Monitoring scheme for examining carbon–water coupling in a forested watershed

Nirmala Liyanage[A], Thomas Bishop[A], Willem Vervoort[A] and Michael Nelson[A]

[A]Faculty of Agriculture, Food and Natural resources, University of Sydney, Sydney, Australia.
Email nirmala.liyanage@sydney.edu.au,thomas.bishop@sydney.edu.au, willem.vervoort@sydney.edu.au and michael.nelson@sydney.edu.au

Abstract

Management of carbon and water in landscapes is one of the key issues of our time due to increased carbon emission and its associations with climate change. Sequestration of carbon in terrestrial ecosystems is proposed to overcome these challenges; however countries such as Australia where water is a limited resource are facing difficulties in providing water for carbon sequestration. Therefore it is important to understand the scale dependency of carbon and water and their coupling in ecosystems. The present study is the starting point of a series of experiments on carbon and water coupling in an ecosystem where sampling variance at four spatial scales was tested. A balanced nested sampling design with nine main stations, and 72 sampling sites at four spatial scales (5, 30, 100 and 400m) was established in a first order *Eucalyptus* forest catchment and soil carbon and clay variation were estimated. The dominant spatial scales in terms of variation were 5m and 400m for both clay and carbon, each comprising about 40% of the variation. However, at the 30m and 100m scales, 5-9% variations were observed suggesting the possibility for increasing the block size for soil carbon accounting.

Key Words

Nested sampling design, spatial scales, clay content, soil carbon, Eucalyptus forest catchment.

Introduction

In tackling increased carbon emission and its associated climate change, increasing attention is being given to sequestration of carbon in terrestrial ecosystems. Carbon, nitrogen and water processes are cyclic and strongly interrelated; therefore one cycle cannot be managed or disturbed without affecting the other. In order to increase carbon sequestration in ecosystems, water needs to be provided, however, countries such as Australia where water is a limited resource are facing challenges.

Carbon and water processes and their coupling have been studied extensively in the past; however, the focus has generally been at one spatial scale. A series of studies by M. Lark in recent times (Lark 2005; Corstanje & Lark 2008) has explored methods to examine scale dependency in the variation of individual properties, and their co-variation with other properties. In this assessment, we adopt one approach, the nested sampling designs first proposed by Youden and Mehlich (1937), where the data is analysed in the form of a random-effects nested ANOVA, except the nested scales are associated with distances in space, rather than regions. Lark (2005) extended the approach to enable an analysis of covariance for both balanced and unbalanced designs, allowing the correlations between different variables at different scales to be explored.

In terms of carbon and water, this scale dependency is important to understand as it has implications for how we manage carbon and water at different scales, depending on the strength and type of relationship. For example, the dilemma we face is that some studies have stated that storing more carbon via trees in landscapes resulting less water being available for the environment (Jackson *et al.* 2005). This if true would have dire consequences for the potential of storing carbon in Australia’s dry landscapes. However, the study was based on catchment aggregated data so is limited to one scale.

In this paper, we describe the monitoring design, initial results and their implications, and future work.

Methods

Study Area

The study was conducted within a first-order forested catchment of Wollondilly River at Arthursleigh (34°33'49"S and 150°04'58"E) near Marulan, in the Southern Highlands of New South Wales, Australia. The region has a temperate climate (based on the Köppen classification) with mean annual precipitation of 800mm and mean annual temperature around 19.2°C (Bureau of Meteorology 2010). The study area is approximately 175 ha.

There has been no detailed soil survey performed in the area, however, the soil has been identified as Tenosols in the present survey. Soils have developed over sedimentary rocks, with a sandy texture consisting of 75-80% of sand. The soil depths range between 0.3 and 0.7m while the density of the vegetation is relatively low. The tree stratum of the area is mainly formed by Eucalyptus species, which are considered a part of the remaining virgin forests of Australia. Scattered shrub vegetation is also present in the area, however, a quite distinct range of heights is observed among the species, namely 10–15m for Eucalyptus and 0.50–1.0m for others. Coarse woody debris and fine litter materials are in abundance in the area.

Monitoring design, soil sampling and statistical analysis

The experiment was conducted as a balanced nested design (Youden and Mehlich 1937) with nine main stations. Each station consisted of eight sampling locations covering four spatial scales, i.e. 5m, 30m, 100m and 400m (Figure 1).

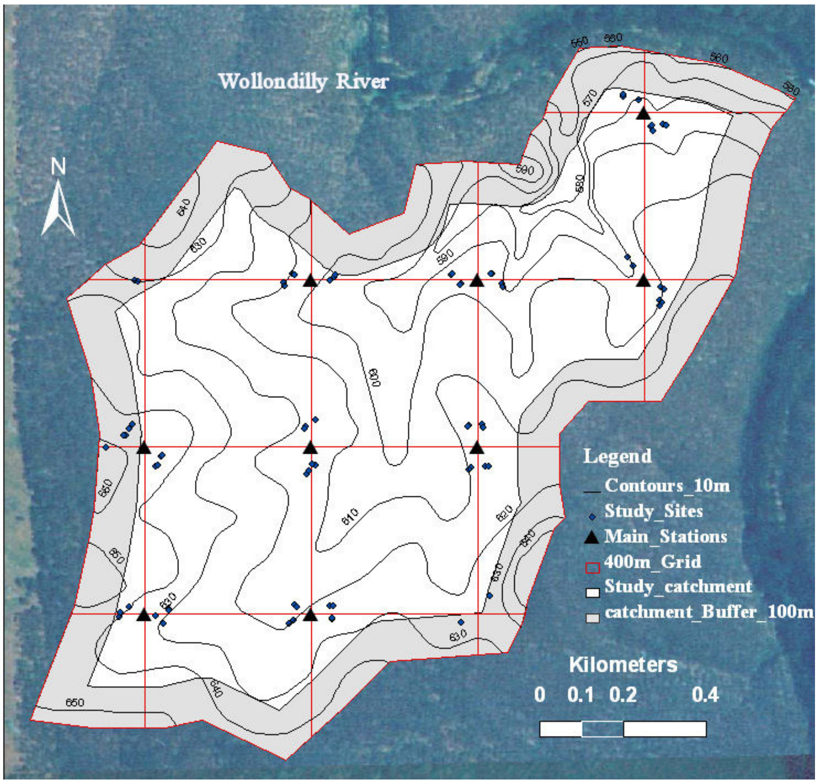

Figure 1. Main stations with study sites at Arthursleigh (©Contour Map -NSW Dept of Lands)

Statistical analysis was performed in the form of a random-effect nested ANOVA, where nested scales are associated with distances in space. To quantify the variance at each scale (σ^2_{5m}, σ^2_{30m}, σ^2_{400m} etc.), the following variance component model is used (Eqn. 1).

$$\begin{aligned}&\sigma^2_{5m},\\&\sigma^2_{5m}+\sigma^2_{30m}\\&\sigma^2_{5m}+\sigma^2_{30m}+\sigma^2_{100m}\\&\sigma^2_{5m}+\sigma^2_{30m}+\sigma^2_{100m}+\sigma^2_{400m}=\sigma^2_{Total}\end{aligned}\qquad(1)$$

The analysis permits the examination of changes in parameter values when moving from tree (5m) to stand (30m) to hill-slope (100m) to catchment (400m) scales. The analysis was performed in *GenStat for Windows* (v 12) and the models were fitted using residual maximum likelihood.

Within the nested framework, two soil core samples each were collected from 72 sites, using a GPS receiver to locate sampling points. Soils were separated into horizons and air-dried in a controlled environment (45°C) and then sieved through a 2-mm mesh. Total carbon and nitrogen in soil were determined using a Vario MAX CNS analyser (Elementar Analysensysteme GmbH) and clay content was measured by the Wet Pipette Method (Gee and Bauder 1986).

Results

Stations 1, 2 and 9 had higher carbon contents in B horizon of soil compared to those of other six stations while higher clay contents were observed in stations 1,2,3 and 6 (Figure 2).

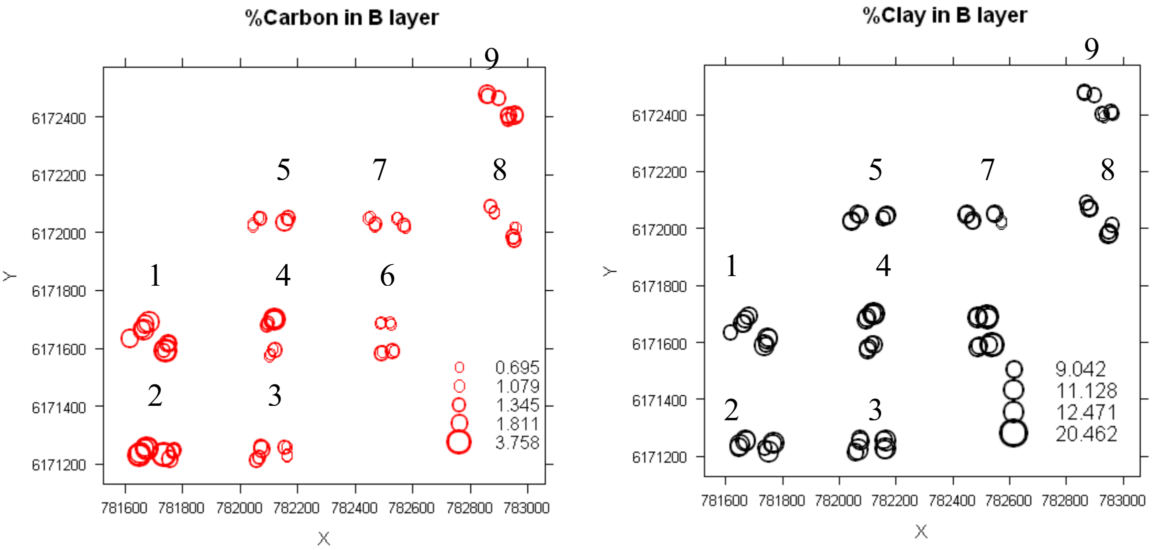

Figure 2. Spatial distribution of study sites at Arthursleigh showing proportional presentation of percentage soil carbon in B horizon (X and Y values are in meters - Projection GDA 1994 Zone 56)

The dominant spatial scales in terms of variation were 5m and 400m for both clay and carbon, each comprising about 40% of the variation (Tables 1 and 2). There are three soil types in the study area and the relief range from 0-26% at study sites. Therefore, we believe that the 400m scale represents variation attributable to soil type and topographic changes. Variation observed at the 5m scale is probably due to the low density of vegetation, where soils are unevenly exposed to sunlight.

Table 1. Carbon variances at each spatial scale

Scale	Variance	Var. Accumulated	%Var. at scale
5-m	0.234	0.234	41.3
30-m	0.0306	0.2646	5.4
100-m	0.0492	0.3138	8.7
400-m	0.2526	0.5664	44.6
Total	0.5664		

Table 2. Clay variances at each spatial scale

Scale	Variance	Var. Accumulated	%Var. at scale
5-m	4.811	4.811	50.4
30-m[1]	0	4.811	0
100-m	0.623	5.434	6.5
400-m	4.109	9.543	43.1
Total	9.543		

[1] The 30-m variance component was negative so it was constrained to a value of 0.

One implication of the results in terms of monitoring carbon is that it could help inform the size of the blocks needed to bulk samples from, when measuring soil carbon. The advantage of composite sampling is the reduction of analytical costs and residual variance but this is at the cost of losing degrees of freedom, which increases the precision of our estimates of a mean and/or a change in the mean. From the results here, a good starting point for composite sampling would be sampling from 5m blocks but there is little advantage for 30m or 100m blocks.

Conclusion and Future work

The dominant spatial scales in terms of variation were 5m and 400m for both clay and carbon, each comprising about 40% of the variation. The current study is the start of a long-term monitoring site for the Faculty of Agriculture, Food and Natural Resources in the University of Sydney. In mid-2010 probes will be installed at some sites to continuously monitor soil moisture and sap flow in trees. These will be augmented by monthly sampling campaigns where soil moisture and respiration will be measured at each site. From this we will use the method described by Lark (2005) to explore the scale-dependent nature of coupling between the carbon and water cycles.

In terms of monitoring carbon, future work should explore how nested designs can be used to identify the optimal size of blocks for composite sampling.

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