Characterizing root architecture of riparian vegetation for assessing bank erosion potential in Queensland Rivers: A stochastic framework to integrate field and LIDAR data

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Key Points

- In this study we outline a method to upscale site specific species assemblage root characteristics to the catchment scale
- Evaluation of model results for 49 sites, across a broad geographic range along the east coast of Queensland, produced unbiased predictions.
- Results show that is possible to focus on assemblages instead of species, making it easier than other models to apply to the diverse species compositions found in Australia.
- Our analysis showed that there was as much variation in root strength characteristics within species (from different sites) as between species.

Abstracts

Sediment budget models predict riverbank erosion using the presence of riparian vegetation as a main factor controlling bank erosion across river systems. The way these catchment scale models relate bank erosion to riparian vegetation is; however, extremely crude. Site scale models rely on the parameters of root tensile strength and root architecture to quantify the reinforcement provided by roots in riverbanks. Root diameter is used to estimate the tensile strength of individual roots, whereas root architecture describes the abundance, root diameter and spatial distribution of roots across the bank face. Limitations of detailed site scale models are that they have been developed a low diversity of tree species in temperate climes, this model structure does not provide the necessary information for application at a catchment scale in tropical environments. In this work, we propose a stochastic approach to upscale root architecture data, collected during extensive fieldwork, to the catchment scale using 1 m^2 resolution vegetation information (canopy high and projected foliage cover) derived from LIDAR. We focused our data collection and analysis at species and assemblage levels in order to better characterize forest structures and targeting key dominant species in the reach. The non-parametric Spearman Rank Correlation Coefficient was calculated between field site root architecture data and LIDAR imagery. A probability density function was then fitted to the field data. Several analytical functions were tested using a Kolmogorov-Smirnov and ranked according to their respective p-values. Monte Carlo simulations were performed, constrained by the Spearman index, using the parameters of the chosen analytical functions found for each site and each distinct riparian forest structure. This method provided a way to upscale root characteristics, essential for sediment budget models. The stochastic nature of the process allowed the quantification and reporting of model uncertainties. Finally, this framework is capable of characterizing the strength provided to a riverbank by the roots of a vegetation community with a highly diverse species composition, typical of those found in Queensland rivers.

Keywords

Root reinforcement, bank erosion, sediment budget, Monte Carlo, Normanby River, O'Connell River, Brisbane River

Introduction

Sediment budget models such as SedNet use the presence/absence of riparian vegetation as one of the main variables for predicting bank erosion as a sediment source at a catchment scale (Prosser *et al.*, 2001).

This assumption remains unchanged in more recent updates of this modelling approach (Wilkinson *et al.*, 2014). It is widely recognized that the limited predictive capacity of the bank erosion component in the existing catchment scale models, is partly due to the crude way in which riparian vegetation is characterized. This represents a significant limitation on our ability to accurately model catchment sediment sources (Rustomji *et al.*, 2010; Brooks *et al.*, 2013). Models focusing at the site scale, such as the Bank Stability and Toe Erosion Model (BSTEM) (Simon *et al.*, 2009), rely on exhaustively parameterizing bank geotechnical characteristics. This parameterization involves measuring root tensile strength and architecture to quantify the reinforcement to riverbanks provided by the presence of riparian vegetation. Such an approach can only really be applied at the site scale where the bank materials and vegetation can be adequately measured.

The tensile strength function provides information about resistance strength of individual roots in relation to diameter, whereas root architecture describes the abundance, root diameter and spatial distribution of roots across the bank face (Abernethy and Rutherfurd, 2001). Both these parameters are then be used to assess the contribution of riparian vegetation to bank cohesion (Abernethy and Rutherfurd, 2001; Simon *et al.*, 2009; Hubble *et al.*, 2010). Using a species library, or observed data, site-scale models quantify the additional protection provided from vegetation by estimating the numbers and diameter of roots crossing the predicted shear plane (Pollen and Simon, 2005, Hubble *et al.*, 2013). However, being focused at small spatial scale and developed for settings of low diversity of tree species in temperate climes, this model structure had limitations when applied in a highly diverse tropical environment.

Bridging the gap between these two existing modelling scales is a major challenge, but one which is fundamental to improving our ability to better predict bank erosion at the catchment scale using remotely sensed data. In this study, we set out to attempt to bridge this scalar divide, and to do so we propose a stochastic approach to upscale an extensive site-scale root architecture and root tensile strength dataset to the catchment scale. We outline an approach that uses vegetation information derived from LIDAR imagery (canopy height and projected foliage cover) at 1m spatial resolution, as an intermediate step towards up-scaling to the catchment scale using ASTER data (15m resolution).

Methods

The data collection and analysis were focused at both species and assemblage level in order to better characterize forest structures and at the same time targeting dominant riparian species in the study reaches. A total of 49 sites were investigated along the Normanby, O'Connell and Brisbane Rivers; each basin providing distinct forest structures and geomorphological settings, albeit with a number of common species, and similar community structures. Root architecture was recorded across the riverbank using two distinct approaches: one that emulates existing published approaches in which the roots are counted at recently failed banks (Pollen and Simon, 2005, Pollen, 2007) (Figure 1A); and another method in which roots on stable banks were hydraulically excavated (Figure 1B &C). Root architecture was documented, and root pulling tests were then performed to measure tensile strength on a range of root sizes (*sensu* Pollen, 2007).

Figure 1 Examples of failed bank site (A) from which root architecture might be collected; and a stable bank site (B) prior to hydraulic excavation, and (C), the same location immediately following excavation. To the casual observer, this otherwise bare bank would unlikely be considered to possess much by way of riparian root reinforcement. Sampling of stable banks redresses the inherent bias of selecting sites for root analysis that have already failed.

Using an approach adapted from Iwashita *et al.* (2012), a method is outlined for upscaling the data from the site scale to reach and catchment scale. First, the Spearman index, a non-parametric correlation value, was calculated between root architecture from field sites and LIDAR imagery data, and then a probability density function fitted to the field data. Analytical functions were then tested through Kolmogorov-Smirnov test and ranked according to their respective p-values. A stochastic Monte Carlo simulation was then run which produced values of root diameters based on the parameters of the chosen analytical functions found for each site and each distinct riparian forest structure (figure 2). The generated values were constrained by the correlation Spearman index between root diameter and the LIDAR data.

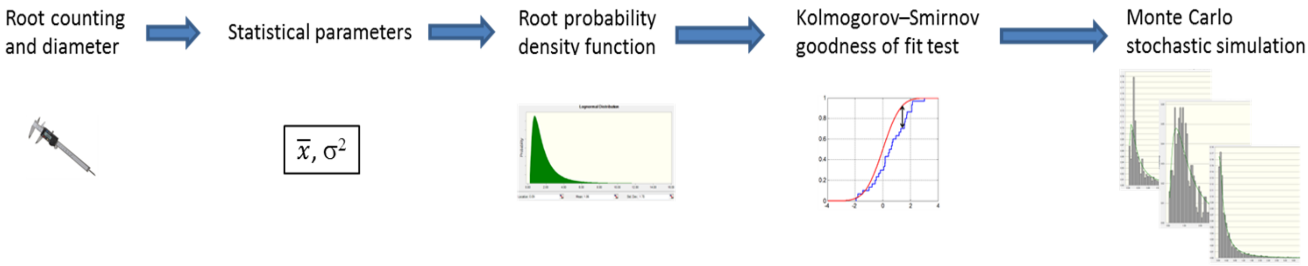


Figure 2. Procedures to apply the Monte Carlo simulation using the root architecture statistical parameters

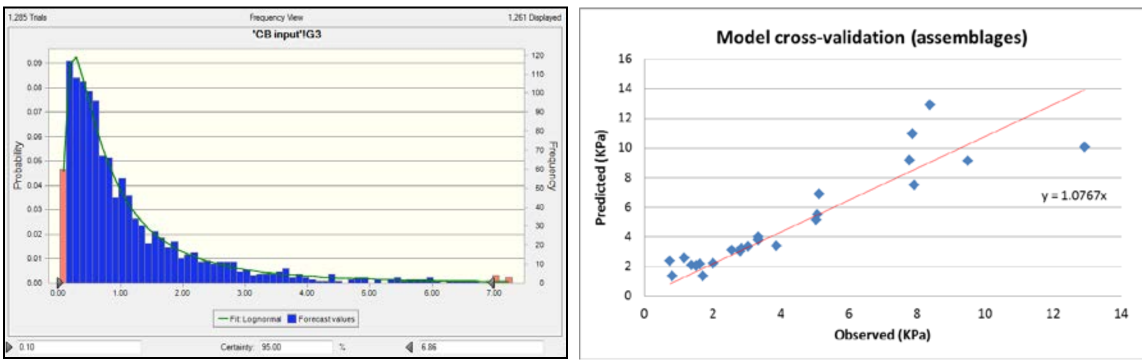
Results and Discussions

The probability density function that best characterized the root diameter frequency for all investigated sites was found to be a lognormal distribution (Fig. 2a). The parameters of the function were then used to differentiate and characterize the forest structure associated with the corresponding root architecture. Overall, the fitted functions for root diameter versus load had a similar "goodness of fit" regardless of whether the relationships were fitted for single species roots or multi-species assemblages (Table 1). These results support the decision to focus on an assemblage level that can encompass the highly diverse riparian zone of Queensland rivers rather than just at the species level. Large savings of effort can be achieved through a focus on more generic descriptions of community assemblages, which can be readily defined from remotely sensed data, rather than having to focus on individual species. Our analysis showed that there was as much variation in root strength characteristics within species (from different sites) as between species, and as such there was no real advantage in constraining the analysis to the species level alone.

Table 1. Examples of root tensile strength functions and their respective R^2 fitted from field tests of root pulling.

Species/Site	Function	R^2
Castanospermum australe	$y = 0.4436x^2 + 1.1001x$	0.87
Ficus opposita	$y = 1.6187x^{1.6551}$	0.92
Casuarina cunninghamiana	$y = 0.1973x^2 + 2.3373x$	0.90
Corymbia clarksoniana (2)	$y = 0.4077x^2 + 1.9195x$	0.79
NM rainforest	$y = 0.4459x^2 + 2.0426x$	0.91
Andromache regrowth	$y = 0.7379x^2 + 0.2703x$	0.82
Grass assemblage	$y = 0.8176x$	0.71
UB trib Riparian Comm	$y = 1.15x^2 + 0.1856x$	0.95

Model evaluation was conducted through cross-validation, where observed values versus predicted values showed an *x* = *y* relation both for species oriented sites and for assemblage oriented sites (Fig. 2b). Additionally, the analysis of the residuals of the validation did not detect inset trends, i.e., the model show some robustness as it can cope with different sampling schemes while not presenting biased predications.



(a) (b)

Figure 2. (a) Example of root diameter histogram generated by Monte Carlo simulation characterizing an assemblage on Granite Normanby River. (b) Model cross-validation: Observed values of root reinforcement versus predicted values.

Conclusions

This approach provides a means to upscale riparian vegetation root characteristics from a site scale to a reach and catchment scale, which is an essential step for improving bank erosion prediction in sediment budget models. Cross-validation indicates that the proposed stochastic approach is unbiased and provides a way to measure the magnitude of prediction uncertainty, which is essential for preventing error propagation in sediment budget models. Finally, by focusing at the community assemblage level instead of species level, this approach provides a practical method for characterizing the geotechnical characteristics of riparian vegetation with high species diversity, which is a characteristic of many tropical and sub-tropical Queensland that rivers.

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References

Abernethy, B., Rutherfurd, I. D. (2001). The distribution and strength of riparian tree roots in relation to riverbank reinforcement. Hydrol. Process. 15, 63–79.

Brooks, A.P., Spencer, J., Olley, J., Pietsch, T., Borombovits, D., Curwen, G., Shellberg, J., Howley, C., Gleeson, A., Simon, A., Bankhead, N., Klimetz, D., Eslami-Endargoli, L., Bourgeault, A., (2013) An Empirically-based Sediment Budget for the Normanby Basin: Sediment Sources, Sinks, and Drivers on the Cape York Savannah. Griffith University, 506pp.

Hubble, T. C. T., Airey, D. W., Sealey, H. K., Carli, E. V., Clarke, S. L. (2013). A little cohesion goes a long way: Estimating appropriate values of additional root cohesion for evaluating slope stability in the Eastern Australian highlands. Ecological Engineering 61P, 621– 632.

Hubble, T.C.T., Docker, B.B., Rutherfurd, I.D.(2010) The role of riparian trees in maintaining riverbank stability: A review of Australian experience and practice, Ecological Engineering, Volume 36, Issue 3, pp. 292-304

Iwashita, F. Friedel, M J., Ribeiro, G. F., Stephen, (2012). Intelligent estimation of spatially distributed soil physical properties. Geoderma 170, 1–10.

Pollen, N., Simon, A. (2005). Estimating the mechanical effects of riparian vegetation on stream bank stability using a fiber bundle model. Water Resources Research 41, W07025.

Pollen,N. (2007). Temporal and spatial variability in root reinforcement of streambanks: Accounting for soil shear strength and moisture, CATENA, Volume 69, Issue 3, pp. 197-205

Prosser, I., Rustomji, P., Young, B., Moran, C. & Hughes, A., 2001. Constructing river basin sediment budgets for the National Land and Water Resources Audit. *CSIRO Land and Water Techincal Report.* Canberra, CSIRO.

Midgley T. L., Fox, G. A., Heeren, D. M. (2012). Evaluation of the bank stability and toe erosion model (BSTEM) for predicting lateral retreat on composite streambanks. Geomorphology 145–146, 107–114.

Rustomji, P., Shellberg, J., Brooks, A., Spencer, J., Caitcheon, G. (2010) A catchment sediment and nutrient budget for the Mitchell River, Qld. A report to the Tropical Rivers and Coastal Knowledge (TRaCK) Research Program. CSIRO Water for a Healthy Country National Research Flagship. 119 pp http://track.gov.au/publications/registry/876

Simon, A., Pollen-Bankhead, N., & Thomas, R. E. (2011). Development and application of a deterministic bank stability and toe erosion model for stream restoration. *Geophysical Monograph Series*, *194*, 453-474.

Wilkinson, S.N., Dougall, C., Kinsey-Henderson, A.E., Searle, R.D., Ellis, R.J., Bartley, R. (2014) Development of a time-stepping sediment budget model for assessing land use impacts in large river basins, *Science of The Total Environment*, Volumes 468–469, pp 1210-1224