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Large catchment-scale spatiotemporal distribution of soil organic carbon

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ABSTRACT

There are a dearth of studies globally examining soil organic carbon (SOC) at large catchment scales. Here we assess the catchment scale climate and geomorphic controls on SOC. The study was conducted on the east coast of New South Wales, Australia and focussed on a 562 km^2 (Krui River) catchment sampled in 2006 and 2015 and a 606 km^2 (Merriwa River) catchment sampled in 2015. Both catchments have similar soils, topography and landuse. There was no significant difference in SOC between 2006 and 2014 data sets, indicating that SOC was temporally stable over the intervening 8 years (Krui catchment), despite the seasonal variability in climate such as rainfall. SOC concentration was also shown to have no significant difference between Krui catchment and Merriwa catchment, indicating that SOC is spatially stable for catchments of similar land-use, climate and geomorphology. SOC concentrations from all three data sets were compared to a range of terrain attributes. Similar with other studies, elevation, as a surrogate for orographic rainfall, was found to have the strongest significant control on SOC % at the large catchment scale. Confirmation of the use of elevation as a surrogate for rainfall was made by comparing SOC with rainfall obtained from a network of weather stations across the study sites. Relationships between SOC and other terrain attributes found inconsistent relationships. The findings demonstrate that for catchments with similar soils, topography and climate that SOC can be reliably predicted using simple topographic variables. The methods here provide a robust tool which can be used for SOC assessment at other sites as well as assist in understanding SOC distribution and controls for longer term and regional scales.

1. Introduction

There is a global demand for soil data and information for food security and global environmental management. Amidst growing concerns of the potential effects of global warming and climate change, efforts to reduce atmospheric CO_2 concentrations have received widespread attention. Despite these efforts, the interaction of atmospheric CO_2 concentration with global terrestrial carbon storage is one of the largest and most uncertain feedbacks of the carbon cycle (Xia et al., 2010; Minasny et al., 2013; Martin et al., 2014; Schimel et al., 2015; Hoyle et al., 2016). The inherent uncertainty of soil carbon stores is due, in part, to the complex interaction among several biophysical and hydroclimatic processes that drive SOC distribution, including the dynamics of rainfall, soil moisture, insolation, and temperature. The current uncertainty of carbon cycle feedbacks, and the complexity of interactions of controls on, and transport of, soil carbon at regional scales, justifies continued investigation into soil C dynamics.

Total soil pool carbon content (estimated at 2300 GtC), is higher than that held by the atmospheric (800 GtC) and vegetative (550 GtC) pools combined (Riebeek, 2011). A small variation in soil C stores could therefore lead to a marked change in the CO_2 concentration of the atmosphere (Luo et al., 2010). The reliable assessment of soil C stocks is therefore of key importance for assessing the potential of various soil conservation and atmospheric CO_2 mitigation strategies, such as carbon sequestration. This has resulted in a demand for a more accurate mapping of the soil carbon pool at a better resolution (Minasny et al., 2013). Improving the tools that model the spatial distributions of SOC stocks at national scales is a priority, both for monitoring changes in SOC and as an input for global carbon cycles studies (Martin et al., 2014).

Mapping soil organic carbon storage, its spatial distribution, and its dynamic changes is prerequisite to:

- Building a soil carbon pool inventory
- Assessing soil carbon's historical deficit or surplus
- Identify potential locations for soil-based carbon sequestration
- Help localise the variables controlling soil carbon
- Assist in natural resource management and monitoring (Xia et al.,

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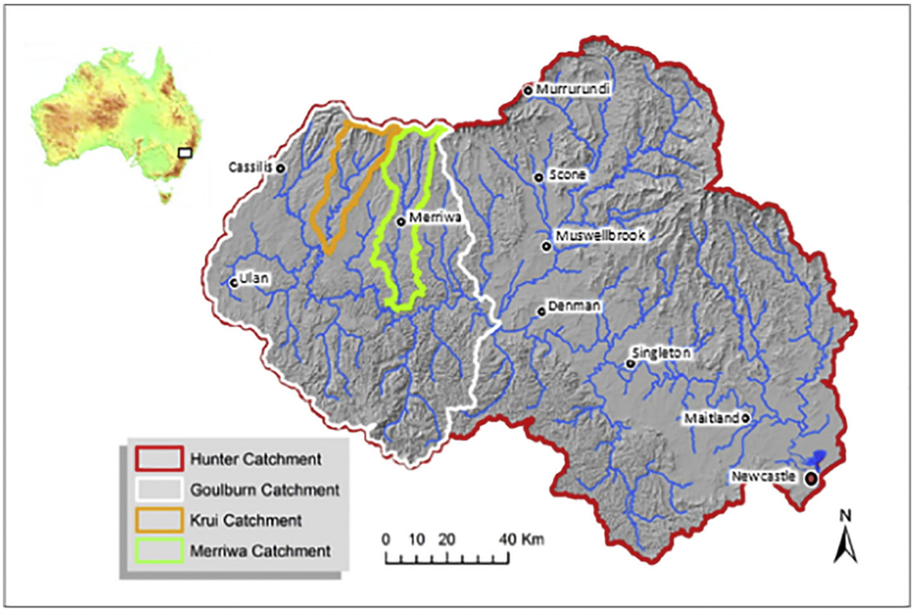

Fig. 1. Location map of Krui (orange outline) and Merriwa River catchments (green outline), Goulburn River catchment (purple outline) and Hunter River catchment (blue outline). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2010).

Many environmental controls on soil organic carbon have been analysed at site-specific plot-scales, while long term temporal, or large spatial studies of SOC dynamics are less common. As the ability to map and model SOC distribution improves with continual improvements in technology, traditional sampling is an important component for validation and improvement of models and baseline estimates of carbon accounting.

Studies examining the spatial distribution of SOC use topography-based terrain attributes as the most widely used covariates. Land-use, or vegetation indices, derived from remotely sensed images, also play an important role (Minasny et al., 2013; Hoyle et al., 2016). More recent models have shown that land-use, vegetation, soil moisture and terrain parameters, such as elevation, insolation, and wetness index, were the key variables affecting SOC distribution (Adhikari and Hartemink, 2015; Minasny et al., 2006). Terrain attributes, such as elevation, slope and curvature, may aid spatial estimation of soil properties as it is recognised that topographic relief has a great influence on soil formation (Jenny, 1941; Mueller and Pierce, 2003). Catenary soil development is recognised to occur in many landscapes largely in response to the way water moves through and over the landscape. Furthermore, terrain attributes can characterize these flow paths and, therefore, soil attributes (Moore et al., 1993). Topography also indirectly affects soil moisture through its influence on insolation. Topographic slope and aspect allows for greater or lesser incident radiation from the sun onto the land surface, as well as for longer or shorter periods of time, depending on the latitude and time of year. As SOC patterns in the landscape are strongly influenced by the distribution of water and soil (Pennock and Corre, 2001), it is likely that SOC can be predicted from topography or terrain parameters that help characterize flow paths both at the hillslope, catchment and regional scale (Kunkel et al., 2011; Oueslati et al., 2013). The authors have conducted focussed hillslope terrain analysis both in the study catchments and elsewhere with mixed results in understanding the spatial and temporal distribution of SOC (Hancock et al., 2010a, 2010b, 2012; Martinez et al., 2009, 2010a).

Since the development of digital soil mapping technologies in the late 1990s, and formalization of the discipline by McBratney et al. (2003) mapping of soil carbon at the field and regional scales has become an area of active research (Minasny et al., 2013). There have been numerous global estimations of soil carbon stocks, most of them derived from existing soil maps, with varying results and unstated uncertainties (Minasny et al., 2013). Minasny et al. (2013) summarises 40 recent studies of soil carbon concentration and carbon density maps that have been produced using digital soil mapping technology. For those studies, Minasny et al. (2013) found that half of those studies do not show any validation, and the other half mostly used cross-validation and internal validation. For model accuracy, most of those studies do not show any uncertainty of prediction.

This study investigates the spatiotemporal distribution of surface SOC concentrations across two large (~600 and ~700 km^2 catchments) with similar geomorphology, climate, soils, vegetation and land-use. It forms part of a long-term investigation of hydrology, sediment transport and soil properties in the region (Chen et al., 2015; Hancock and Coulthard, 2012; Hancock et al., 2010a, 2010b; Hancock et al., 2015; Kunkel et al., 2016; Martinez et al., 2008, 2009, 2010a, 2010b; Rüdiger et al., 2007; Wells and Hancock, 2014).

Here we will:

(1) assess the large catchment-scale spatiotemporal distribution of SOC for two geomorphologically similar catchments.
(2) evaluate the relationship of SOC with topographic and soil attributes and.
(3) develop and assess a model for the spatial distribution of SOC based on DEM-derived terrain attributes.

2. Site description

The study is located within the Goulburn River catchment (6540 km^2), in the Hunter Valley region of New South Wales, Australia (Fig. 1). We focus on the Krui River (562 km^2) and Merriwa River (606 km^2) catchments, which lie to the north-west inside the Goulburn River catchment which are geomorphically similar (Kunkel et al., 2016). A true-colour Landsat image of the Krui River and Merriwa River catchments, acquired on 8 June 2014, is shown in Fig. 2.

The study site is bounded to the north by the Liverpool Ranges, where topography is rugged, while the landscape to the south, around Merriwa and Cassilis, is hilly to undulating (Story et al., 1963). Elevations for both catchment range from approximately 200 m in the south (Merriwa Plateau) to 1200 m in the north (Liverpool Range). The