Runoff and erosion in woody encroachment, pasture and woodland vegetation in semi-arid New South Wales, Australia

Carlos Alfonso Muñoz-Robles B.Sc., M.Sc.

A thesis submitted for the degree of Doctor of Philosophy of the University of New England

Ecosystem Management
School of Environmental and Rural Science
University of New England
Armidale, New South Wales, 2351
AUSTRALIA

November 2010

Declaration

I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree or qualification.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

Carlos Alfonso Muñoz-Robles

15th November 2010.

Abstract

Woody encroachment is the increase in density, cover, extent or biomass of woody plants. It has been reported from arid and semi-arid areas around the world. Woody encroachment is the result of changes in factors such as weather and climate, grazing pressure, fire regimes, and combinations of these. The most widely recognised effects of woody encroachment are the decline in herbaceous forage production and carrying capacity for livestock, decreased biodiversity and socioeconomic value of affected areas, and, in some cases, increased runoff and soil erosion. The eco-hydrological responses of areas of woody encroachment and of pastures established after removing the woody vegetation are not well understood in semi-arid Australia. The aim of this thesis was to investigate runoff, erosion and associated factors in woody encroachment, and how these compare with other vegetation states in semi-arid Australia from an eco-hydrological perspective.

The hydrological and erosional responses of vegetated patches and inter-patches in four vegetation states were compared using small-scale (1 m^2) rainfall simulation in four vegetation states across the Cobar pediplain in semi-arid New South Wales. The four vegetation states were: (1) woody plant encroachment (>1200 stems ha^{-1}), (2) recently established pastures (<23 years of age), (3) long-established pasture (50–100 years of age), and (4) open woodland (<330 stems ha^{-1}). A moderate rainfall intensity of 35 mm h^{-1} was used, which resembled a natural 2-year return period storm in the region. Three types of patches and inter-patches were defined according to their capacity to retain resources from high to low retention capacity: well vegetated patches, medium vegetated patches and inter-patches. Inter-patches produced runoff and sediment while patches functioned as sinks for these resources, confirming that patches and inter-patches are functional units from an eco-hydrological perspective, with a pervasive influence over soil hydrological and erosional characteristics irrespective of vegetation state.

Runoff and sediment production were related to the amount and components of ground cover, surface roughness, slope and topsoil sand fraction. Total ground cover, herbaceous ground cover and surface roughness were related to runoff and sediment in well vegetated patches. Herbaceous and litter cover were the main ground cover components related to

runoff and sediment in medium vegetated patches. Cryptogam cover, surface roughness and sand fraction were related to runoff and sediment production in inter-patches. Cryptogam cover in well vegetated patches was associated with higher runoff and sediment production, but cryptogam cover in inter-patches was associated with lower sediment concentration and production.

Runoff and sediment production at the site scale (30 m × 30 m), computed as the weighted average of the small-scale responses of constituent patches and inter-patches, generally did not differ significantly among vegetation states. The main exception was one pasture site where the pasture had undergone a specific management regime targeting the retention of ground cover. This illustrated the effect of pasture management on reducing runoff and sediment production. Small-scale runoff and sediment production ceased when total ground cover was ≥73% regardless of vegetation state.

A case study was used to assess the feasibility of high resolution satellite imagery to map ground cover and assess its spatio-temporal changes in two adjacent hillslopes over two consecutive years (2008 and 2009). One hillslope was an area of woody encroachment, and the other hillslope a recently established pasture which had a water spreading system (a series of contour banks designed to slow and spread runoff) established in 2009. The application of image fusion to high-resolution Quickbird satellite images increased the spatial detail of the multi-spectral Quickbird data to 1 m and preserved the original radiometric information. As the radiometric quality of fused images was high, standard quantitative digital image analysis was undertaken, and ground cover was mapped with accuracies of 84% in the woody encroachment and 86% in the pasture. From 2008 to 2009, ground cover increased twice as much in the woody hillslope (10%) compared with the pasture (5%). Potential causes of the ground cover increase were higher rainfall and livestock exclusion in the second year and, additionally in the case of the pasture hillslope, the establishment of the water spreading system also contributed to the ground cover increase in 2009.

Small-scale rainfall simulation responses were up-scaled by integrating the hydrological responses of patches and inter-patches and slopes in the two examined hillslopes with the

maps of ground cover derived from the fused Quickbird images. This modelling approach is a novel exploration tool that describes the spatial distribution of runoff and sediment production within hillslopes. The outcome of the modelling incorporates transfer of runoff among areas with different amounts of ground cover, the spatial distribution of ground cover and the connectivity of runoff source areas. The estimates of runoff and sediment in the woody hillslope were similar over two consecutive years, but were lower than in the pasture hillslope. Estimated runoff and sediment within the pasture hillslope were lower in the second year than in the first year following the establishment of a water spreading system in 2009. The results highlighted the importance of patchiness and the connectivity of runoff source areas for runoff and sediment production at the hillslope scale.

The relationships between gully volume and topography, vegetation cover and location of tracks were explored in an area of woody encroachment within the study region with a high density of gullies. Site characteristics of 32 sub-catchments with and without gullies were compared. All gullies were active. Eroded gully volume was found to be a function of sub-catchment areas and gully length as well as being inversely related to distance of the gully heads to the nearest vehicular track. Stable sub-catchments (those without gullies) had gentler slopes, higher foliage projective cover and higher ground cover than unstable sub-catchments (those with gullies). The mean topographic threshold that specified the minimum drainage area and slope conditions for gully development was developed for the first time in woody encroachment areas in the region.

Overall, the study showed that runoff and erosion in the four vegetation states are mostly site-dependent. Hydrological and erosional responses in woody encroachment were generally not significantly different from those in recently and long-established pastures and woodland. The study showed that ground cover type and amount and its spatial distribution largely determine runoff and erosion responses in the studied systems. There is potential in using high resolution satellite imagery and spatial modelling to apply accepted concepts of semi-arid patchiness to link small-scale eco-hydrological and erosional responses to larger scales appropriate for management. The study showed that factors related to gully erosion in woody encroachment areas are related to topographic thresholds that can be used for the identification of areas susceptible to gullying.

Acknowledgements

I am indebted to CONACYT-México for granting me a PhD scholarship to study in Australia. I also thank the National Action Plan for Salinity and Water Quality through the Central West Catchment Management Authority for funding the operation of this project.

My gratitude to my principal supervisor Nick Reid, and co-supervisors Matthew Tighe, Sue Briggs, Brian Wilson and Paul Frazier. I thank you all for your encouragement, patience, guidance and support throughout the duration of my PhD.

I thank David Tongway and CSIRO for the donation of the rainfall simulator to UNE, and acknowledge David Tongway and Víctor M. Reyes Gómez for their advice on rainfall simulation.

Thanks to David Tarboton (Utah State University) and Angeles Mayor (Universidad de Alicante), who generously provided code and software which were used for data analysis in my thesis.

I thank Andrew Mosely, Peter Weston, Anthony Gibson and Shane Gasparini, and CMA staff Carolyn Raine, Jane Chrystal and Rodney Campbell for being an effective link between me and the farmers. This research would not have been possible without the support of the farmers who allowed me to conduct my research in their properties. Thank to Warren Furphy, Chloe Parkins and Megan Good, who provided invaluable field assistance and good company during the field trips.

Being away from my family, friends and my beloved México was sometimes hard, but I always had good moments with fellow PhD students and staff of the Ecosystem Management Department. Thank you for being my family in Australia: Megan Good, Nick Shultz, Lisa Warnecke, James Turner, Jodi Price, Rhiannon Smith, Melissa Danks, Subhashni Taylor, Penelope Nelson, Cate Macgregor and Stuart Green. I will never forget your friendship and support, and I am in debt with all of you. I also want to thank Benjamín and Graciela, who encouraged me to do my PhD in Australia and gave me

support during the first 6 months of my stay in Australia. I also thank my friends in Mexico, who always gave me long-distance support: Brenda Ávila, Namy Gutiérrez, Josefina Ascencio, Gabriela Gutiérrez, Aarón Bueno, Daniel Núñez, Víctor Reyes, Elvia, Alejandra, Emmanuel, Manuel Baca and Karina Grajales.

Very especially, I thank to my parents Alfonso and Olivia and my sisters Ana and Gabriela for supporting me throughout the PhD process.

Publications arising from this thesis

The contents of some of the chapters of this thesis have been submitted to the following journals or conference proceedings:

Papers

- Muñoz-Robles, C., Reid, N., Tighe, M., Briggs, S., Wilson, B. (Chapter 2). Soil hydrological and erosional responses in patches and inter-patches in vegetation states in semi-arid Australia Geoderma. In press.
- Muñoz-Robles, C., Reid, N., Tighe, M., Briggs, S., Wilson, B. (Chapter 3; under review). Soil hydrological and erosional responses in areas of woody encroachment, pasture and woodland in semi-arid Australia. Journal of Arid Environments.
- Muñoz-Robles, C., Frazier, P., Tighe, M., Reid, N., Briggs, S., Wilson, B. (Chapter 4; under review). Assessing ground cover from fused Quickbird data in semi-arid woody vegetation and pasture in south-eastern Australia. International Journal of Applied Earth Observation and Geoinformation.
- Muñoz-Robles, C., Reid, N., Frazier, P., Tighe, M., Briggs, S., Wilson, B. (Chapter 6). 2010. Factors related to gully erosion in woody encroachment in south-eastern Australia. Catena. 83, 148-157.

Conference proceedings

- Muñoz-Robles, C., Tighe, M., Reid, N., Briggs, S., Wilson, B. (Chapter 2). Hydrological and erosional responses in woody plant encroachment areas of semi-arid south-eastern Australia. Presented at the 19th World Congress of Soil Science in Brisbane, Australia 1-6 August 2010.

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