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Controls of soil respiration in a salinity-affected ephemeral wetland

Paul L. Drake [a,b,c,*], Caroline A. McCormick [d], Michael J. Smith [a]

[a] Natural Resources Branch, Department of Parks and Wildlife, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983, Australia
[b] Future Farm Industries Cooperative Research Centre, CSRIO, Leeuwin Centre Building 46, 65 Brockway Road, Floreat 6014, Australia
[c] School of Plant Biology, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009, Australia
[d] Science and Conservation Division, Department of Parks and Wildlife, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983, Australia

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ABSTRACT

The total efflux of CO_2 derived from metabolic processes in soil (R_{soil}) exerts a large control on the terrestrial carbon balance. In landscapes that have been radically transformed by humans, the natural carbon balance may be altered by shifts in R_{soil}. After accounting for temperature, we sought to determine the main factors that govern R_{soil} at Toolibin Lake, an ephemeral wetland threatened by salinization as a result of land clearing. We found strong statistical support for a positive effect of soil gravimetric water content (θ) on R_{soil} and weaker support for a negative effect of salinity (measured as the electrical conductivity of a soil extract (EC_e)) on R_{soil}. We also detected weak support for a positive interaction between θ and EC_e, such that θ had a greater positive effect on R_{soil} at elevated soil salinities. These results confirm not only that soil moisture is an important driver of R_{soil} under native conditions, but also that elevated soil salinities have the potential to accentuate the link between R_{soil} and moisture content.

1. Introduction

Soil respiration (R_{soil}), the total efflux of CO_2 derived from metabolic processes in soil, is mainly a function of the rate of microbial decomposition of organic matter (heterotrophic respiration) and the rate of root respiration (autotrophic respiration) (Hanson et al., 2000). These processes, in turn, are controlled by a number of environmental factors. These include: soil temperature, soil water content, soil salinity, soil organic matter, and soil nutrient-content (Raich and Schlesinger, 1992). The balance between respiration and photosynthesis (P_n) will determine whether an ecosystem is a net source or sink of CO_2. Hence forecasting ecosystem metabolic rates, net CO_2 fluxes into the atmosphere and atmospheric CO_2 concentrations is dependent on an understanding of how R_{soil} scales with changing environmental factors.

Secondary salinity, defined by Jolly et al. (2008) as “soil and/or water salinization caused by human-induced activities such as land use change”, has affected the structure and species composition of many naturally occurring ecosystems. Because global climate models predict rising air (Solomon et al., 2007) and, consequently, soil temperatures, there has been much research into the temperature dependence of R_{soil} (see reviews by Raich and Schlesinger (1992) and Singh and Gupta (1977)). However, much less research has been undertaken to resolve the link between soil salinity and R_{soil}, despite the potential for a large component of the Earth's land surface to develop saline soils as a result of secondary salinization. In Australia, for example, 5.4 Mha of land has been assessed as having a high potential to develop salinity (National Land and Water Resources Audit, 2001) and much of this is in the wheatbelt of Western Australia (George et al., 2008), the setting of the present study. Furthermore, studies that have investigated soil salinity and R_{soil} have been largely confined to laboratory incubation experiments. For example, both Setia et al. (2010) and Wong et al. (2008) observed a decrease in soil respiration at high salinities in experimental microcosms. Laboratory-based research on the relationship between R_{soil} and soil salinity is an attractive option because it enables accurate control of the quantity and elemental composition of salt in soil. It remains uncertain how transferrable these studies are to native conditions where multiple environmental factors have the potential to co-limit R_{soil}.

The exposure of freshwater wetlands to salinization can have profound effects on biota. Through time, salinization will eradicate salinity-sensitive species in both soil microbial and vegetation communities. Under such conditions the concentration of salt in soil may be negatively correlated with R_{soil} because higher concentrations are associated with a soil ecosystem impoverished of respiring biota (Ghollarata and Raiesi, 2007; Pathak and Rao, 1998; Tripathi et al., 2006). A contrasting view is that cellular osmotic stress, induced by salinity, will stimulate inefficient conversion of substrate carbon to energy and as a consequence release a greater quantity of CO_2 (Saviozzi et al., 2011). In the latter case the amount of respiring biomass in soil may well decrease, but the total efflux of CO_2 will increase. A synthesis of these observations suggests that, in saline soils, the balance between the eradication of respiring biota versus the rate of CO_2 efflux per unit of resilient live biota ultimately determines R_{soil}. In the context

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[*] Corresponding author at: Natural Resources Branch, Department of Parks and Wildlife, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983, Australia. Tel.: +61 8 9219 8055; fax: +61 8 9334 0367.
E-mail address: paul.drake@dpaw.wa.gov.au (P.L. Drake).

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of wetland ecosystems, understanding the factors that alter this balance has global ramifications because about a quarter of the Earth's soil organic carbon stock occurs in wetlands (Dean and Gorham, 1998).

In addition to uncertainties on the form of the relationship between soil salinity and R_{soil}, other environmental factors are likely to co-limit respiratory processes. For example, a metabolic substrate for R_{soil}, soil organic matter (or the labile carbon pool), is highly variable in both space and time and its concentration will constrain R_{soil}. In situations where R_{soil} is already limited by the availability of soil organic matter, elevated soil salinity may have little effect. Here we investigate environmental predictors of R_{soil} at Toolibin Lake, an ephemeral wetland threatened by secondary salinity. Although we focus on the control exerted on R_{soil} by soil salinity, we also consider the potential for other environmental factors to constrain R_{soil}. We hypothesize that high soil salinity, along with low soil moisture will co-limit R_{soil}. Our objective was to ascertain what environmental factors are the salient predictors of R_{soil} measured under natural conditions at Toolibin Lake.

2. Material and methods

2.1. The study site

All measurements were carried out at Toolibin Lake (556800 E; 6357400 N). Toolibin Lake is a fresh to brackish ephemeral wetland covering an area of approximately 300 ha. The lake is located in the upper reaches of the Blackwood–Arthur River catchment in south-western Australia. Average annual rainfall between 1912 and 2010 was 408 mm with the majority falling between May and August when temperatures were, on average, lowest. Most of the Toolibin Lake catchment was cleared of native vegetation to establish agriculture in the last 100 years. The soils of the Toolibin Lake bed (and the study plot) are dominated by clay and silt overlaid by a thin organic A-horizon of less than 5 cm thick. The deep clay and silt sediments include a small fraction of sand and gravel which shows heterogeneity in both vertical and horizontal planes.

The groundwater beneath Toolibin Lake is typically within 3 m from the surface and has a salinity in excess of 30,000 mg L^{-1}. Surface water inflows into Toolibin Lake are highly variable in both volume and salt load (George and Dogramaci, 2000). Installation of a separator gate and levee in 1995 has enabled managers to exclude highly saline inflows and a network of pumps is positioned on the lake bed to lower saline groundwater beneath vegetation.

Despite management interventions, the surface soil sediments of the lake bed are relatively saline. Thus the combination of periodic surface water inundation and elevated saline groundwater has resulted in a spatial gradient in surface soil salinity from the bank of the wetland (the riparian fringe) to the lake bed. We established a plot on the perimeter of the wetland incorporating this spatial gradient. The plot had dimensions of 20 m (parallel to the wetland shoreline) by 60 m (perpendicular to the wetland shoreline), referred to henceforth as the x-axis and y-axis respectively (Fig. 1). The plot was surveyed using dGPS techniques and elevation referenced to a local benchmark, located in the basin of the lake. The orientation of the plot, from the wetland bank to the lake bed, ensured that a range of soil salinity would be present.

All measurements or sampling described in subsequent sections were carried out on the same day in spring to coincide with the end of the winter wet period. No surface water was present in the wetland or surrounding riparian fringe during the period of measurement. The plot was divided into three transects (Fig. 1). Transect one spanned the axis coordinates (x, y) 0 m, 0 m to 0 m, 60 m. Transect two spanned the axis coordinates 10 m, 0 m to 10 m, 60 m. Transect three spanned the axis coordinates 20 m, 0 m to 20 m, 60 m. Soil properties were determined at 4 m intervals along each transect. Thus a fixed grid of 48 points was established within the plot from which soil properties were ascertained. Within the plot, three native tree species dominated the canopy strata. These were: *Acacia acuminata* Benth., *Casuarina obesa* Miq. and *Eucalyptus rudis* Endl.

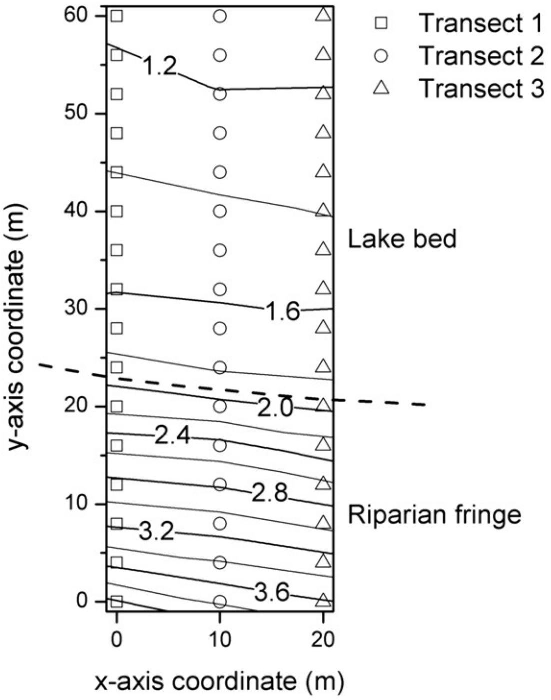

Fig. 1. Diagrammatic representation of the experimental plot showing three transects. Measurements were made every 4 m along each transect (indicated by symbols). Contours represent the ground surface level (m) of the plot above the lake basin. The dashed line is the approximate position of the transition from the lake bed to the riparian fringe.

2.2. Soil respiration

At each sampling point (every 4 m along each transect) soil respiration (R_{soil}, μmol CO_2 m^{-2} of soil surface area s^{-1}) and soil evaporative flux (F_W, mmol H_2O m^{-2} soil surface area s^{-1}) at the soil surface were measured according to Healy et al. (1996) with an open flow gas exchange system (model Li-6400, Li-cor Biosciences, Lincoln, Nebraska) incorporating a soil CO_2 flux chamber (model Li-6400-09, Li-cor Biosciences, Lincoln, Nebraska) ($n = 3$ iterative measurements per sampling point). The system was vented to ensure that the pressures inside and outside the chamber were in dynamic equilibrium. The soil surface was not disturbed prior to measurements except to ensure that the chamber was inserted to the depth of the stop ring (1 cm from the soil surface), and measurement periods were kept brief to minimize artifacts induced by disrupting diffusion gradients (Davidson et al., 2002b). The respiration chamber was kept shaded throughout measurements to minimize heating. Soil temperature was recorded at 5 cm from the soil surface approximately 15 cm adjacent to the location of the respiration chamber with a soil temperature probe. Measurements were made between 11 am and 3 pm (local standard time) and over this period the average soil and air temperatures were, respectively, 13.6 ± 0.2 °C and 22.2 ± 0.4 °C. Although soil temperature did not vary markedly, a fixed Q10 temperature coefficient of 2.0 (Luo and Zhou, 2006) was used to normalize data to a mean soil temperature (14 °C).

2.3. Soil salinity

Soil salinity was quantified as soil electrical conductivity (EC, μS cm^{-1}) by two methods: 1) through electromagnetic induction with a handheld ground conductivity meter, an EM 38® (Geonics