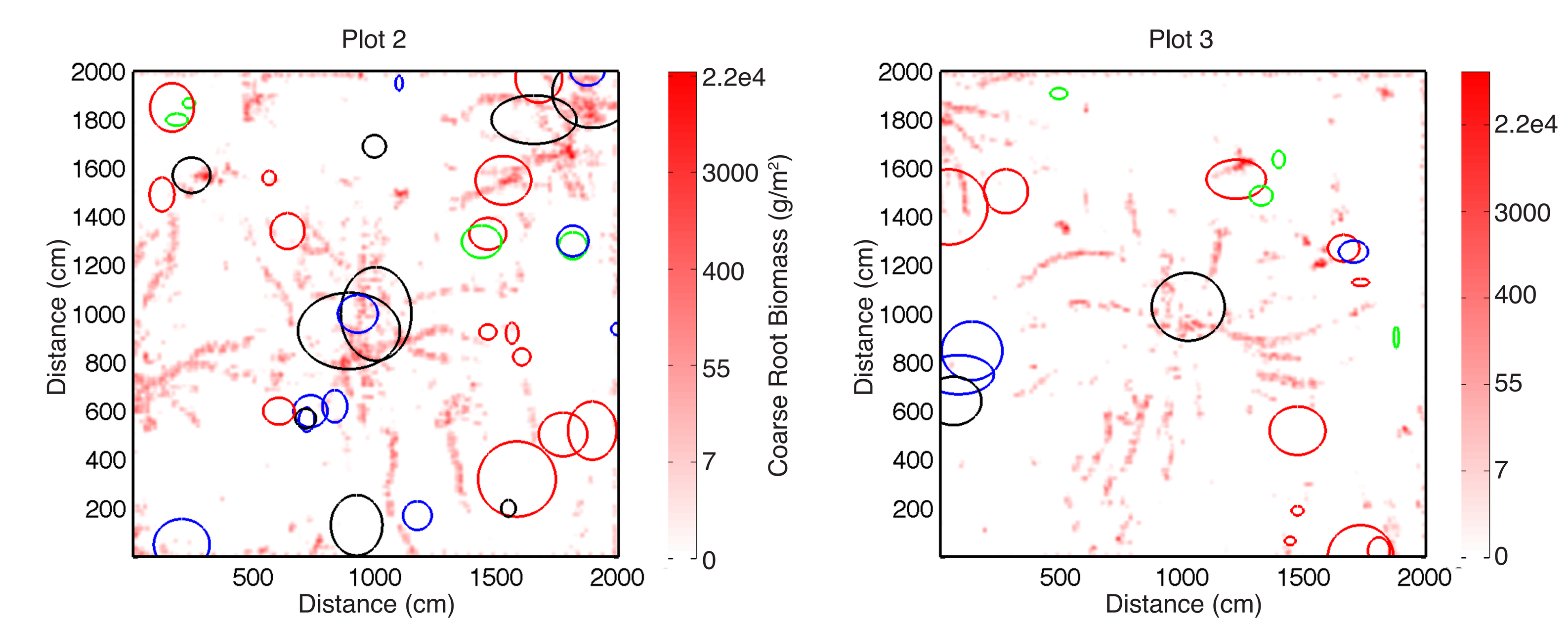
Wang, L., et al., 2009. Spatial heterogeneity and sources of soil carbon in southern African savannas. Geoderma, 149, 402-408.

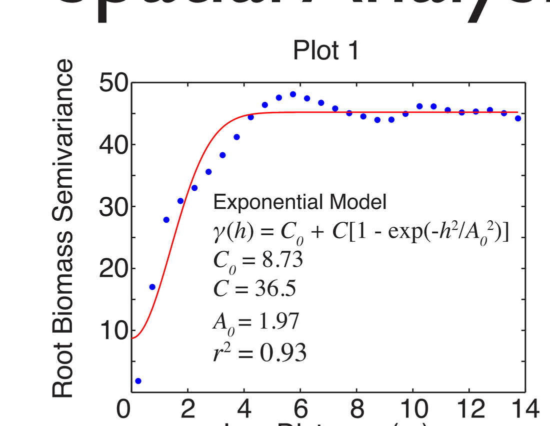
Root Biomass Maps

We converted the GPR returns to biomass values using the predictive relationships determined for each plot and interpolated the *x*-direction and *y*-direction returns to create maps of coarse root biomass. Also shown are the outlines of trees and shrubs in the plots. **Most large roots were attributable to *A. mellifera*, the dominant semi-tree, with roots extending well beyond the canopies.**





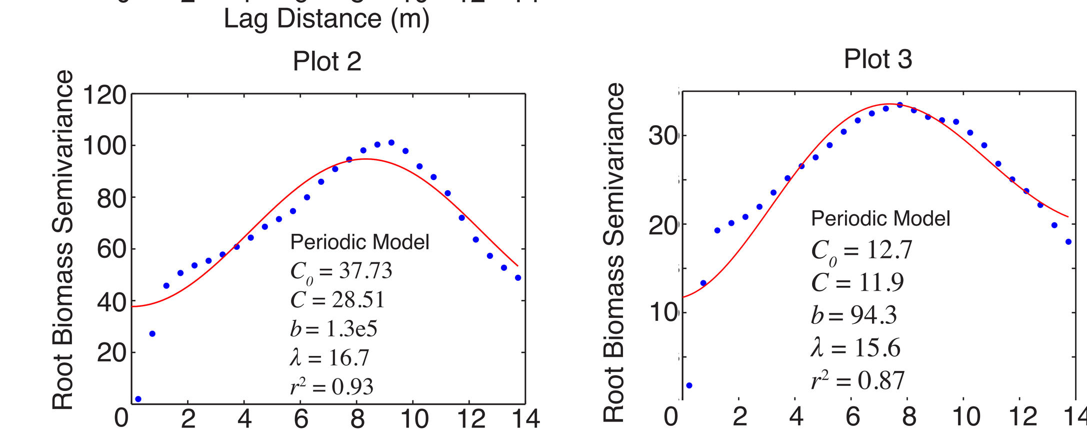
Spatial Analysis of GPR Data



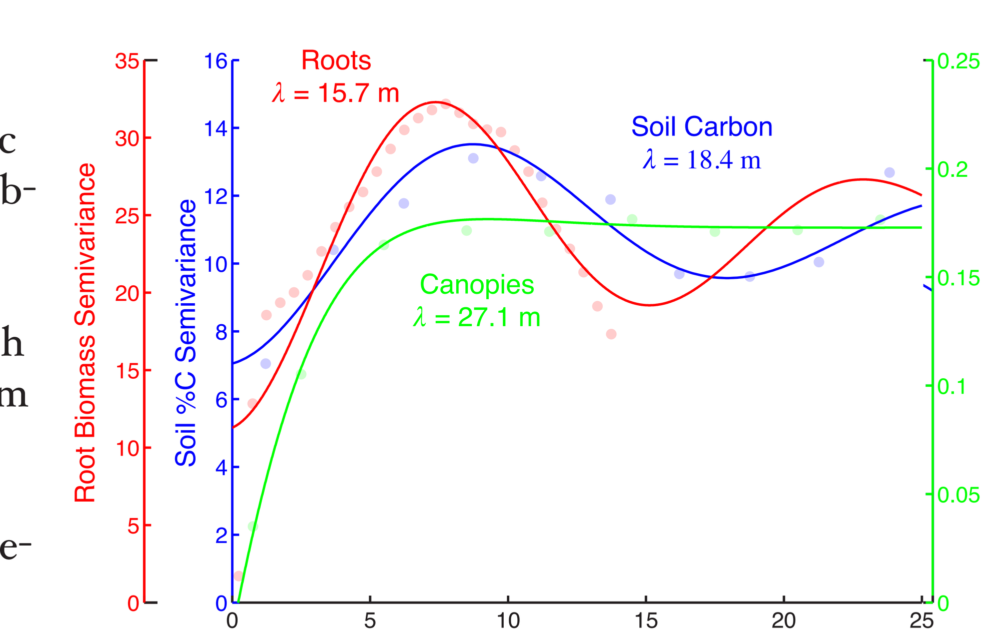
Semivariograms of the GPR return (pixels above threshold) for plots one and two showed periodicity that was best fit by a "hole-effect" model (Ma and Jones, 2007):

$$\gamma(h) = C_0 + C[1 - \exp(-h/b)\cos(2\pi h/\lambda)]$$

where λ is the wavelength of the periodicity. The periodicity is caused by the clustering of roots where trees are located. In plot one, the higher pixel threshold reduced the ability of the GPR to detect clustering so a standard spherical model provided a better fit to the semivariogram.



A previous study of the spatial distribution of soil carbon at the Tshane site found a periodic semivariogram, which was attributed to the patchy distribution of tree canopies (Wang et al., 2009). Our data, combined with aboveground mapping data from Caylor et al., 2003), show that the length-scale of soil carbon semivariance periodicity is in between those of roots and canopies, but is closer to roots. This suggests that **the root systems of woody plants contribute more to soil carbon pools than their canopies.**



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