Dynamics of soil labile carbon and nitrogen pools in riparian zone of Wyaralong Dam in southeast Queensland, Australia

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Abstract

Purpose Soil labile carbon (C) and nitrogen (N) pools are considered to be sensitive indicators of changes in soil C and N pools. In this study, we examined possible factors affecting temporal and seasonal variations in soil labile C and N pools in the riparian zones in southeast Queensland, Australia.

Materials and methods Soil and sediment samples were collected from two sites in the riparian areas. The spatial and seasonal variability of soil moisture, hot-water extractable organic C and total N (HWEOC and HWETN), microbial biomass C and N (MBC and MBN), and the relationships among them were examined.

Results Soil labile C and N pools decreased along the transects in both soil depths of the two soil types, with the peak or bottom of values detected between upland slope and the riparian zone. Other factors rather than soil moisture were more important in regulating seasonal changes of soil HWEOC and HWETN except the dry-rewetting influence in November 2013. Soil moisture played a significant role in the seasonal variation of MBC and MBN. Soil labile C and N pools at Site 1 (S₁, heavy texture) were significantly higher than those at Site 2 (S₂, light texture).

Conclusions Soil moisture would be an important driving factor for the spatial and temporal

distribution of soil labile C and N pools. Our study highlighted the importance of riparian zones as the hotspot of soil C and N dynamics, especially at the onset of rewetting dry soil in subtropical Australia.

Keywords Riparian zone • Dry-rewetting • Hot-water extractable carbon and total nitrogen • Microbial biomass carbon and nitrogen

1 Introduction

Riparian zone is defined as the interface between terrestrial and aquatic ecosystems, which represents an important ecological component of the landscape (Lowrance et al. 1985; Malanson 1991; Davies and Nelson 1994), and displays a greater variation in characteristics than either of the systems it connects (Naiman et al. 1988).

Riparian areas play an important role in removing nitrogen (N), from water flowing through riparian soils (Schade et al. 2001). The effectiveness of reducing N concentrations vary, based on the slope of banks, rainfall, soil factors (pH, temperature, redox potential, etc.), soil moisture, land use, vegetation and so on (Clinnick 1985; Wenger 1999). Environmental changes, especially changes in soil aeration condition and flooding, are always considered to affect soil N dynamics in riparian zone (Venterink et al. 2002; Gergel et al. 2005; Hernandez and Mitsch 2007) . Water fluctuation, induced aerobic and anaerobic conditions have a significant influence on soil N mineralization process in the riparian soil (Antheunisse et al. 2007; Hou et al. 2007). On the other hand, periodic flooding also leads to the redistribution of soil organic matter (SOM) in riparian sites (Nilsson and Svedmark 2002). Decomposition of SOM is lessened and incomplete, while the humification of SOM is decreased under anaerobic soils (Wershaw 1993; Sahrawat 2003).

49 River damming is one of the most prominent human impacts on fresh water ecosystems, which has
50 caused global-scale ecological changes in riparian zones (Nilsson et al. 2005; Braatne et al. 2008).
51 Dams affect riparian zones by altering the magnitude, frequencies, and periods of flood events
52 (Stanford and Gaufin 1974; Nilsson and Berggren 2000). With damming, the previous riparian zones
53 are inundated and drained intermittently (Brizga et al. 2007), which leads to the alteration of oxic and
54 anoxic periods (Ponnamperuma 1972). Therefore, soil C and N dynamics may be influenced by the
55 anthropogenic flood-control measures (Chai et al. 2009; Wu et al. 2013; Wu et al. 2015). As inundation
56 can cause sedimentation, and sudden increase of nutrient release in the new reservoirs (Chang and Wen
57 1998; St. Louis et al. 2000; Rosa et al. 2004), damming is also related to the climate change problems.
58 Soil moisture varies not only because of the dry/flooding events, but also due to seasonal precipitation
59 in the riparian zone. It is reported that precipitation is the primary driver for seasonal changes of N
60 cycling in semi-arid and arid areas (Austin et al. 2004). It is well known that rewetting dry soil results
61 in a pulse of mineral N and CO₂, which is called the Birch-Effect (Birch 1958; Xu et al. 2004; Tang
62 and Baldocchi 2005; Jarvis et al. 2007; Inglima et al. 2009). The flush of N mineralization is thought to
63 occur from enhanced availability of SOM through the increase in fungal and microbial biomass
64 (Griffiths and Birch 1961; Jager and Bruins 1975; Orchard and Cook 1983; Scheu and Parkinson 1994),
65 breakdown and release of occluded SOM from soil aggregates (Denef et al. 2001), decomposition of
66 dead microbial biomass (Bottner 1985), and a hypo-osmotic stress response of soil microbial
67 community (Kieft et al. 1987; Fierer and Schimel 2002; Fierer and Schimel 2003; Jarvis et al. 2007). In
68 the riparian areas, soil N cycling would be expected to be closely related to rapid water level changes
69 or a dry-rewetting regime (Neill 1995; Venterink et al. 2002). Soil microbial composition may also vary
70 with water contents (Barnard et al. 2013; Barnard et al. 2015). The alteration of soil moisture not only

affects microbial activity, but also C and N availability through plant-microbe interaction (Ladwig et al. 2015).

Labile SOM is considered as the more sensitive indicator to be detected even with small change in total SOM (Lefroy et al. 1993; Ghani et al. 2003; Haynes 2005; Laik et al. 2009; Wang and Wang 2011), and

is highly responsive to changes in C inputs to soil and provides a measurable index before changes in total SOM (Gregorich and Ellert 1993; Gregorich and Janzen 1996; Haynes and Beare 1996). This

indicates that the influence of changes in soil management can be observed sooner in the labile C and N pools than in the total SOM (Lee et al. 2009). However, concerns about the impact of flooding on

soil C and N pools in riparian areas have mainly been focused on total SOM such as N removal in riparian buffers (Pinay et al. 1992; Gergel et al. 2005; Mayer et al. 2007; Ye et al. 2012; Wu et al. 2013;

Wu et al. 2015). There has been little work conducted to examine the relationship between soil labile C and N pools, determined by the various techniques, which has important implications for

transformation dynamics of SOM. Therefore, the nature of organic C and N determined by these methods has not been fully clarified. To our knowledge, this was the first paper investigating soil labile

C and N dynamics in the subtropical riparian zone of a dam in the Southern Hemisphere.

In this study, we investigated the spatial and seasonal dynamics of soil labile C and N pools within the riparian zone of Wyaralong Dam in Southeast Queensland, Australia. We aimed to (1) quantify the

temporal and seasonal influence of soil moisture change on soil labile C and N pools along the transects, and (2) identify the key factors regulating the spatial and seasonal patterns of soil labile C

and N pools in the riparian zone. We hypothesized that labile C (hot-water extractable organic C (HWEOC) and microbial biomass C (MBC)) and N (hot-water extractable total N (HWETN) and

microbial biomass N (MBN)), would be influenced by the soil moisture alteration in the riparian zone significantly at both spatial and temporal levels.

2. Materials and methods

2.1 Study site

This study was conducted in the riparian zone of Wyaralong Dam. Wyaralong Dam (27°54'28.77"S, 152°52'53.59"E) is located on the Teviot Brook in eastern Beaudesert (Fig. 1), southeast Queensland. The Wyaralong Dam was constructed by the Queensland Government from October 2009 to December 2010. Its main focus is the area to be inundated (ca.1230 ha) with the catchment of 546 km². This area has a subtropical climate with the mean minimum temperature of 13.1 °C (-3.7°C to 25.5 °C), mean maximum temperature of 26.5°C (13.3 °C to 40.1°C), and mean annual rainfall of 965.9 mm (841.0 mm to 1136.0 mm) (since 2007). Climate data were collected from a meteorological station (Beaudesert Drumley Street) about 12.7 km away from the study site. Historical dam storage data were collected from Seqwater.

2.2 Experimental design and field experiments

Two sites in the riparian zone of Wyaralong Dam were selected in January 2013 (Fig. 1). Both of them were dominated by grassland (including *Cynodon dactylon*, *Heteropogon contortus*, *H. contortus*, *Imperata cylindrical*, *Chamaecrista rotundifolia* and *Chrysocephalum apiculatum*) (Zheng et al. 2014), but were of different soil types and slope degrees. They represented two main kinds of riparian soils in this area. The soil type of Site 1 (S₁) was Dermosols (Isbell 1996), with a relative clayey texture and slope degree of 8-16°; while the Site 2 (S₂) soil was Kurosols (Isbell 1996), with a relative sandy texture and slope degree of 4-10° (Table 1). Samplings were carried out in February 2013 (summer), May 2013 (autumn), August 2013 (winter), November 2013 (spring), February 2014 (summer) and August 2014 (winter), respectively. Three parallel transects spaced ca. 5 meters apart with 6 to 10

sampling points (depending on the water level) along each transect were selected. All the sampling points were selected according to the 100% of full water level (Fig. 2). Three soil cores were collected from each point to be mixed as one composite soil sample within each soil depth (0-10 cm and 10-20 cm) using an auger with 7.5 cm in diameter; while three sediment sample (0-10 cm) from each point along each transect at each site were collected to be mixed as one composite sediment sample with spade (Fig. 2). All soil samples were sealed with plastic bags and transferred to laboratory. Although soil samples were collected from the two sites, it is impossible to directly compare soil properties between the sites, since they differed in many aspects such as soil type, slope degree and vegetation type. However, we still can gain some insight into the spatial and seasonal patterns of soil C and N pools in the riparian zones, and expect to observe some underlying mechanisms in common.

2.3 Laboratory analyses

All the soil and sediment samples were mixed thoroughly and sieved through 2-mm screen, with parts of the samples oven dried (40 °C) and the rest stored in the cold room at 4 °C as fresh samples prior to analysis. Moisture was determined by placing 10 g of fresh soil or sediment samples into the oven at 105 °C until reaching a constant weight (48h), and all results were expressed on an oven-dry basis. Soil pH and electrical conductance (EC) were measured with a pH/EC meter using a soil-to-water ratio of 1:5.

HWEOC and HWETN were determined by adding 7 g of air-dried to 35 ml water and incubating in a capped and sealed tube at 70 °C for 18 h. Following incubation, the suspension was shaken by an end-to-end shaker for 5 minutes followed by centrifuging at 10000 rpm for 10 minutes. The suspension was filtered through a 33 mm Millex syringe-driven 0.45 µm filter. The concentration of total organic C

(TOC) and total soluble N (TSN) in the filtered solution was measured using a Shimadzu TOC-VCSH/CSN TOC/N analyser (Chen and Xu 2005).

To measure MBC and MBN, fumigation-extraction method was used. Two sub-samples of fresh soil (5 g) were weighed (for direct extraction and fumigation). One of the sub-soil samples was fumigated by chloroform for 24 h. Both fumigated and non-fumigated (directly extracted) sub-samples were mixed with 25 ml of 0.5 M K₂SO₄ and each mixture was shaken with an end-to-end shaker for 30 min, followed by filtering through a Whatman No. 42 filter paper. The TOC and TSN of both extractions were measured using a Shimadzu TOC-VCSH/CSN TOC/N analyser (Chen and Xu 2005). The MBC and MBN were derived from the equations as described by Vance et al. (1987) and Brookes et al. (1985) respectively.

2.4 Statistical analyses

Data from the same site (0-10 cm and 10-20 cm) were subjected to three-way analysis of variance (ANOVA) to assess the interaction of slope position, soil depth and sampling season. To quantify the differences in the interaction of slope position and soil depth within each sampling season, two-way ANOVA was used. Changes in labile SOM were analysed using one-way ANOVA with slope position as a factor. All comparisons among the different slope position treatments, soil depths, and seasons were conducted by the Duncan's Multiple Range Test (DMRT). Significant differences in basic soil properties and labile SOM were reported at $P < 0.05$. The normality of all data was checked before ANOVA. All above statistical analyses were carried out using SAS for windows version 9.2 (Analytical Software, NC, USA). Regression analyses were used to assess the spatial distribution of soil moisture, labile SOM, and the correlations among soil moisture, soil labile C and N pools by OriginPro for

windows version 8.5 (Analytical Software, MA, USA).

3 Results

3.1 Monthly rainfall, temperature and dam levels

There was a great reduction in total annual rainfall during 2014 compared with 2013 (Fig. 3). A wet summer (174 mm, February) and dry winter (4.4 mm, August) in 2013 occurred; while a dry summer (10.2 mm, February) and relative wet winter (57.4 mm, August) were recorded in 2014. There were marked increases in both of minimum and maximum temperatures for two years, particularly during November to March (Fig. 3).

The water levels of Wyaralong Dam fluctuated from 89.5 % to 100.7 % of full water level within 2013 to 2014 (Fig. 4). There was a remarkable increase of water level after the construction of Wyaralong Dam. The heavy rain always led to the increase of water level with a time lag between the rainfall episodes and the water level peaks; while the water level stayed relatively stable compared with the variation of monthly total rainfall. Anthropogenic controls as well as other natural factors like evaporation, inflow and outflow processes may also contribute to the fluctuation of water level within this area (Tanny et al. 2011).

3.2 Soil basic chemical parameters

When all the data from the six sampling times were pooled together for both sites, there were no significant interactions among the soil slope position, soil depth, and sampling time (Table 2). However, the interactive influence of soil depth and soil slope position was significant on soil moisture and most

of the labile C and N pools at both sites (Table 2). Soil moisture, HWEOC, HWETN, MBC, and MBN were significantly higher in the 0-10 cm soil depth than those in the 10-20 cm soil depth except for MBN in summer 2014 (Table S1).

3.2.1 Soil moisture

In order to assess the trend for the spatial and temporal distribution of soil properties, DMRT was used and the relationship between the distance from Sp₁ (Slope position 1, the most upper slope position soil) and soil moisture were detected. Generally, soil moisture contents were significantly higher in the lower slope position than in the upper slope position in both depths ($P < 0.01$) at both sites (Fig. 5). Soil moisture contents varied among different seasons, with the lowest observed in summer 2014 (Fig. S1).

3.2.2 HWEOC and HWETN

Compared with HWEOC, HWETN was much lower in all corresponding samples. At S₁, concentration of HWEOC increased from Sp₁ to the peak between Sp₂ and Sp₄, and then decreased to the minimum values in the sediment ($P < 0.01$) in spring 2013, summer 2014 and winter 2014 in the 0-10 cm soil depth (Fig. 6a). Similar pattern could be detected in the 10-20 cm soil depth (Fig. 6b). Similar to the pattern of HWEOC, HWETN also decreased along the transects with the peak found between Sp₂ and Sp₄ in spring 2013, and winter 2014 ($P < 0.01$), respectively in the 0-10 cm soil depth at S₁ (Fig. 6c). However, HWETN decreased first with the minimum value at Sp₇, and then increased in the sediment ($P < 0.05$) in the 10-20 cm soil depth in summer 2014 ($P < 0.05$) (Fig. 6d).

More temporal patterns of HWEOC could be found at S₂. HWEOC was generally decreased along the

transects from upper slope position to the sediment (summer 2013: $P < 0.05$; other seasons: $P < 0.01$) in the 0-10 cm soil depth (Fig. S2a). Similar trends were also found in the 10-20 cm soil depth (Fig. S2b). The spatial trend of HWETN corresponded well with the HWEOC (Fig. S2).

Pronounced seasonal patterns were found at both sites. Interestingly, among the different seasons, the highest concentration of HWEOC and HWETN were found during autumn 2013 followed by summer 2013 and 2014, and the lowest concentration during winter 2013 and 2014 in both the soil layers at both sites (Figs. 7 and S3).

3.2.3 MBC and MBN

MBN was low at both sites, and also showed wide spatial variation at both sites (Figs. 8 and S4). Specifically, the highest concentrations of MBC could be found within the first three slope positions, and then decreased to the minimum in the sediment in three seasons at S₁ (Fig. 8a, b). MBN had similar trends. Nevertheless, MBN increased dramatically in autumn 2013 at both soil depths ($P < 0.05$) (Fig. 8c, d).

On the other hand, much more significant differences were found for MBC and MBN at S₂ (Fig. S4). Generally, MBC decreased dramatically in autumn 2013 (0-10 cm depth: $P < 0.01$; 10-20 cm depth: $P < 0.05$), winter 2013 (0-10 cm depth: $P < 0.01$; 10-20 cm depth: $P < 0.05$), spring 2013 ($P < 0.01$), and summer 2014 ($P < 0.01$) at both soil depths. The spatial distribution of MBN was similar to that of MBC.

Large seasonal variations in soil MBC and MBN were also observed at both sites (Figs. 9 and S5). At S₁, maximum concentration of MBC was found in February 2013 and November 2013 at most of slope

positions in the 0-10 cm soil depth. The highest MBN was also detected at both soil depths in summer 2013 and spring 2013. Compared with the S_1 , seasonal variation at the S_2 was not so obvious and significant (Fig. S5). For those at slope positions with significant differences, MBC and MBN were found to be high mainly in summer and spring 2013.

3.2.4 Relationship between soil moisture and HWEOC or HWETN

Soil HWEOC and HWETN displayed different dependencies on soil moisture from both of the soil types during different seasons. At S_1 , significant effects of soil moisture on HWEOC were observed in most of the seasons in the 0-10 cm soil depth (Table 3). For the 10-20 cm soil depth, significant relationships between soil moisture and HWEOC were only found in spring 2013 ($P < 0.05$) and summer 2014 ($P < 0.01$), with the minimum value of HWEOC detected in the riparian soil. HWETN showed similar trend as HWEOC with soil moisture in both soil depths.

At S_2 , HWEOC was significantly decreased with soil moisture along the transects until reaching the lowest in the riparian zone, and increased a little bit in the sediment within the 0-10 cm soil depth in winter 2013 ($P < 0.01$), summer and winter 2014 ($P < 0.05$), respectively; while the relationship between soil moisture and HWETN within the 0-10 cm soil depth could also be well predicted by polynomial curves in winter and spring 2013 ($P < 0.05$) and summer 2014 ($P < 0.01$), respectively (Table 4). In the 10-20 cm soil depth, similar trend could also be found for the relationship between soil moisture and HWEOC, and between soil moisture and HWETN.

3.2.5 Relationship between soil moisture and soil MBC or MBN

The correlations between soil moisture and MBC from both soil depths in summer 2014 at S_1 were

significant ($P < 0.01$), with the lowest value of MBC in the riparian zone. The trend was also applied for the correlation between soil moisture and MBN at both soil depths in summer 2014 ($P < 0.05$). However in spring 2013, both of MBC and MBN decreased significantly with soil moisture along the transects at the two depths ($P < 0.01$) (Table 5). Significant relationship was also found between soil moisture and MBC in the 10-20 cm soil depth in winter 2013 ($P < 0.05$). It was observed that the correlation between soil moisture and MBN in autumn was opposite in the 0-10 cm and 10-20 cm soil depths.

For 0-10 cm soil at S_2 , the correlation between soil moisture and MBC was predicted by binominal model in summer 2014, with the peak of MBC at soil moisture in the riparian zone ($P < 0.05$) (Table 6). Both of MBC and MBN decreased dramatically with soil moisture in autumn and winter 2013 (MBC: $P < 0.05$; MBN: $P < 0.01$).

3.5 Relationship among the soil C and N pools

Significant and positive relationships existed between HWEOC and MBC ($R^2 = 0.719$ to 0.846 , $P < 0.01$) at S_1 in summer 2014 (Table S2). Similar trends were found between MBN and HWETN at S_1 in summer 2014 ($R^2 = 0.841$ to 0.960 , $P < 0.01$) (Table S2). At S_2 , it was observed that MBC was positively and significantly related to HWEOC at both soil depths in autumn 2013 ($P < 0.05$), winter 2013 ($P < 0.01$), spring 2013 ($P < 0.01$), and summer 2014 ($P < 0.01$); but no significant relationship was found in summer 2013. The trends of correlation between MBN and HWETN in the 0-10 cm soil depth were similar to those between MBC and HWEOC (Table S3).

4 Discussion

4.1 Temporal variation of soil labile C and N pools

Given the labile nature of HWEOC and HWETN, they could give an early indication of SOM changes (Ghani et al. 2003). Hot-water extractable methods were thought to extract both simple organic compounds and carbohydrates, and some parts of soil microbial components (Sparling et al. 1998; Chen et al. 2004; Curtin et al. 2006; Rovira and Vallejo 2007). Ghani et al. (2003) indicated that about 40-50% of the C in the HWEOC extract was present as carbohydrates. Sparling et al. (1998) reported that MBC took up 45% of HWEOC. Generally, HWEOC and HWETN decreased along the transects at both soil depths for two different soil types with the peak or bottom of values detected mainly in the riparian zone between Sp₂ and Sp₄ in this study. Similar trend was also found in the temporal distribution of MBC and MBN. Significant and positive correlations between HWEOC and MBC, and between HWETN and MBN could be found in some seasons for both soil depths at the two sites. These results were consistent with previous findings (Zhang et al. 2006), indicating that HWEOC consisted of a labile pool of SOM including MBC (Cheshire 1979; Ghani et al. 2003). Higher soil total C and N, and larger pools of labile C and N in these slope positions of the riparian zone between Sp₂ and Sp₄, together with their strong relationships, tend to suggest that these areas may have greater quantity and quality of SOM available for decomposition by the microbial community compared with the other slope positions. Microbial dynamics and diversity may also be high in these positions.

Similar trend could also be detected when comparing the spatial distribution of soil labile C and N pools, with the correlation between soil moisture and soil labile C and N pools. Therefore, we assume that soil moisture is an important driving factor for the spatial distribution of labile C and N pools along the transect. The hydrological cycle could lead to the changes in the duration of the oxic and

anoxic phases, soil moisture and SOM (Ponnamperuma 1972; De Jager et al. 2012). Studies reported that soil moisture could affect the structure and diversity of the soil community (Tang et al. 2011). The water regime was clearly critical factor in regulating soil microbial diversity in floodplain soils (Rinklebe and Langer 2006). Unfortunately, we did not analyze the fungi and bacterial communities in this study. However, MBC: MBN ratios may shed some light on it. Generally, bacteria have the C: N of 3-6, while fungi have higher C:N ratios of 5-17 (Anderson and Domsch 2006; Cleveland and Liptzin 2007; Strickland and Rousk 2010; Liao et al. 2016). In this study, MBC: MBN ratios varied dramatically along the transects, indicating the temporal shift of microbial composition. For example, soil MBC: MBN ratios decreased dramatically from 7.69 in Sp₁ to 3.85 in the sediment in the 0-10 cm soil depth at S₁ in winter 2013 ($P < 0.01$), suggesting the microbial communities may shift from fungi to bacteria. It was consistent with the previous findings that bacteria were commonly dominant under flooded conditions while fungi under upland conditions (Bai et al. 2000; Nakamura et al. 2003).

However, the distribution of HWEOC did not always show consistent with that of MBC. For example, significant difference was detected for MBC in the 0-10 cm soil depth at S₁ in winter 2013 ($P < 0.01$), but no obvious variation in HWEOC was found. This may be due to the fact that HWEOC would have extracted not only MBC, but also root exudates, soluble carbohydrates and amino acids. Vegetation can directly contribute a C input to the soil through litterfall and root exudation (Hamilton and Frank 2001; Anaya et al. 2007). Otherwise, plants could also affect the quantity and activity of microorganism as the energy source (Chen et al. 2004), and then lead to the chain variation of the soil components (Ros et al. 2010).

It is also interesting to note the inconsistency between the temporal distribution of HWEOC and

HWETN in this study. For example, HWEOC increased to the peak of value between Sp₂ and Sp₃ in the 0-10 cm soil depth at S₁ in summer 2014. However, the corresponding HWETN decreased dramatically from Sp₁ to Sp₄. It is reported that although HWETN was mainly in organic form (80% on average), significant amounts of NH₄-N were also related due to hydrolysis of heat-labile organic N (Curtin et al. 2006). Thus, NH₄-N may participate in the soil N dynamics immediately. This assumption was supported by Jiang et al. (2016) who actually measured the spatial variation of $\delta^{15}\text{N}$ in the same experiment, and found the extraordinary low value of $\delta^{15}\text{N}$ in those slope positions.

HWEOC, HWETN, MBC, and MBN decreased significantly with increasing soil depth. It was consistent with previous findings (Zhang et al. 2006; Ros et al. 2009). Because the majority of the organic matter input occurs in the topsoil, the topsoil layer shows the highest SOM and microbial activity (Ros et al. 2009). In addition, the vertical distribution of roots and plant litter might also contribute to the labile C and N distribution (Zhang et al. 2006). On the other hand, it was possible that labile organic C and N in the deeper layers might have been consumed due to the longer residence time of the substrate (Dodla et al. 2012).

The concentrations of labile C and N at S₁ were significantly higher than those at S₂. The differences in soil texture were considered to affect soil microbial properties significantly (Ausec et al. 2009; Li et al. 2010). Due to the capacity of clay to retain SOM, the positive correlation between HWEOC, or MBC and clay content was reported previously (Merckx et al. 1985; Van Veen et al. 1985; Kaiser et al. 1992; Poret-Peterson et al. 2007). However, it seems that more significant temporal and seasonal patterns were found at S₂, suggesting the influence of slope degree (Wenger 1999).

4.2 Seasonal variation of soil labile C and N pools

Factors such as precipitation, temperature, and plant growth, regulate soil C and N cycling, and seasonal patterns of soil labile C and N dynamics can simultaneously reflect the effects of these factors (Parker and Schimel 2011). HWEOC and HWETN concentrations were significantly higher in spring 2013 followed by the summer and winter 2013 and 2014 in this study. The dynamics of precipitation and water fluxes were largely responsible for the seasonal changes in the concentration and fluxes of HWEOC and HWETN in the soils in November 2013. The riparian areas subjected to prolonged drying since September 2013 due to low precipitation, and then received the total rainfall of 60.8 mm within eight days before sample collection on 19 November 2013. The corresponding water level also increased from 96.2 to 97 % of full water level. The dry-rewetting cycles can induce large flushes of SOC and nutrients by releasing drought accumulated SOM, inorganic N, and microbial necromass (Birch 1958; Austin et al. 2004; Schimel et al. 2007; Iovieno and Bååth 2008; Butterly et al. 2009). Rapid water level changes are always tightly coupled with C and N cycling (Neill 1995; Fierer and Schimel 2002; Venterink et al. 2002; Austin et al. 2004; Schimel et al. 2007), which may lead to the variation of soil microbial composition (Barnard et al. 2013; Barnard et al. 2015). Bacteria are believed to dominate in the wet season while fungi may become active and even predominate in dry systems (Aziz et al. 1995; Ipsilantis and Sylvia 2007). Bossio and Scow (1998) found winter flooding resulted in a decrease in fungal and aerobic indicators and an increase in bacterial indicators. The intensity, duration and frequency of dry-rewet affect soil C and N cycles differently. A relatively short drying period and extended wetting period would potentially result in greater cumulative C and N mineralisation relative to a moist control (Sparling and Ross 1988; Cabrera 1993; Appel 1998; Mikha et al. 2005; Miller et al. 2005; Hentschel et al. 2007). However, the size of wetting pulses decreases with the frequency of dry-rewetting cycles, which may be explained by the decrease in labile organic

matter over time (Birch 1958), or by a shift in bacterial community composition as reported for a forest soil (Fierer and Schimel 2003). In our study, the rewetting in November 2013 was featured with high frequency of rainfall. It seemed that dry-rewetting moment appeared at the onset of the wet season.

Seasonal changes lead to differences in temperature and moisture which are important factors controlling soil labile C and N dynamics (Schmidt et al. 2007). Plant litter and root exudates are considered to be the primary source of water-soluble SOM (Qualls et al. 1991). Soil HWEOC and HWETN were high in summer 2013 and 2014 although soil moisture was much lower in summer 2014, suggesting that this increase may cause by other factors such as temperature and plant residues. Higher temperature is known to stimulate microbial activity, plant rhizodeposition, the decomposition of organic C and the release of dissolved organic C from soil organic matter (Kalbitz et al. 2000; Bonnett et al. 2006; Clark et al. 2009). In contrast, the lowest values of HWEOC and HWETN were observed in winter although soil moisture in winter 2014 was also high. Therefore, temperature and plant residues may exert stronger influence in the seasonal pattern of HWEOC and HWETN compared with soil moisture in this study, although the dry-rewetting events were believed to play a pivotal role in the changes of HWEOC and HWETN in November 2013.

However, concentrations of MBC and MBN were not as significantly high as HWEOC and HWETN. Soil MBC was also high in November 2013, indicating the influence of dry-rewetting event. However, MBC in November 2013 showed no significant difference with that in summer 2013. We attributed it to the differences of duration, intensity, and frequency of rainfall. In February 2013, soil and sediment samples were collected two weeks after the high intensity rainfall (174.6 mm) on 28 January. Wu et al. (2015) studied the influence of early dry season on soil microbial biomass in Dongting Lake wetland,

and found that a shorter flooding duration and a longer period after flooding could lead to a higher soil microbial biomass. They attributed it to two reasons: the recovery of soil aerobic microorganisms from stress in drying period (Anderson and Domsch 1993), and the appearance of plants which could supply litterfall and the exudation of the plant roots to soil microorganisms (Hamilton and Frank 2001). For samples collected on 19 November 2013 in our experiment, there was still time lag effect for microbial biomass to reach the summit of MBC and MBN. In addition, the seasonal patterns of MBC and MBN coincided with the corresponding seasonal patterns of soil moisture. Nevertheless, MBC in summer 2014 was still higher than that in winter 2013 at some lower slope positions with higher soil moisture. It is assumed that temperature turned to be the limiting factor when water was no longer a limitation for MBC in those slope positions. Those findings suggest that soil moisture may exert strong influence on soil MBC and MBN together with temperature and plant residues. Previous studies have also demonstrated that soil temperature and moisture play key roles in controlling soil microbial communities (Fierer et al. 2009; Deng et al. 2010). The hydrological cycle could affect the duration of the oxic and anoxic phases, inducing different soil microbial community structure and diversity (Ponnamperuma 1972; Tang et al. 2011; De Jager et al. 2012). We also found significant and strong correlation between MBC and MBN in this study. However, MBN showed more pronounced seasonal fluctuations than MBC, because microorganisms differ much more in their N content than in their C content (Anderson and Domsch 1989).

5 Conclusion

Soil moisture, induced by precipitation and water level fluxes, seems to be the prime driving factor regulating the temporal distributions of labile C and N pools in the riparian areas of Wyaralong Dam in

southeast Queensland, Australia. Under the same precipitation regime, soil labile C and N varied with the slope position, soil depth and soil texture. The significant correlation between different labile C and N pools indicates that they may partly represent similar soil C and N pools. However, other factors rather than soil moisture might exert stronger influence in the seasonal pattern of HWEOC and HWETN although dry-rewetting events were shown to affect the seasonal changes of HWEOC and HWETN significantly in November 2013; while soil moisture might play a much more important role in the seasonal variation of soil MBC and MBN together with temperature. Compared with MBC, MBN is a much more sensitive indicator for soil quality changes in the riparian zone. Riparian areas would be the hotspots for microbial activity driven by different environmental factors, especially in the environment at the beginning of the rewetting dry seasons.

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Figures and Tables

Fig. 1 Soil sampling sites (S_1 and S_2) in the riparian zone of Wyaralong Dam

Fig. 2 Soil and sediment sampling points of Site 1 (S_1) and Site 2 (S_2) at Wyaralong Dam

Fig. 3 Monthly rainfall, maximum temperature and minimum temperature for the Beaudesert Drumley Street Station from January 2013 to December 2014

Fig. 4 Water level fluctuation of Wyaralong Dam from January 2013 to December 2014

Fig. 5 The relationship between distance from Sp_1 and soil moisture in the 0–10 cm soils (a) and 10–20 cm soils (b) at S_1 , and in the 0–10 cm soils (c) and 10–20 cm soils (d) at S_2
 Sp_1 : the most upper slope position; S_1 : Site 1; and S_2 : Site 2

Fig. 6 The relationship between distance from Sp_1 and HWEOC in the 0–10 cm soils (a) and 10–20 cm soils (b), and the relationship between distance from Sp_1 and HWETN in the 0–10 cm soils (c) and 10–20 cm soils (d) at S_1

Sp_1 : the most upper slope position; S_1 : Site 1; HWEOC: hot-water extractable organic C; and HWETN: hot-water extractable total N

Fig. 7 Seasonal patterns of HWEOC in the first six slope positions in 0–10 cm (a) and 10–20 cm (b) soil depth, and seasonal patterns of HWETN in the first six slope positions in 0–10 cm (c) and 10–20 cm (d) soil depth at S_1

Sp : slope position; S_1 : Site 1; HWEOC: hot-water extractable organic C; and HWETN: hot-water extractable total N

Different letters indicated significant differences among the six sampling times at $P < 0.05$

Fig. 8 The relationship between distance from Sp_1 and MBC in the 0–10 cm soils (a) and 10–20 cm soils (b), and the relationship between distance from Sp_1 and MBN in the 0–10 cm soils (c) and 10–20 cm soils (d) at S_1

Sp_1 : the most upper slope position; S_1 : Site 1; MBC: microbial biomass C; and MBN: microbial biomass N

Fig. 9 Seasonal patterns of MBC in the first six slope positions in 0–10 cm (a) and 10–20 cm (b) soil depth, and seasonal patterns of MBN in the first six slope positions in 0–10 cm (c) and 10–20 cm (d) soil depth at S_1

Sp : slope position; S_1 : Site 1; MBC: microbial organic C; and MBN: microbial organic N

Different letters indicated significant differences among the six sampling times at $P < 0.05$

Table 1 Soil sampling sites (S_1 and S_2) information in the riparian zone of Wyaralong Dam

Table 2 Three-way analyses of variation (ANOVA) for soil moisture, hot-water extractable organic C (HWEOC), hot-water extractable total N (HWETN), microbial biomass C (MBC) and microbial biomass N (MBN) in 0–10 and 10–20 cm soil profiles at Site 1 (S_1) and Site 2 (S_2)

Table 3 The effects of soil moisture (SM) on soil hot-water extractable organic C (HWEOC) and hot-water extractable total N (HWETN) at Site 1 (S_1) of Wyaralong Dam

Table 4 The effects of soil moisture (SM) on soil hot-water extractable organic C (HWEOC) and hot-water extractable total N (HWETN) at Site 2 (S_2) of Wyaralong Dam

Table 5 The effects of soil moisture (SM) on soil microbial biomass C (MBC) and microbial biomass N (MBN) at Site 1 (S_1) of Wyaralong Dam

Table 6 The effects of soil moisture (SM) on soil microbial biomass C (MBC) and microbial biomass N (MBN) at Site 2 (S_2) of Wyaralong Dam

Supporting Information

Fig. S1 Seasonal patterns of soil moisture within the first six slope positions in 0-10 cm (a) and 10-20 cm (b) soil depth at S₁, and in 0-10 cm (c) and 10-20 cm (d) soil depth at S₂

Sp: slope position; S₁: Site 1; and S₂: Site 2

Different letters indicated significant differences among the six sampling times at $P < 0.05$

Fig. S2 The relationship between distance from Sp₁ and HWEOC in the 0–10 cm soils (a) and 10-20 cm soils (b), and the relationship between distance from Sp₁ and HWETN in the 0–10 cm soils (c) and 10-20 cm soils (d) at S₂

Sp₁: the most upper slope position; S₂: Site 2; HWEOC: hot-water extractable organic C; and HWETN: hot-water extractable total N

Fig. S3 Seasonal patterns of HWEOC in the first six slope positions in 0-10 cm (a) and 10-20 cm (b) soil depth, and seasonal patterns of HWETN in the first six slope positions in 0-10 cm (c) and 10-20 cm (d) soil depth at S₂

Sp: slope position; S₂: Site 2; HWEOC: hot-water extractable organic C; and HWETN: hot-water extractable total N

Different letters indicated significant differences among the six sampling times at $P < 0.05$

Fig. S4 The relationship between distance from Sp₁ and MBC in the 0–10 cm soils (a) and 10-20 cm soils (b), and the relationship between distance from Sp₁ and MBN in the 0–10 cm soils (c) and 10-20 cm soils (d) at S₂

Sp₁: the most upper slope position; S₂: Site 2; MBC: microbial biomass C; and MBN: microbial biomass N

Fig. S5 Seasonal patterns of MBC in the first six slope positions in 0-10 cm (a) and 10-20 cm (b) soil depth, and seasonal patterns of MBN in the first six slope positions in 0-10 cm (c) and 10-20 cm (d) soil depth at S₂

Sp: slope position; S₂: Site 2; MBC: microbial organic C; and MBN: microbial organic N

Different letters indicated significant differences among the six sampling times at $P < 0.05$

Table S1 Two-way analyses of variation (ANOVA) for hot-water extractable organic C (HWEOC), hot-water extractable total N (HWETN), microbial biomass C (MBC) and microbial biomass N (MBN) in 0-10 and 10-20 cm soil profiles at Site 1 (S₁) and Site 2 (S₂)

Table S2 The effects of hot-water extractable C (HWEOC) on soil microbial biomass C (MBC) and the effect of hot-water extractable total N (HWETN) on soil microbial biomass N (MBN) at Site1 (S₁) of Wyaralong Dam

Table S3 The effects of hot-water extractable C (HWEOC) on soil microbial biomass C (MBC) and the effect of hot-water extractable total N (HWETN) on soil microbial biomass N (MBN) at Site2 (S₂) of Wyaralong Dam

Table 1 Soil sampling sites (S₁ and S₂) information in the riparian zone of Wyaralong Dam

Site	Soil type	Parent material	Slope degree	Coordinates		pH	EC ($\mu\text{S m}^{-1}$)
S ₁	Black, Grey, Brown Dermosols	Alluvia	8-16 °	27°56'8"S	152°46'9"E	5.22 (0.23)	216.61 (41.02)
S ₂	Brown, Black Kurosols	Alluvia	4-10 °	27°56'19"S	152°51'18"E	4.37 (0.17)	152.98 (22.43)

Table 2 Three-way analyses of variation (ANOVA) for soil moisture, hot-water extractable organic C (HWEOC), hot-water extractable total N (HWETN), microbial biomass C (MBC) and microbial biomass N (MBN) in 0-10 and 10-20 cm soil profiles at Site 1 (S₁) and Site 2 (S₂)

Soil Profile (cm)		Moisture (%)			HWEOC (mg.kg ⁻¹)			HWETN (mg.kg ⁻¹)			MBC (mg.kg ⁻¹)			MBN (mg.kg ⁻¹)		
		DF	F	P	DF	F	P	DF	F	P	DF	F	P	DF	F	P
S ₁	Sd	1	290.65	< 0.01 **	1	136.96	< 0.01 **	1	114.84	< 0.01 **	1	76.23	< 0.01 **	1	50.86	< 0.01 **
	Sp	9	93.34	< 0.01 **	9	9.40	< 0.01 **	9	7.16	< 0.01 **	9	30.12	< 0.01 **	9	10.62	< 0.01 **
	St	5	279.94	< 0.01 **	5	240.24	< 0.01 **	5	162.73	< 0.01 **	4	10.44	< 0.01 **	4	27.32	< 0.01 **
	Sd x Sp	8	16.91	< 0.01 **	8	1.92	0.0603	8	2.45	< 0.05 *	8	4.25	< 0.01 **	8	2.08	< 0.05 *
	Sd x St	5	15.46	< 0.01 **	5	10.89	< 0.01 **	5	6.98	< 0.01 **	4	2.44	0.0500	4	4.17	< 0.01 **
	Sp x St	29	11.04	< 0.01 **	29	1.94	< 0.01 **	29	1.54	< 0.05 *	22	0.71	0.8209	22	1.38	0.1349
	Sd x Sp x St	24	0.93	0.5637	24	0.45	0.9887	24	0.41	0.9932	18	0.88	0.6033	18	0.57	0.9165
S ₂	Sd	1	358.58	< 0.01 **	1	345.52	< 0.01 **	1	201.19	< 0.01 **	1	185.16	< 0.01 **	1	67.32	< 0.01 **
	Sp	9	88.57	< 0.01 **	9	25.60	< 0.01 **	9	9.47	< 0.01 **	9	35.91	< 0.01 **	9	14.72	< 0.01 **
	St	5	162.26	< 0.01 **	5	259.74	< 0.01 **	5	182.20	< 0.01 **	5	16.09	< 0.01 **	5	11.16	< 0.01 **
	Sd x Sp	8	4.20	< 0.01 **	8	5.48	< 0.01 **	8	1.71	0.0978	8	5.20	< 0.01 **	8	3.19	< 0.01 **
	Sd x St	5	3.56	< 0.01 **	5	40.54	< 0.01 **	5	32.52	< 0.01 **	5	1.15	0.3358	5	0.61	0.6569
	Sp x St	34	9.25	< 0.01 **	34	4.76	< 0.01 **	34	1.78	< 0.01 **	34	1.00	0.4727	34	1.17	0.2730
	Sd x Sp x St	29	0.71	0.8605	29	1.49	0.0618	29	0.65	0.9164	29	0.94	0.5378	29	0.89	0.5988

Table 3 The effects of soil moisture (SM) on soil hot-water extractable organic C (HWEOC) and hot-water extractable total N (HWETN) at Site 1 (S₁) of Wyaralong Dam

Soil depth	HWEOC (mg.kg ⁻¹)	HWETN (mg.kg ⁻¹)
Time of sampling: 12/02/2013 (summer)		
0-10 cm	HWEOC = 404.3 +48.1 SM -0.785 SM ² (R ² = 0.837, n=6, <i>P</i> < 0.05)	HWETN = 90.2 +2.13 SM -0.0462 SM ² (R ² = 0.900, n=6, <i>P</i> < 0.05)
10-20 cm	ns	ns
Time of sampling: 21/05/2013 (autumn)		
0-10 cm	ns	ns
10-20 cm	ns	ns
Time of sampling: 20/08/2013 (winter)		
0-10 cm	HWEOC = 1379.95 -37.14 SM +0.459 SM ² (R ² = 0.957, n=6, <i>P</i> < 0.01)	HWETN = 152.6 -4.46 SM +0.560 SM ² (R ² = 0.999, n=6, <i>P</i> < 0.01)
10-20 cm	ns	ns
Time of sampling: 19/11/2013 (spring)		
0-10 cm	HWEOC = 3915.89 -60.3 SM +0.02090 SM ² (R ² = 0.984, n=8, <i>P</i> < 0.01)	HWETN = 548.7 -16.9 SM +0.166 SM ² (R ² = 0.825, n=8, <i>P</i> < 0.01)
10-20 cm	HWEOC = 8280.1 -536.9 SM +10.3 SM ² (R ² = 0.802, n=7, <i>P</i> < 0.05)	HWETN = 776.5 -51.8 SM +1.01 SM ² (R ² = 0.722, n=7, <i>P</i> < 0.05)
Time of sampling: 20/02/2014 (summer)		
0-10 cm	HWEOC = 2394.99 -141.04 SM +2.41 SM ² (R ² = 0.719, n=10, <i>P</i> < 0.01)	ns
10-20 cm	HWEOC = 2317.6 -196.6 SM +4.81 SM ² (R ² = 0.916, n=9, <i>P</i> < 0.01)	HWETN = 130.1 -8.66 SM +0.225 SM ² (R ² = 0.524, n=9, <i>P</i> < 0.05)
Time of sampling: 28/08/2014 (winter)		
0-10 cm	HWEOC = 1122.13 -23.18 SM +0.126 SM ² (R ² = 0.694, n=8, <i>P</i> < 0.05)	HWETN = 133.8 -3.23 SM +0.02116 SM ² (R ² = 0.867, n=8, <i>P</i> < 0.01)
10-20 cm	ns	ns

SM: soil moisture; HWEOC: hot-water extractable C; and HWETN: hot-water extractable N

Table 4 The effects of soil moisture (SM) on soil hot-water extractable organic C (HWEOC) and hot-water extractable total N (HWETN) at Site 2 (S₂) of Wyaralong Dam

Soil depth	HWEOC (mg.kg ⁻¹)	HWETN (mg.kg ⁻¹)
Time of sampling: 12/02/2013 (summer)		
0-10 cm	ns	ns
10-20 cm	ns	HWETN = 650.2 -62.5 SM +1.56 SM ² (R ² = 0.904, n=5, <i>P</i> < 0.05)
Time of sampling: 21/05/2013 (autumn)		
0-10 cm	ns	HWETN = 80.1 -2.48 SM +0.0157 SM ² (R ² = 0.665, n=7, <i>P</i> < 0.05)
10-20 cm	ns	
Time of sampling: 20/08/2013 (winter)		
0-10 cm	HWEOC = 953.3 -43.2 SM +0.655 SM ² (R ² = 0.968, n=7, <i>P</i> < 0.01)	HWETN = 106.4 -5.60 SM +0.0928 SM ² (R ² = 0.734, n=7, <i>P</i> < 0.05)
10-20 cm	HWEOC = 205.2 -2.45 SM -0.0529 SM ² (R ² = 0.828, n=6, <i>P</i> < 0.05)	HWETN = 39.8 -2.66 SM +0.0583 SM ² (R ² = 0.813, n=6, <i>P</i> < 0.05)
Time of sampling: 19/11/2013 (spring)		
0-10 cm	ns	ns
10-20 cm	HWEOC = 2542.0 -231.3 SM +6.50 SM ² (R ² = 0.889, n=8, <i>P</i> < 0.01)	ns
Time of sampling: 20/02/2014 (summer)		
0-10 cm	HWEOC = 942.6 -53.5 SM +1.01 SM ² (R ² = 0.615, n=10, <i>P</i> < 0.05)	HWETN = 69.6 -3.20 SM +0.0386 SM ² (R ² = 0.892, n=10, <i>P</i> < 0.01)
10-20 cm	HWEOC = 519.6 -47.0 SM +1.50 SM ² (R ² = 0.953, n=9, <i>P</i> < 0.01)	HWETN = 33.3 -1.92 SM +0.0378 SM ² (R ² = 0.956, n=9, <i>P</i> < 0.01)
Time of sampling: 28/08/2014 (winter)		
0-10 cm	HWEOC = 742.0 -40.3 SM +0.707 SM ² (R ² = 0.626, n=10, <i>P</i> < 0.05)	ns
10-20 cm	ns	HWETN = 10.4 +1.15 SM -0.0610 SM ² (R ² = 0.849, n=9, <i>P</i> < 0.01)

SM: soil moisture; HWEOC: hot-water extractable C; and HWETN: hot-water extractable N

Table 5 The effects of soil moisture (SM) on soil microbial biomass C (MBC) and microbial biomass N (MBN) at Site 1 (S₁) of Wyaralong Dam

Soil depth	MBC (mg.kg ⁻¹)	MBN (mg.kg ⁻¹)
Time of sampling: 12/02/2013 (summer)		
0-10 cm	ns	ns
10-20 cm	ns	ns
Time of sampling: 21/05/2013 (autumn)		
0-10 cm	ns	MBN = -17.9+2.23 SM -0.0312 SM ² (R ² = 0.798, n=6, <i>P</i> < 0.05)
10-20 cm	ns	MBN = 19.9-1.29 SM +0.0372 SM ² (R ² = 0.927, n=5, <i>P</i> < 0.05)
Time of sampling: 20/08/2013 (winter)		
0-10 cm	ns	ns
10-20 cm	MBC = 13.1+5.63 SM -0.157 SM ² (R ² = 0.945, n=5, <i>P</i> < 0.05)	ns
Time of sampling: 19/11/2013 (spring)		
0-10 cm	MBC = 535.8-23.7 SM +0.276 SM ² (R ² = 0.942, n=8, <i>P</i> < 0.01)	MBN = 89.1-4.12 SM +0.0508 SM ² (R ² = 0.989, n=8, <i>P</i> < 0.01)
10-20 cm	MBC = -118.5+20.0 SM -0.505 SM ² (R ² = 0.954, n=7, <i>P</i> < 0.01)	MBN = -22.6+3.35 SM -0.0820 SM ² (R ² = 0.973, n=7, <i>P</i> < 0.01)
Time of sampling: 20/02/2014 (summer)		
0-10 cm	MBC = 167.3-11.0 SM +0.193 SM ² (R ² = 0.905, n=10, <i>P</i> < 0.01)	MBN = 14.9-1.56 SM +0.0361 SM ² (R ² = 0.688, n=10, <i>P</i> < 0.05)
10-20 cm	MBC = 131.6-8.95 SM +0.174 SM ² (R ² = 0.914, n=9, <i>P</i> < 0.01)	MBN = 14.8-1.74 SM +0.0502 SM ² (R ² = 0.598, n=9, <i>P</i> < 0.05)

SM: soil moisture; MBC: microbial biomass C; and MBN: microbial biomass N

Table 6 The effects of soil moisture (SM) on soil microbial biomass C (MBC) and microbial biomass N (MBN) at Site 2 (S₂) of Wyaralong Dam

Soil depth	MBC (mg.kg ⁻¹)	MBN (mg.kg ⁻¹)
Time of sampling: 12/02/2013 (summer)		
0-10 cm	ns	ns
10-20 cm	ns	ns
Time of sampling: 21/05/2013 (autumn)		
0-10 cm	MBC = 20.5 +3.64 SM -0.127 SM ² (R ² = 0.750, n=7, <i>P</i> < 0.05)	MBN = 14.2 -0.393 SM (R ² = 0.877, n=7, <i>P</i> < 0.01)
10-20 cm	MBC = 125.5 -11.2 SM +0.269 SM ² (R ² = 0.856, n=6, <i>P</i> < 0.05)	ns
Time of sampling: 20/08/2013 (winter)		
0-10 cm	MBC = 97.1 -4.96 SM +0.0686 SM ² (R ² = 0.721, n=7, <i>P</i> < 0.05)	MBN = 11.3-0.343 SM (R ² = 0.954, n=7, <i>P</i> < 0.01)
10-20 cm	ns	MBN = 13.6 -1.26 SM +0.0309 SM ² (R ² = 0.920, n=6, <i>P</i> < 0.05)
Time of sampling: 19/11/2013 (spring)		
0-10 cm	ns	ns
10-20 cm	MBC = 72.5 -5.89 SM +0.146 SM ² (R ² = 0.821, n=8, <i>P</i> < 0.01)	MBN = -0.394 +0.425 SM -0.0183 SM ² (R ² = 0.738, n=8, <i>P</i> < 0.05)
Time of sampling: 20/02/2014 (summer)		
0-10 cm	MBC = 21.1 +1.40 SM -0.0915 SM ² (R ² = 0.565, n=10, <i>P</i> < 0.05)	ns
10-20 cm	MBC = 17.8 -0.898 SM +0.00955 SM ² (R ² = 0.833, n=9, <i>P</i> < 0.01)	MBN = 2.18 +0.280 SM -0.017 SM ² (R ² = 0.777, n=9, <i>P</i> < 0.01)

SM: soil moisture; MBC: microbial biomass C; and MBN: microbial biomass N

Fig. 1 Soil sampling sites (S_1 and S_2) in the riparian zone of Wyaralong Dam

Sp; Slope position; Sp1: the most upper slope position; T; Transect

Fig. 2 Soil and sediment sampling points of Site 1 (S₁) and Site 2 (S₂) at Wyaralong Dam

Fig. 3 Monthly rainfall, maximum temperature and minimum temperature for the Beaudesert Drumley Street Station from January 2013 to December 2014

Fig. 4 Water level fluctuation of Wyaralong Dam from January 2013 to December 2014

Fig. 5 The relationship between distance from Sp₁ and soil moisture in the 0–10 cm soils (a) and 10-20 cm soils (b) at S₁, and in the 0–10 cm soils (c) and 10-20 cm soils (d) at S₂

Sp₁: the most upper slope position; S₁: Site 1; and S₂: Site 2

Fig. 6 The relationship between distance from Sp₁ and HWEOC in the 0–10 cm soils (a) and 10–20 cm soils (b), and the relationship between distance from Sp₁ and HWETN in the 0–10 cm soils (c) and 10–20 cm soils (d) at S₁

Sp₁: the most upper slope position; S₁: Site 1; HWEOC: hot-water extractable organic C; and HWETN: hot-water extractable total N

Fig. 7 Seasonal patterns of HWEOC in the first six slope positions in 0-10 cm (a) and 10-20 cm (b) soil depth, and seasonal patterns of HWETN in the first six slope positions in 0-10 cm (c) and 10-20 cm (d) soil depth at S₁

Sp: slope position; S₁: Site 1; HWEOC: hot-water extractable organic C; and HWETN: hot-water extractable total N

Different letters indicated significant differences among the six sampling times at $P < 0.05$

Fig. 8 The relationship between distance from Sp_1 and MBC in the 0–10 cm soils (a) and 10–20 cm soils (b), and the relationship between distance from Sp_1 and MBN in the 0–10 cm soils (c) and 10–20 cm soils (d) at S_1

Sp_1 : the most upper slope position; S_1 : Site 1; MBC: microbial biomass C; and MBN: microbial biomass N

Fig. 9 Seasonal patterns of MBC in the first six slope positions in 0-10 cm (a) and 10-20 cm (b) soil depth, and seasonal patterns of MBN in the first six slope positions in 0-10 cm (c) and 10-20 cm (d) soil depth at S₁

Sp: slope position; S₁: Site 1; MBC: microbial organic C; and MBN: microbial organic N
 Different letters indicated significant differences among the six sampling times at $P < 0.05$

Fig. S1 Seasonal patterns of soil moisture within the first six slope positions in 0-10 cm (a) and 10-20 cm (b) soil depth at S₁, and in 0-10 cm (c) and 10-20 cm (d) soil depth at S₂. Sp: slope position; S₁: Site 1; and S₂: Site 2. Different letters indicated significant differences among the six sampling times at $P < 0.05$.

Fig. S2 The relationship between distance from Sp₁ and HWEOC in the 0–10 cm soils (a) and 10-20 cm soils (b), and the relationship between distance from Sp₁ and HWETN in the 0–10 cm soils (c) and 10-20 cm soils (d) at S₂

Sp₁: the most upper slope position; S₂: Site 2; HWEOC: hot-water extractable organic C; and HWETN: hot-water extractable total N

Fig. S3 Seasonal patterns of HWEOC in the first six slope positions in 0-10 cm (a) and 10-20 cm (b) soil depth, and seasonal patterns of HWETN in the first six slope positions in 0-10 cm (c) and 10-20 cm (c) soil depth at S₂

Sp: slope position; S₂: Site 2; HWEOC: hot-water extractable organic C; and HWETN: hot-water extractable total N

Different letters indicated significant differences among the six sampling times at $P < 0.05$

Fig. S4 The relationship between distance from Sp₁ and MBC in the 0–10 cm soils (a) and 10-20 cm soils (b), and the relationship between distance from Sp₁ and MBN in the 0–10 cm soils (c) and 10-20 cm soils (d) at S₂

Sp₁: the most upper slope position; S₂: Site 2; MBC: microbial biomass C; and MBN: microbial biomass N

Fig. S5 Seasonal patterns of MBC in the first six slope positions in 0-10 cm (a) and 10-20 cm (b) soil depth, and seasonal patterns of MBN in the first six slope positions in 0-10 cm (c) and 10-20 cm (d) soil depth at S_2

Sp: slope position; S_2 : Site 2; MBC: microbial organic C; and MBN: microbial organic N

Different letters indicated significant differences among the six sampling times at $P < 0.05$

Table S1 Two-way analyses of variation (ANOVA) for hot-water extractable organic C (HWEOC), hot-water extractable total N (HWETN), microbial biomass C (MBC) and microbial biomass N (MBN) in 0-10 and 10-20 cm soil profiles at Site 1 (S₁) and Site 2 (S₂)

Soil Profile (cm)			Moisture (%)			HWEOC (mg.kg ⁻¹)			HWETN (mg.kg ⁻¹)			MBC (mg.kg ⁻¹)			MBN (mg.kg ⁻¹)		
			DF	F	P	DF	F	P	DF	F	P	DF	F	P	DF	F	P
12/02/2013	S ₁	Sd	1	39.92	< 0.01 **	1	113.25	< 0.01 **	1	140.79	< 0.01 **	1	27.41	< 0.01 **	1	32.13	< 0.01 **
		Sp	5	21.34	< 0.01 **	5	2.967	0.036 *	5	3.14	0.02 *	5	2.08	0.1111	5	0.98	0.4521
		Sd x Sp	4	0.61	0.6576	4	0.13	0.9711	4	0.54	0.7911	4	1.86	0.1577	4	1.00	0.4295
	S ₂	Sd	1	14.55	< 0.01 **	1	98.54	< 0.01 **	1	109.94	< 0.01 **	1	13.11	< 0.01 **	1	8.37	< 0.01 **
		Sp	5	4.80	< 0.01 **	5	2.36	0.0586	5	2.06	0.1134	5	1.41	0.2631	5	2.28	0.0859
		Sd x Sp	4	0.07	0.9895	4	0.45	0.5007	4	0.37	0.8282	4	0.43	0.7842	4	0.84	0.5173
	S ₁	Sd	1	69.70	< 0.01 **	1	39.46	< 0.01 **	1	47.19	< 0.01 **	1	34.32	< 0.01 **	1	4.73	0.04 *
		Sp	5	91.53	< 0.01 **	5	2.46	0.0684	5	2.33	0.0808	5	6.78	< 0.01 **	5	2.44	0.0702
		Sd x Sp	4	1.92	0.1464	4	0.10	0.9817	4	0.23	0.9184	4	1.44	0.2562	4	0.53	0.7155
21/05/2013	S ₂	Sd	1	89.19	< 0.01 **	1	60.75	< 0.01 **	1	75.59	< 0.01 **	1	131.96	< 0.01 **	1	24.63	< 0.01 **
		Sp	6	10.59	< 0.01 **	6	2.49	0.0514	6	3.22	0.02 *	6	24.29	< 0.01 **	6	5.23	< 0.01 **
		Sd x Sp	5	1.10	0.3855	5	0.20	0.9600	5	0.66	0.6584	5	2.29	0.0782	5	1.34	0.2814
	S ₁	Sd	1	39.60	< 0.01 **	1	31.42	< 0.01 **	1	44.49	< 0.01 **	1	37.71	< 0.01 **	1	21.19	< 0.01 **
		Sp	5	53.93	< 0.01 **	5	2.06	0.1131	5	2.32	0.0815	5	10.04	< 0.01 **	5	1.32	0.2945
		Sd x Sp	4	1.27	0.3142	4	0.96	0.4505	4	1.35	0.2865	4	1.62	0.2087	4	1.05	0.4079
	S ₂	Sd	1	104.82	< 0.01 **	1	194.59	< 0.01 **	1	135.66	< 0.01 **	1	52.17	< 0.01 **	1	18.62	< 0.01 **
		Sp	6	38.68	< 0.01 **	6	6.49	< 0.01 **	6	5.09	< 0.01 **	6	15.58	< 0.01 **	6	7.85	< 0.01 **
		Sd x Sp	5	0.86	0.5242	5	0.47	0.7916	5	0.20	0.9582	5	1.64	0.1876	5	1.56	0.2110
19/11/2013	S ₁	Sd	1	92.98	< 0.01 **	1	44.58	< 0.01 **	1	39.87	< 0.01 **	1	21.92	< 0.01 **	1	5.94	0.02 *
		Sp	7	44.57	< 0.01 **	7	5.95	< 0.01 **	7	5.21	< 0.01 **	7	18.50	< 0.01 **	7	12.02	< 0.01 **
		Sd x Sp	6	0.15	0.9881	6	0.21	0.9720	6	0.45	0.8395	6	2.27	0.0659	6	1.09	0.3910

12/02/2014	S ₂	Sd	1	33.16	< 0.01**	1	184.11	< 0.01**	1	148.14	< 0.01**	1	50.69	< 0.01**	1	20.99	< 0.01**
		Sp	8	9.35	< 0.01**	8	15.65	< 0.01**	8	5.65	< 0.01**	8	19.09	< 0.01**	8	6.71	< 0.01**
		Sd x Sp	7	1.02	0.4368	7	1.08	0.3962	7	0.65	0.7086	7	1.25	0.3041	7	0.23	0.9738
	S ₁	Sd	1	29.77	< 0.01**	1	11.20	< 0.01**	1	5.96	0.02*	1	5.19	0.03*	1	0.06	0.8077
		Sp	9	199.33	< 0.01**	9	13.32	< 0.01**	9	4.57	< 0.01**	9	35.91	< 0.01**	9	11.96	< 0.01**
		Sd x Sp	8	1.84	0.1011	8	0.59	0.7826	8	0.47	0.8687	8	1.91	0.0892	8	2.96	0.02*
	S ₂	Sd	1	78.98	< 0.01**	1	182.82	< 0.01**	1	146.73	< 0.01**	1	67.52	< 0.01**	1	20.55	< 0.01**
		Sp	9	181.00	< 0.01**	9	76.72	< 0.01**	9	46.07	< 0.01**	9	32.40	< 0.01**	9	8.34	< 0.01**
		Sd x Sp	8	3.17	< 0.01**	8	5.94	< 0.01**	8	1.73	0.1257	8	1.08	0.3994	8	0.81	0.6013
28/08/2014	S ₁	Sd	1	0.93	< 0.01**	1	30.09	< 0.01**	1	34.80	< 0.01**						
		Sp	7	47.30	< 0.01**	7	7.32	< 0.01**	7	10.61	< 0.01**						
		Sd x Sp	6	2.69	0.3409	6	1.54	0.2009	6	2.32	0.0606						
	S ₂	Sd	1	127.74	< 0.01**	1	327.22	< 0.01**	1	241.43	< 0.01**						
		Sp	9	50.70	< 0.01**	9	34.21	< 0.01**	9	16.24	< 0.01**						
		Sd x Sp	8	1.07	0.4075	8	2.80	0.02*	8	1.14	0.3633						

* and ** indicate significance at $P < 0.05$ and $P < 0.01$ respectively;

Sd -soil depth; and Sp – slope position

Table S2 The effects of hot-water extractable C (HWEOC) on soil microbial biomass C (MBC) and the effect of hot-water extractable total N (HWETN) on soil microbial biomass N (MBN) at Site1 (S1) of Wyaralong Dam

Soil depth	MBC (mg.kg ⁻¹)	MBN (mg.kg ⁻¹)
Time of sampling: 12/02/2013 (summer)		
0-10 cm	ns	ns
10-20 cm	MBC = -86.7+ 0.258 HWEOC (R ² = 0.991, n=5, <i>P</i> < 0.01)	MBN = -26.4+ 0.665 HWETN (R ² = 0.716, n=5, <i>P</i> < 0.05)
Time of sampling: 21/05/2013 (autumn)		
0-10 cm	ns	ns
10-20 cm	ns	ns
Time of sampling: 20/08/2013 (winter)		
0-10 cm	ns	ns
10-20 cm	ns	ns
Time of sampling: 19/11/2013 (spring)		
0-10 cm	MBC = -94.5+0.0817 HWEOC (R ² = 0.830, n=8, <i>P</i> < 0.01)	MBN = -15.2 -16.9 SM +0.151 HWETN (R ² = 0.896, n=8, <i>P</i> < 0.01)
10-20 cm	ns	ns
Time of sampling: 20/02/2014 (summer)		
0-10 cm	MBC = -43.6+0.123 HWEOC (R ² = 0.719, n=10, <i>P</i> < 0.01)	MBN = -3.88+ 0.0869 HWETN (R ² = 0.960, n=10, <i>P</i> < 0.01)
10-20 cm	MBC = -22.1 + 0.0894 HWEOC (R ² = 0.846, n=9, <i>P</i> < 0.01)	MBN = -1.80+ 0.0645 HWETN (R ² = 0.841, n=10, <i>P</i> < 0.01)

HWEOC: hot-water extractable C; HWETN: hot-water extractable N; MBC: microbial biomass C; and MBN: microbial biomass N

Table S3 The effects of hot-water extractable C (HWEOC) on soil microbial biomass C (MBC) and the effect of hot-water extractable total N (HWETN) on soil microbial biomass N (MBN) at Site2 (S2) of Wyaralong Dam

Soil depth	MBC (mg.kg ⁻¹)	MBN (mg.kg ⁻¹)
Time of sampling: 12/02/2013 (summer)		
0-10 cm	ns	ns
10-20 cm	ns	ns
Time of sampling: 21/05/2013 (autumn)		
0-10 cm	MBC = -26.9 + 0.175 HWEOC (R ² = 0.957, n=6, <i>P</i> < 0.01)	MBN = -2.61 + 0.248 HWEOC (R ² = 0.811, n=6, <i>P</i> < 0.01)
10-20 cm	MBC = -16.0 + 0.177 HWEOC (R ² = 0.749, n=5, <i>P</i> < 0.05)	ns
Time of sampling: 20/08/2013 (winter)		
0-10 cm	MBC = -25.5 + 0.135 HWEOC (R ² = 0.869, n=7, <i>P</i> < 0.01)	MBN = -5.82 + 0.267 HWEOC (R ² = 0.925, n=7, <i>P</i> < 0.01)
10-20 cm	MBC = -25.9 + 0.168 HWEOC (R ² = 0.812, n=6, <i>P</i> < 0.01)	MBN = -1.55 + 0.263 HWEOC (R ² = 0.795, n=6, <i>P</i> < 0.05)
Time of sampling: 19/11/2013 (spring)		
0-10 cm	MBC = -3.18+0.0233 HWEOC (R ² = 0.973, n=9, <i>P</i> < 0.01)	MBN = -0.914 -16.9 SM +0.0254 HWETN (R ² = 0.719, n=9, <i>P</i> < 0.01)
10-20 cm	MBC = - 8.45 + 0.0436 HWEOC (R ² = 0.953, n=8, <i>P</i> < 0.01)	MBN = -4.34 + 0.0937 HWEOC (R ² = 0.801, n=8, <i>P</i> < 0.01)
Time of sampling: 20/02/2014 (summer)		
0-10 cm	MBC = -1.52+0.041 HWEOC (R ² = 0.920, n=10, <i>P</i> < 0.01)	MBN = 0.409+ 0.0793 HWETN (R ² = 0.734, n=10, <i>P</i> < 0.01)
10-20 cm	MBC = -3.29 + 0.0482 HWEOC (R ² = 0.899, n=9, <i>P</i> < 0.01)	MBN = 0.324+ 0.0871 HWETN (R ² = 0.467, n=10, <i>P</i> < 0.05)

HWEOC: hot-water extractable organic C; HWETN: hot-water extractable total N; MBC: microbial biomass C; and MBN: microbial biomass N